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Report on integration of payloads/sensors on Lander platform

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NAUTILOS - New Approach to Underwater Technologies for Innovative, Low-cost Ocean observation is an H2020 project funded under the Future of Seas and Oceans Flagship Initiative, coordinated by the National Research Council of Italy (CNR). The project unites a substantial consortium of 21 entities spanning 11 European countries. This consortium boasts a wide range of expertise, encompassing ocean sensing and sampling instrumentation development and integration, data processing and modelling, operational oceanography, biology and ecosystem research, biogeochemistry, climate change science, water science, technological marine applications, and research infrastructure development.

NAUTILOS is poised to bridge critical gaps in marine observation and modelling, specifically targeting chemical, biological, and deep ocean physics variables. This will be achieved through the development of a novel generation of cost-effective sensors and samplers. These cutting-edge technologies will integrate within observation platforms and will be deployed in large-scale demonstrations across European seas.

The primary goal of this project is to enhance and expand the existing European marine observation tools and services. The ultimate aim is to acquire data at significantly higher spatial resolution, temporal consistency, and prolonged durations compared to what is currently available at the European scale. Moreover, the project is committed to democratizing the monitoring of the marine environment, making this valuable information accessible to a broad spectrum of users, both traditional and non-traditional alike.

NAUTILOS is one of two projects included in the EU's efforts to support the European Strategy for Plastics in a Circular Economy by supporting the demonstration of new and innovative technologies to measure the Essential Ocean Variables (EOV).

More information on the project can be found at: http://www.nautilos-h2020.eu.

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EXECUTIVE SUMMARY

This deliverable represents the culmination of work carried out in sub-task (ST) 5.4.3, entitled "Report on integration of payloads/sensors on Lander platform" up to M36. It provides a comprehensive overview of the intricate process of integrating a diverse array of payloads and sensors onto the ATLANTIS Lander platform provided by CEiiA. This platform primary objective is to enable deep-sea observation and the precise monitoring of chemical, biological, and physical parameters in the challenging underwater environment.

This report details the challenges and solutions involved in integrating the following NAUTILOS payloads and sensors:

- UL-FE Deep ocean CTD (T4.5);
- AQUATEC Active Acoustic Profiling Sensor (T3.4);
- AQUATEC AQUAmodem 1000 (acoustic modem);
- AQUATEC AQUAmodem Op2 (optical modem);
- EDGELAB AUV docking system.

The integration efforts encompassed meticulous considerations for data collection, sensor placement, and the development of bespoke solutions. It outlines the mechanical configurations, secure attachment methods, and isolation measures employed to ensure robust and reliable integration. Also, the development of software to facilitate communication and data exchange between these integrated systems is highlighted, underscoring the project's commitment to seamless operation.

In summary, this report encapsulates the substantial strides made in the integration of sensors, payloads, and communication systems, within the NAUTILOS project. These integrated systems stand as a testament to the project's commitment to pushing the boundaries of deep-sea exploration.

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LIST OF ACRONYMS AND ABBREVIATIONS

Abbreviation	Definition
CTD	Conductivity, Temperature, and Depth (sensor)
EOV	Essential Ocean Variable
R/V	Research Vessel

I. Introduction

In the pursuit of advancing marine research and exploration, NAUTILOS project has been a beacon of innovation and collaboration. At the heart of this endeavour, one of the critical tasks is the integration of payloads and sensors onto the ATLANTIS Lander platform, a fundamental aspect of Work Package 5 (WP5). This report is dedicated to the comprehensive documentation of the integration process and the outcomes of this effort.

1. Context

The integration of payloads and sensors onto the Lander platform is critical for the realization of NAUTILOS' mission. This task enables us to equip the Lander platform with the necessary tools and instruments to carry out its WP6 and WP7 missions effectively. It is a dynamic process that requires the adaptation of hardware, the implementation of communication systems, and the integration of a suite of specialized sensors. Moreover, when necessary to proceed with mechanical integration before sensor/payload delivery this became an extremely demanding effort for CEiiA that nevertheless always succeeded.

2. Objectives

The primary objective of this report is to provide a detailed account of the integration of payloads and sensors onto the Lander platform, carried out under the leadership of CEiiA. This report aims to shed light on the intricate process of preparing the Lander platform to conduct unique missions vital to the project in the following WP6 controlled missions and WP7 demonstrations. Moreover, it presents the outcomes of bench testing and verification, essential steps in ensuring the platform's readiness for later field trials.

3. Report Structure

This report is structured to provide a comprehensive understanding of the integration process. It begins with an overview of the Lander platform. Subsequently, we delve into the integration process in greater detail, later breaking down the integration of individual payloads and sensors, with a specific focus on each component. Field tests, including descriptions and results, are discussed. Finally, a summary of the key findings and outcomes.

This document serves as a valuable resource not only for the NAUTILOS project team but for the broader scientific community, providing insights into the integration of specialized equipment onto a vital marine exploration platform.

II. Lander Platform Overview

Seafloor Landers are integral tools in oceanographic research, serving as versatile platforms for a wide range of *in situ* measurements and experiments. Their scientific instrumentation is custom-tailored to the specific objectives of each mission, making them adaptable and versatile.

The payloads incorporated into these landers are thoughtfully chosen to suit the scientific goals, and they encompass a diverse array of equipment. These typically include telemetry systems, video cameras, illuminating lights, and an extensive array of environmental sensors, each meticulously designed to capture and record an array of parameters for each case study. These sensors can measure critical factors such as temperature, salinity, chlorophyll fluorescence, optical backscatter, pH, oxygen concentrations, bioluminescence, and an array of other environmental data.

One of the distinctive challenges in deep-sea research is achieving real-time communication with seafloor landers. Acoustic modems are the primary communication technology employed in this context, allowing data transfer over considerable distances, often from the sea surface. However, it's important to note that this method is characterized by relatively low data transfer rates, which can be limiting. Recently developed optical modems enable significantly higher bandwidth communication compared to acoustic modems, offering greater data transfer capabilities. This advancement is particularly beneficial when dealing with extensive data series or payloads that incorporate high-density data acquisition devices, such as video cameras or sonar systems. Therefore, the incorporation of optical modems presents a promising solution to enhance the efficiency of data capture and transmission during deep-sea lander missions, further advancing the capabilities of oceanographic research in the deep sea.

The ATLANTIS Lander

The ATLANTIS Lander provided by CEiiA (Figure 1) is a highly adaptable modular platform designed to function effectively at depths of up to 2000 meters. Its primary mission is to facilitate deep-sea observation and the monitoring of both chemical and biological data, in addition to various other physical variables of the profound ocean environment. The platform offers extensive versatility, allowing the seamless integration of a wide array of sensors and other electronic devices.

A robust steel structure serves as the backbone for all its components. Syntactic foam blocks are incorporated to ensure buoyancy, enabling the platform to return to the surface, once a mission is completed.

Buoyancy analysis depends on weight distribution and therefore it was performed for all field missions expected in WP6 and WP7.

Figure 1 - ATLANTIS lander platform provided by CEiiA.

Integral to its design are two containers: a computational systems container and a power (battery) container. The first, manages all systems throughout a mission, including data acquisition and storage. The second, as the name suggests, contains a bank of batteries that supplies power to all the systems incorporated into the Lander.

The payload consists of an ensemble of sensors selected for collecting invaluable data from the depths of the sea. It also encompasses various communication devices, enabling interactions with the surface or other underwater systems. As mentioned before, ATLANTIS is highly customizable, which means the suite of sensors and other payloads can be changed between deployments. In NAUTILOS project several sensors and payloads are included as described in the following sections.

Each of these sensors and devices is securely attached to the platform's structure, ensuring their reliability and functionality in the challenging deep-sea environment. Apart from securing sensors, structural analysis and buoyancy analysis are performed to ensure safe operation (deployment and recovery).

The general dimensions of ATLANTIS Lander are 1600×1600×1500 mm (Figure 1). The weight can vary between 400-500 kg, depending on the payload and respective configuration.

III. Payloads and Sensors Integration Overview

Integrating a diverse array of systems onto the platform required careful planning and execution to ensure optimal conditions for data collection, and the physical integrity of the installed sensors and other payloads, and the platform itself.

The integration process followed a structured and iterative workflow designed to systematically address each aspect of the task (Figure 2). Here's an overview of the process:

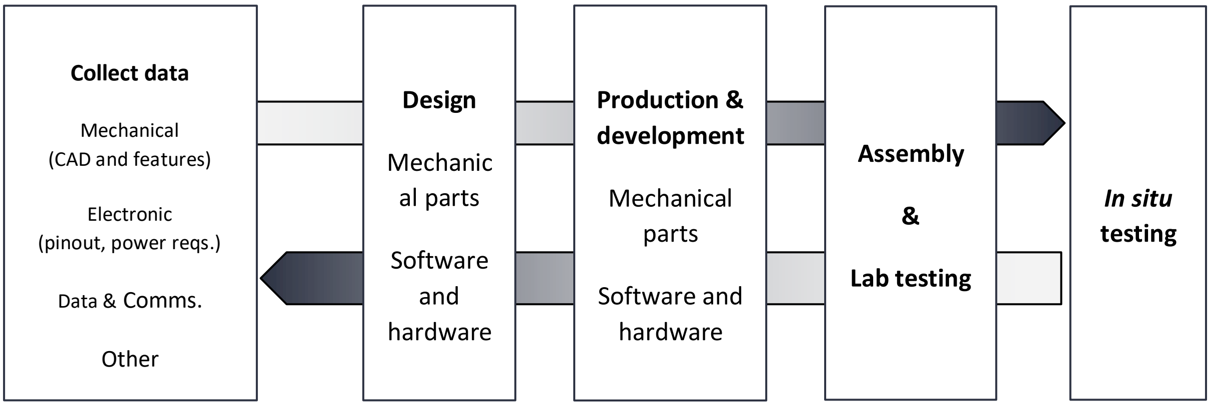


Figure 2 - Schematic picture showing the Integration workflow.

1. Data Collection and Analysis

In the initial phase, we established a comprehensive understanding of the systems to be integrated. This involved gathering critical information about them, including their shapes, dimensions, power requirements, mechanical and electrical interfaces, data formats and communications protocols. This crucial step allowed for a profound understanding of the unique characteristics of each sensor.

In the context of the NAUTILOS project, it's important to highlight that the development and integration of payloads operated concurrently, creating a dynamic and complex environment. This overlapping of processes posed distinct challenges, necessitating numerous iterations and adaptability.

In this highly dynamic context, continuous interaction and feedback loops were established between partners. These interactions included the exchange of preliminary designs, often in the form of Computer-Aided Design (CAD) drawings, and the creation of mock (dummy) systems. Such mock systems provided opportunities for refining and validating the integration of payloads. Moreover, the dynamic nature of the project necessitated the evolution of communication and data protocols, essential for ensuring data transfer between the integrated payloads and the platform. When necessary to proceed with mechanical integration before sensor/payload delivery, this became an extremely demanding effort for CEiiA, but it was always successful thanks to the commitment of all partners involved.

2. Design

After the data collection and analysis phase, the subsequent step entailed the careful selection of optimal locations on the platform for the installation of sensors. This process involved consideration of factors such as the best placement and orientation of sensors to optimize data collection, minimizing both the potential for interference between devices and the risk of unnecessary external exposure to debris, and ensuring uniform distribution of weight. Throughout this phase, we diligently explored trade-offs and design solutions to guarantee the seamless integration of all payloads. With the installation sites determined, the focus shifted to the design of all the essential components and structures necessary to support the sensors securely. This phase was characterized by the development of custom solutions tailored to the precise installation needs of each sensor on the platform.

Throughout the design process, two essential types of documents were generated. Firstly, detailed drawings were created for every individual part involved in the solutions adopted for each sensor or component attached to the Lander. These drawings served as a crucial reference for the production phase. Additionally, a set of drawings was meticulously prepared for each assembly incorporated into the Lander. These assembly drawings provided invaluable guidance during the integration process. Some examples will be provided throughout the present deliverable.

For the link between payloads and the platform, underwater cables and bulkhead connectors were chosen or manufactured. Additionally, internal electronics were adapted to meet the power and communication requirements of the integrated payloads. The modularity of the mission management software played a pivotal role in facilitating the integration of new payloads, ensuring a streamlined and adaptable process.

Once all the mechanical and electrical interfaces are fully designed and defined for a proposed configuration of the Lander, having a full set of intended sensors, rigorous Weight vs. Buoyancy as well as a stability analysis were performed. These analyses aim to quantify the Lander's operational weight-buoyancy status, which in turn determines its descent and ascent speed (before and after the operation period respectively), as well as its attitude underwater and on the surface (when it is ready for being deployed or recovered), which is critical for determining the demanded logistical efforts. In some cases, fine-tuning the positioning of equipment or adding more buoyancy (in form of syntactic foams) may result from these endeavours.

The design process adhered to the highest standards to ensure the integrity and functionality of the integrated sensors. This dedication to quality underpinned the entire design process, ensuring that the integration of sensors on the platform would meet the rigorous demands of ocean exploration and research.

Again, collaboration with sensor developers played a critical role in the integration process. The proposed designs were shared and scrutinized by the developers to ensure that they were aligned with the requirements and specifications of each sensor and NAUTILOS case missions:

controlled scenarios (WP6) and demonstrations (WP7). This collaborative approach allowed for the refinement of the installation solutions.

3. Production and Development

Following the approval from sensor developers, the project entered a pivotal phase where components and structures designed for sensor installation were manufactured. This tangible progression marked the transformation of design concepts into physical realities, and it encompassed not only hardware but also critical software and communication protocol development.

In addition to the physical components, a parallel effort involved the electrical integration, meaning the development of software and drivers required to interface with the sensors and payloads effectively. The software development process involved implementing communication protocols that were essential for gathering data from the sensors and payloads. These protocols enabled reliable data transmission and allowed for real-time data capture from the environment.

4. Assembly and Lab Testing and Validation

The assembly and lab validation phase was a critical juncture in the preparation of the platform for its field missions. During the assembly process, every component, structure, and system was attached to the platform. This phase demanded precision to ensure that the sensors, payloads, communication, and energy equipment fit harmoniously within the platform.

In a controlled laboratory setting, a series of rigorous tests were conducted to validate the functionality and performance of the integrated systems. These tests confirmed that sensors and payloads were operating within their designated parameters and that communication systems, software, and data protocols were functioning optimally. The lab validation process served as a crucial precursor to the field tests, providing the project team with essential insights to fine-tune the system.

5. *In* Situ Testing and Validation

The final phase of the integration process involved rigorous *in situ* testing with the platform now housing the sensors. These tests were essential to validate the functionality, data collection capabilities, and physical integrity of the sensors in real-world conditions. Bench tests are part of WP5, however water tests will be included in WP6, in particular in D6.3 "Report on testing results of the joint operations of sensors, buoy, lander and ASV in ST6.3.1.

IV. Detailed Payloads and Sensors Integration

1. NAUTILOS Payloads and Sensors

Below is a table (Table 1) with an overview of the systems that we integrated into the Atlantis Lander.

Table 1 - NAUTILOS sensors and payload integration overview

Payload/Sensor	Owner	Collected parameters	Mechanical Integration	Electronic Integration
Deep Ocean CTD	UL-FE	Conductivity, Temperature, Depth (pressure)	Yes	Power and data logging
Active Acoustic Profiling sensor **AQUA*scat* Mk.II**	AQUATEC	Acoustic backscatter, Temperature, Pressure	Yes	No, Standalone
Optical Modem **AQUA*modem* Op2**	AQUATEC	N/A	Yes	Power and Comms
Acoustic Modem **AQUA*modem* 1000**	AQUATEC	N/A	Yes	Power and Comms
AUV Docking system	EDGELAB	N/A	Yes	Power

2. Deep Ocean CTD (UL-FE)

a. Overview

The CTD instrument, an acronym for Conductivity (C), Temperature (T), and Depth (D), stands as one of the most frequently employed tools in the field of oceanography (Figure 3). This instrument, designed by UL-FE (D4.5 “Report on development and laboratory tests of Deep Ocean CTD sensor”), takes precise measurements of conductivity, temperature, and pressure (from which depth is derived). These data points can then be processed to derive salinity values. This capability enables the monitoring of temporal variations in seawater conditions in the deployment location, contributing significantly to our understanding of the world's oceans.

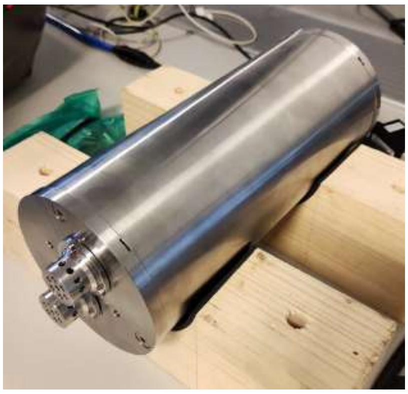


Figure 3 - UL-FE CTD sensor developed in the scope of NAUTILOS project.

The UL-FE Deep Ocean CTD sensor (Figure 4) has been engineered to meet the demands of deep-sea usage. Its watertight design and non-corrosive properties make it exceptionally well-suited for use at depths of up to 2000 meters in the harsh sea environment. Measuring 120 mm in diameter and 302 mm in length, this compact yet powerful instrument is well-equipped to deliver reliable data. For data exchange and power supply, the UL-FE CTD sensor features a female connector (MCBH5F) designed to interface with the platform where it is installed.

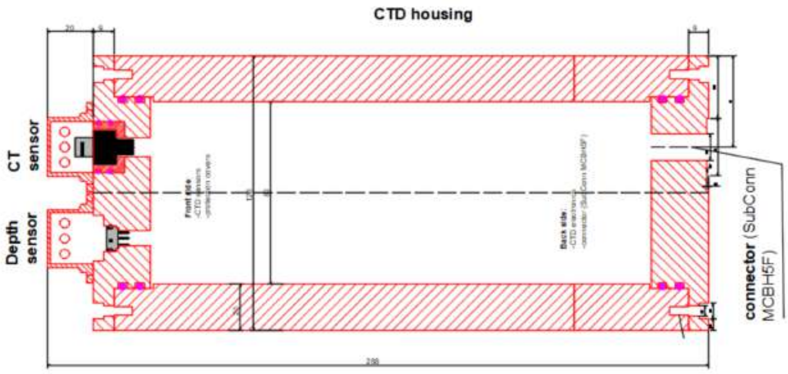


Figure 4 - UL-CTD housing drawing.

The inclusion of the UL-FE CTD sensor on the ATLANTIS Lander enhances the platform's capacity to collect essential data for oceanographic research.

b. Mechanical

The attachment of the CTD sensor to the ATLANTIS Lander provided by CEiiA was a carefully considered process, aimed at ensuring the sensor's protection from potential impacts (Figure 5). To achieve this, a dedicated sheet metal bracket was fabricated from high corrosion-resistant 316L stainless steel sheet, with a thickness of 2.5 mm. This choice of material and thickness was made to withstand the harsh underwater conditions and to provide robust support for the sensor.

To prevent direct contact between the CTD sensor and the stainless-steel brackets, neoprene strips were employed. These strips served as an effective isolation layer, safeguarding the sensor from potential damage, and ensuring that it remained securely in place.

The assembly of the CTD and the stainless-steel brackets were then secured to the Lander's structure using M6 bolts with prevailing torque nuts. Both the bolts and nuts were made of high corrosion-resistance A4 stainless steel (Figure 6). This choice of materials further reinforced the durability of the assembly, ensuring that the CTD sensor was not only securely attached but also well-protected from the challenging environmental conditions of the deep sea.

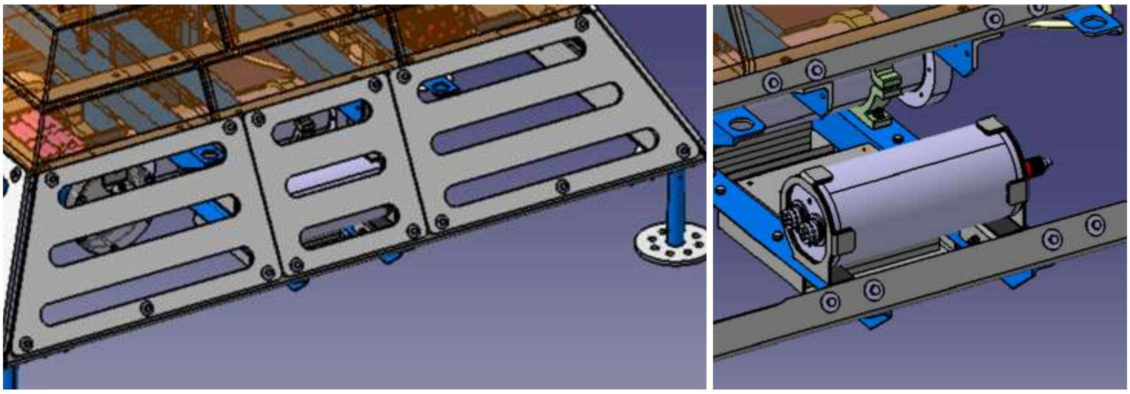


Figure 5 - UL-CTD CAD integration.

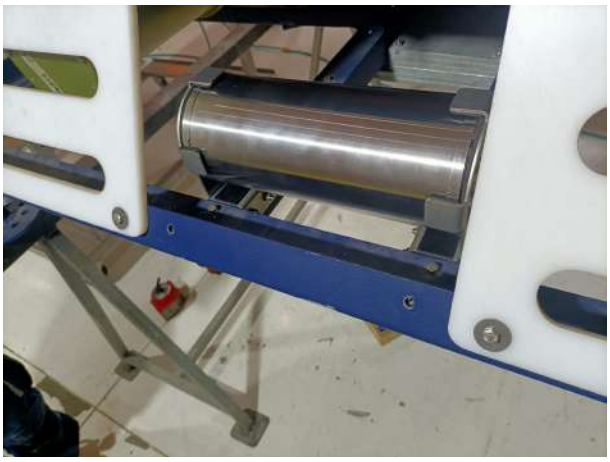


Figure 6 - UL-CTD ATLANTIS Lander integration.

Upon receiving the sensor in CEiiA headquarters it was possible to conclude a difference in size and therefore **<u>it was not possible to consider the original bracket</u>** for mechanical integration. Due to the difference in the CTD length, CEiiA was able to reorganize RH efforts and budget to redesign and produce another bracket support for the CTD considering the additional 14 mm in length (Figure 7), in time for WP6 controlled scenario missions.

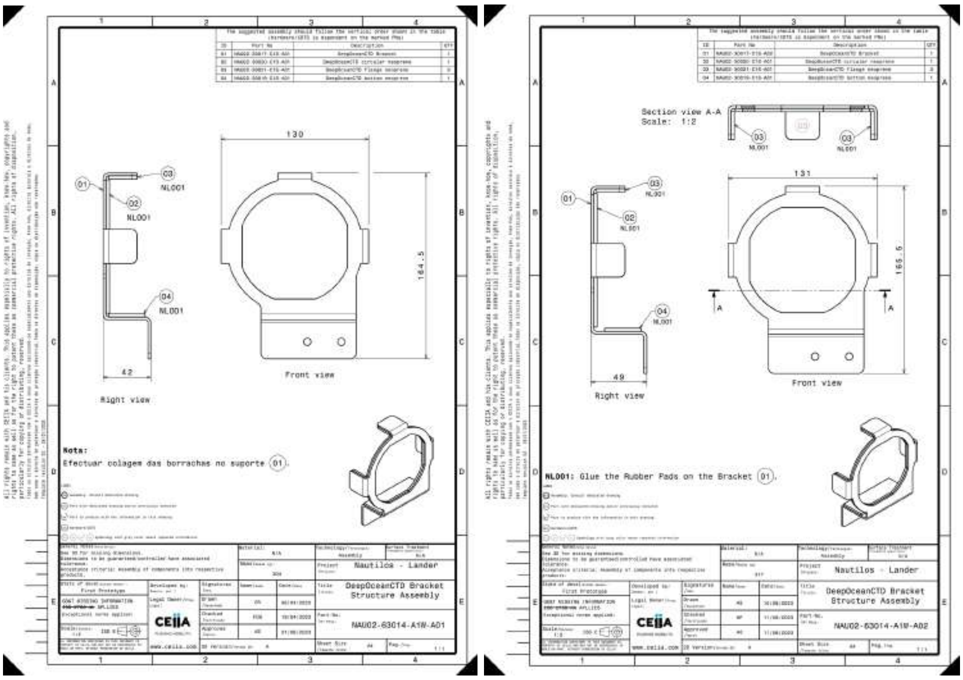


Figure 7 -UL-CTD Support Bracket version A01(length 288mm) / A02(length 302mm)

c. Electrical

The CTD sensor not only requires a secure attachment to the Lander but also depends on the Lander to provide it with the necessary power for its operation. Furthermore, the ATLANTIS Lander was tasked with recording and managing the measurements made by the CTD sensor.

To achieve this, a connection was established between the sensor and the Lander's communication container. Both the power and data connections were possible through a single underwater cable with MCBH5M-MCBH5M terminations.

Internally, a 15 VDC power channel was assigned to the CTD port. This channel can supply up to 3 A and can be controlled via software. Communication is possible via an RS-485 interface on the onboard computer.

d. Software

As part of the integration of the CTD sensor with the ATLANTIS Lander, a dedicated driver was developed for the onboard software. This driver was designed in accordance with the specifications provided by UL-FE, ensuring that the CTD sensor could be efficiently and accurately controlled and monitored.

One of the key features of the software integration is the ability to configure data recording parameters. The software allows for the programming of intervals between periods of data acquisition. During these intervals, both the CTD sensor and the Lander can enter a deep sleep mode, conserving energy and optimizing resource utilization. This intelligent sleep mode contributes to the Lander's overall operational capability.

The software further allows for the customization of the number of samples and the sampling rate during acquisition periods. This flexibility enables researchers to tailor the CTD sensor's operation to the specific requirements of their experiments, ensuring that the precise data needed can be collected.

To improve reliability, the onboard software can detect acquisition errors, and retry the process a number of configurable times. If after this number of retries, there is no successful reading, this sampling period will be skipped, and a new attempt will occur on the next one.

Additionally, the software accounts for the cold start process, considering the warm-up time required for the sensor to reach its optimal operating state. This feature ensures that measurements taken by the CTD sensor are accurate and reliable from the outset of data collection.

Data is stored in a JSON format, see a sample below (Figure 8) (Figure 9).


```
[
      {
      "time_stamp": "2023-10-11 11:01:22.234650",
      "conductivity": 0.10104,
      "temperature": 18.954,
      "pressure": 0.0
      },
      {
      "time_stamp": "2023-10-11 11:01:24.324840",
      "conductivity": 0.050481,
      "temperature": 18.955,
      "pressure": 0.0
      },
      {
      "time_stamp": "2023-10-11 11:01:26.412588",
      "conductivity": 0.050484,
      "temperature": 18.955,
      "pressure": 0.0
      },
      {
      "time_stamp": "2023-10-11 11:01:28.498803",
      "conductivity": 0.050484,
      "temperature": 18.954,
      "pressure": 0.0
      },
      {
      "time_stamp": "2023-10-11 11:01:30.583395",
      "conductivity": 0.050487,
      "temperature": 18.954,
      "pressure": 0.0
      },
]
```


Figure 8 - Example of UL-CTD data sample in JSON format.

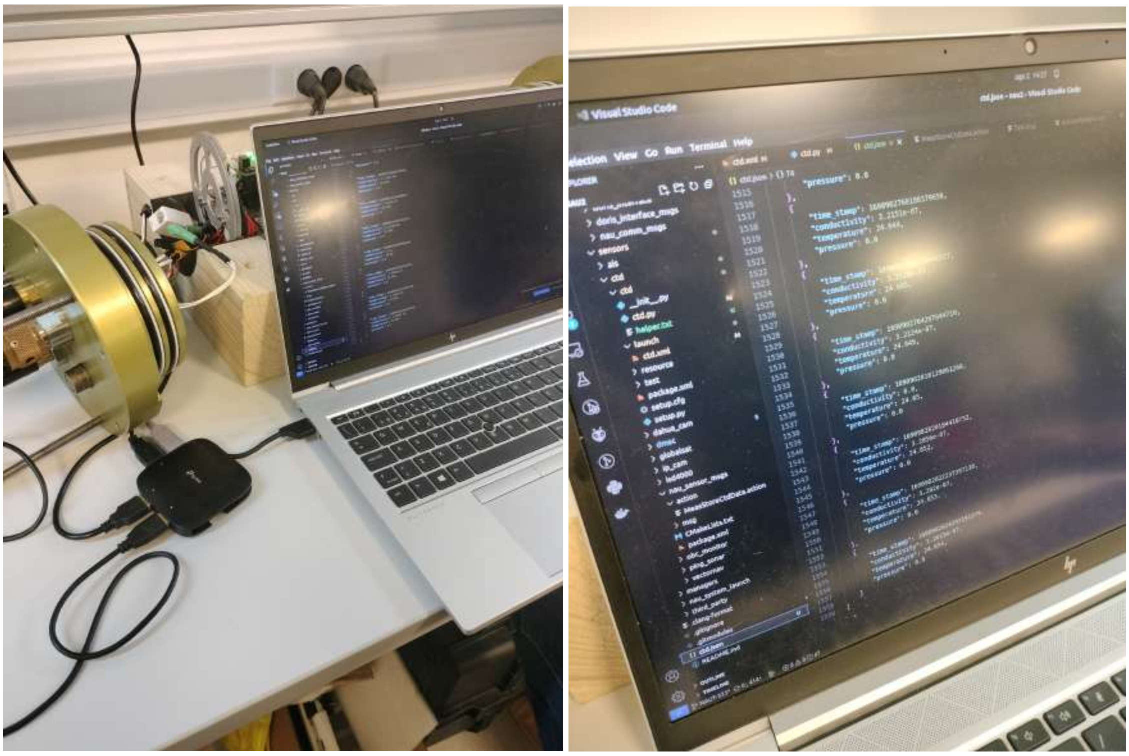


Figure 9 -UL-CTD Data logging with ATLANTIS Lander - bench tests.

3. Active Acoustic Profiling Sensor (AQUATEC)

a. Overview

The new AQUATEC Acoustic Profiler sensor has been designed for the measurement and analysis of acoustic backscatter from suspensions of particles in liquids (Figure 10). This instrument aims to overcome the limitations of existing technologies and offers improved functionality for a wide range of applications in science and industry.

Its main functions include analyzing suspended particle characteristics, estimating particle size and load, detecting and quantifying bubbles, and distinguishing between particle compositions. This instrument has broad applications in oceanography, coastal engineering, and industrial processes, and it can also be used for observing marine life, ice particles, and detecting microplastics. It offers improved data quality, measures particle velocity and turbulence, and features advanced hardware components for enhanced performance and adaptability to various measurement scenarios.

Figure 10 - AQUATEC Acoustic profiling sensor.

b. Mechanical

The AQUAscat 1000 is composed of a cylindrical main body with a diameter of 80 mm and a length of 500 mm, as well as two transducers connected by cables (Figure 11).

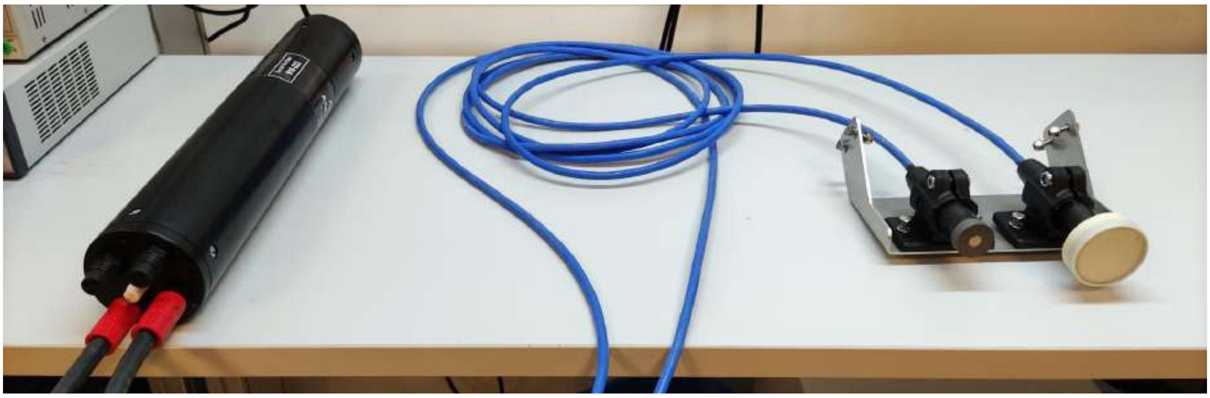


Figure 11 - AQUATEC Acoustic profiling sensor - bench tests.

To position the transducers effectively and minimize interference, a new Lander fairing, made of 10 mm thick HDPE plate, was custom-designed. This fairing was crafted in a manner that allows the transducers to point 45 degrees upward (Figure 12), providing an unobstructed view of the water column.

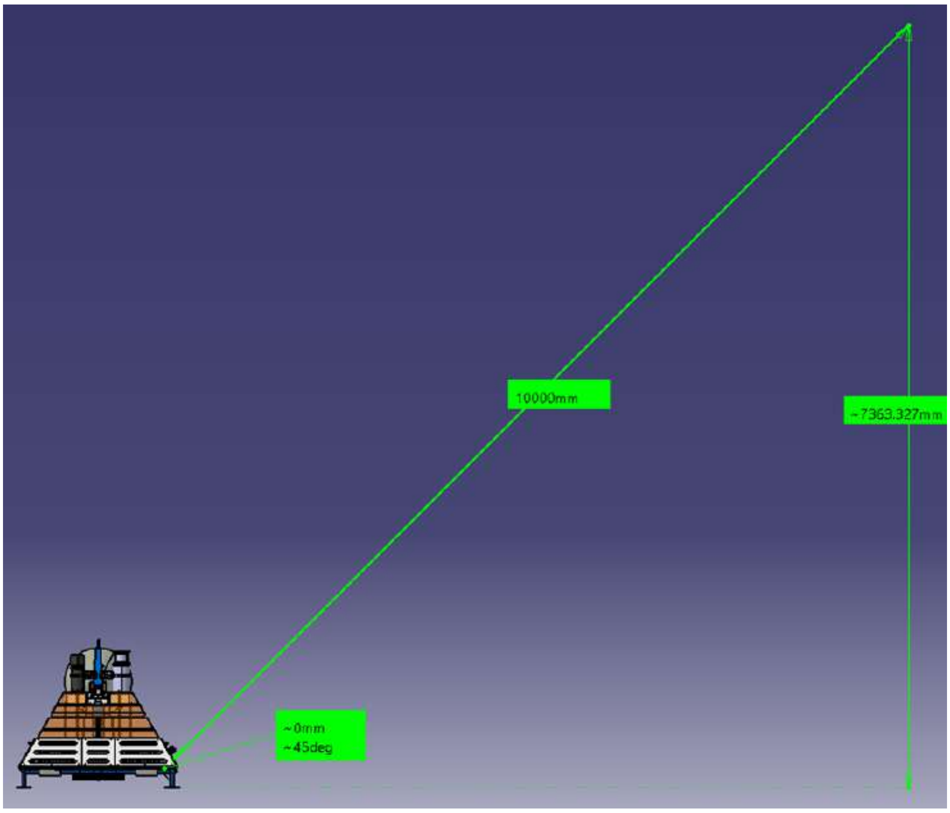


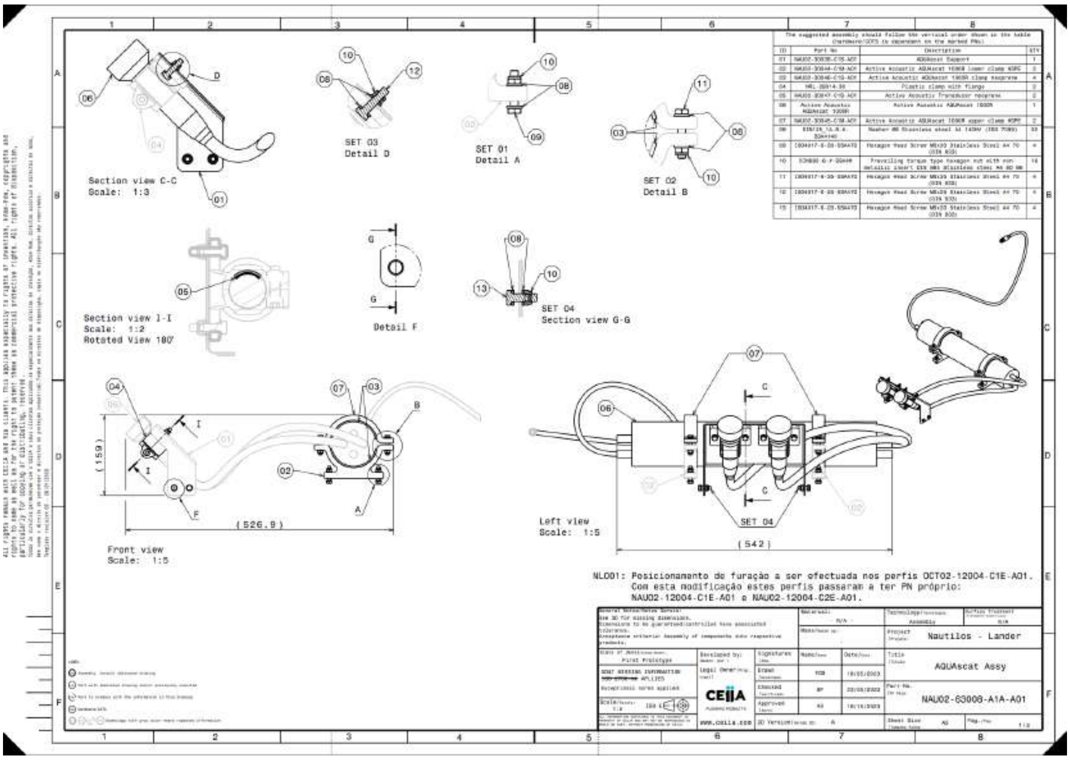
Figure 12 - CAD with AQUATEC Acoustic profiling sensor position calculations.

The main body of the AQUA*scat* 1000 did not have specific position restrictions, so it was placed in the Lander's payload zone, where it is shielded from potential impacts and near the camera (to be considered for field missions, if applicable). Once the positioning was agreed upon, the necessary components for securing both the main body and transducers to the Lander were produced.

For the transducers, a dedicated sheet metal bracket made from 316L stainless steel with a thickness of 2.5 mm was created. Additionally, two off-the-shelf plastic clamps were used to affix the transducers to the sheet metal bracket. The sheet metal bracket was securely attached to the Lander structure using M6 bolts and prevailing torque nuts, both made of A4 material, chosen for their high corrosion resistance in underwater conditions.

To secure the cylindrical main body to the Lander structure, dedicated HDPE clamps were designed, which embraced the main body. This attachment was facilitated by M6 bolts and prevailing torque nuts made of high corrosion-resistant A4 stainless steel. New holes were introduced to the Lander structure to accommodate these brackets, with M6 bolts and prevailing torque nuts ensuring a robust connection.

In addition, neoprene strips were employed to prevent direct contact between the main body and the HDPE bracket. These strips acted as a protective isolation layer, preserving the integrity of the main body and maintaining its secure positioning (Figure 13Figure 14 Figure 15).



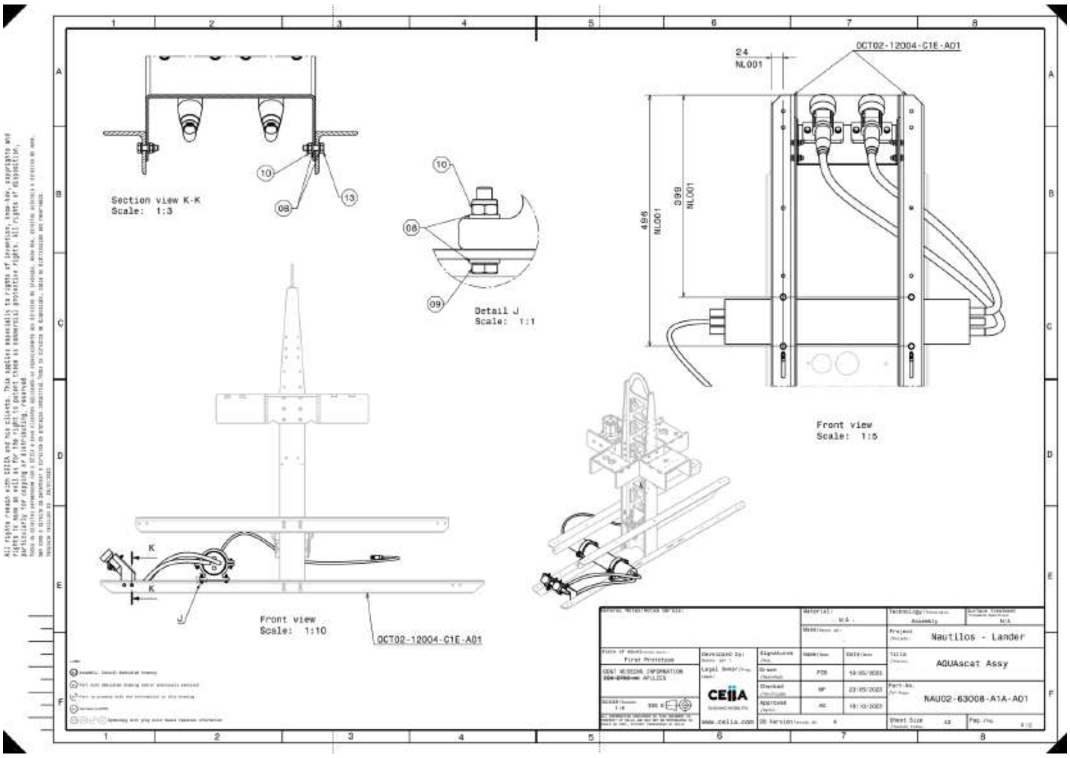


Figure 13 - AQUATEC Acoustic Profiler Assembly Technical Drawing.

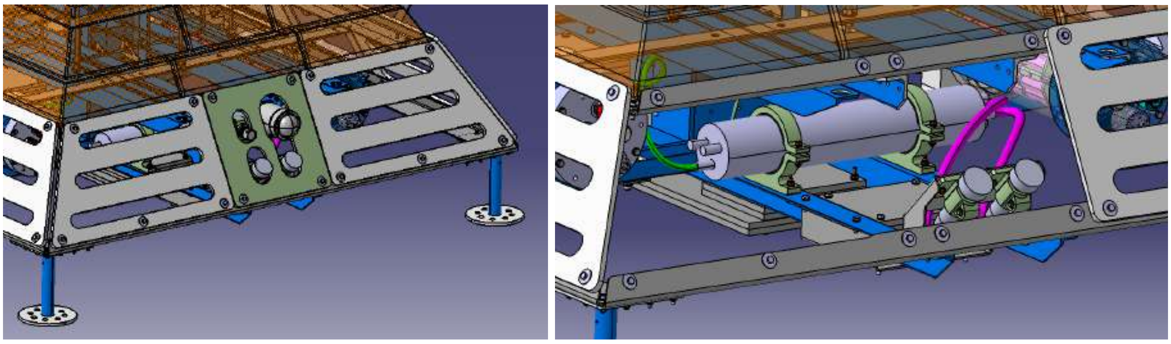


Figure 14 - AQUAtec Acoustic profiling sensor CAD integration.

Figure 15 - AQUATEC Acoustic profiling sensor ATLANTIS Lander integration.

c. Electrical

No electrical integration was required for this system. This sensor operates independently of the Lander.

d. Software

No software integration was required for this system. This sensor operates independently of the Lander.

4. AQUAMODEM 1000 (AQUATEC)

a. Overview

The AQUA*modem* 1000, developed by AQUATEC, serves as a vital component in acoustic communication (Figure 16). Notably, this modem possesses data storage capability, allowing instruments to function as data loggers. This dual functionality supports the transfer of information via acoustics and the retention of data for future instrument use.

Designed to operate at depths of up to 2000 meters, the AQUAmodem 1000 has different power requirements depending on its operational mode. By default, when the RS232/TTL interface remains inactive, the modem conserves power by operating in its lowest-power mode, the timed/triggered state. Upon interface activity, the modem seamlessly transitions to its receiving mode. In the event that the host sends commands, including data for transmission, the modem switches to transmission mode, subsequently returning to the receiving mode as needed.

In terms of acoustic transmission, these modems operate within the 8 to 14 kHz frequency range, delivering a maximum acoustic power output of 185 dB re 1V/µPa @ 1 m. These capabilities empower the modems to establish communication over distances exceeding 5 kilometers, achieving data rates of more than 100 bps. The AQUAmodem 1000 is an essential asset for the ATLANTIS Lander missions within the NAUTILOS project, enabling real-time communication in the challenging deep-sea environment.

Figure 16 - AQUATEC Acoustic modem.

b. Mechanical

The placement of the AQUA*modem* 1000 was a crucial decision, with a focus on minimizing interference during communications with other surface and underwater devices, being in a position that could easily communicate with its pair. To achieve this, the existing small HDPE platform atop the ATLANTIS Lander was utilized to support the modem. This required specific modifications to the HDPE platform, including the creation of holes tailored to the modem's geometry and fixation needs. In addition to this, CEiiA designed a dedicated sheet metal bracket and an HDPE clamp to provide a secure and robust attachment of the modem to the Lander structure. Neoprene strips were employed to ensure complete isolation, from a corrosion perspective, between the modem and these various fixation elements.

The bracket was crafted from a high-corrosion-resistant 316L stainless steel sheet, with a thickness of 2.5 mm. This choice of material and thickness was made to withstand the demanding underwater conditions, providing a stable foundation for the modem.

To fasten the modem to the Lander's HDPE platform, we employed M5 aluminum bolts provided by AQUATEC. This decision helped prevent galvanic corrosion since the main body of the modem is also constructed from aluminium.

For the secure attachment of the sheet metal bracket to the Lander structure, M6 bolts were used in conjunction with prevailing torque nuts, both composed of high-corrosion-resistant A4 stainless steel. The same type of bolts and nuts were used to fix the HDPE clamp, ensuring a tight embrace of the modem against the sheet metal bracket (Figure 17).

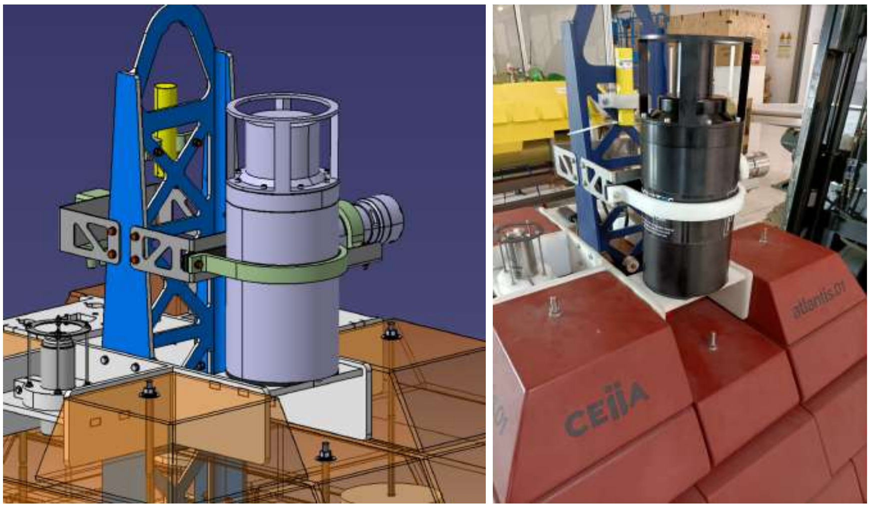


Figure 17 - AQUATEC Acoustic modem CAD and ATLANTIS Lander integration.

c. Electrical

The AQUA*modem* 1000 depends on the Lander to provide the necessary power for its operation.

To achieve this, a connection was established between the sensor and the Lander's communication container. Both the power and data connections were possible through a single underwater cable with MCIL12F – MCIL12M terminations.

Internally, a 24 VDC power channel was assigned to the AQUAmodem 1000 port, this channel can supply up to 2.5 A. The channel can be controlled via software. Communication is possible via an RS-2332 interface on the onboard computer.

d. Software

As part of the integration of the AQUA*modem* 1000 with the ATLANTIS Lander, a dedicated driver was developed for the onboard software. This driver was created in accordance with the specifications provided by AQUATEC.

Through the software developed, we can access multiple features, such as sending telemetry, controlling the status of the mission, entering in sleep mode, or waking up the ATLANTIS Lander.

The driver developed for the AQUA*modem* offers a versatile range of capabilities. It can instruct the modem to send and receive pings, facilitating reliable communication with other modems. The software also enables the exchange of messages between modems. Additionally, it allows for the customization of internal configurations, ensuring adaptability to specific project requirements and mission objectives.

On top of the low-level modem instructions, we defined our own message set (Table 2). This facilitates the transfer of information and commands between the operator – at the surface – and the platform.

Below is a table with the message definitions (Table 3).

Table 2 - Message structure used for communication.

MSG ID	**SEQ**	**TIME**	**SYS ID**	**PAYLOAD** (Param 1 … Param N)

Table 3: Message definitions.

Message Description	Telemetry A	Telemetry B	Telemetry C	Send Command (Lander)	Jump to Task	Set Mission State	Ack
Message ID	$TELEA	$TELEB	$TELEC	$CMDLD	$JMPTK	$SETMS	$ACKCM
Sequence No	Sequence	Sequence	Sequence	Sequence	Sequence	Sequence	Sequence
Timestamp	time/date	time/date	time/date	time/date	time/date	time/date	time/date
System ID	Source ID	Source ID	Source ID	Source ID	Source ID	Source ID	Source ID
Param 1	Lat	Battery SOC		CMD	Task ID	State	ACK (OK/NOK)
Param 2	Lon	mission status		data 1			Sequence (ack'ed)
Param 3	Roll	vehicle status		data 2			
Param 4	Pitch			data 3			
Param 5	Yaw			data 4			
Param N				data N			

5. AQUA*MODEM* OP2 (AQUATEC)

a. Overview

The AQUA*modem* Op2 is an underwater optical modem system developed by AQUATEC (Figure 18 and Figure 19). Two modems are used as a pair. The pair of modems transparently converts a cabled RS232 serial connection into an optical link to allow a non-contact data connection between subsea logging equipment, such as the Lander, and a visiting mobile asset, like a ROV.

The primary objective of this system is to facilitate real-time communication with the Lander, eliminating the need to retrieve the system to the surface for high-speed data download. By using the optical modem link, the visiting mobile asset can access data logged by the Lander as if it were physically connected through a cabled link.

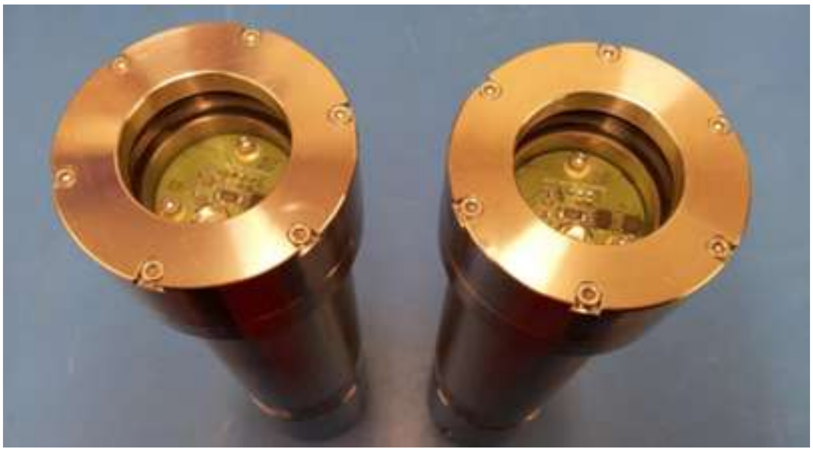


Figure 18 - AQUATEC optic modems.

The AQUA*modem* Op2 has been engineered to meet the demands of deep-sea usage. Its watertight design and non-corrosive properties make it exceptionally well-suited for use at depths of up to 3500 meters in the harsh sea environment.

Figure 19 - AQUATEC optic modems with mounting instructions.

b. Mechanical

The attachment of the AQUA*modem* Op2 to the ATLANTIS Lander was a carefully considered process, aimed at ensuring that it was in a position that could communicate easily with its pair installed on the EDGELAB AUV. Furthermore, it needed to be protected from damage and that raised the need to design a protective structure (docking system, presented in section 5), mainly to avoid impacts during the operation with the AUV as well as to ensure that the correct alignment between both modems would be achieved.

To achieve this, a dedicated sheet metal bracket was fabricated from high corrosion-resistant 316L stainless steel sheet, with a thickness of 2.5 mm. This choice of material and thickness was made to withstand the harsh underwater conditions and to provide robust support for the modem.

To fix the modem to the bracket, CEiiA produced HDPE dedicated clamps to embrace it, secured with M6 bolts and prevailing torque nuts made of high corrosion-resistance A4 stainless steel.

To prevent direct contact between the modem and the stainless steel bracket, neoprene strips were employed. These strips served as an effective isolation layer, safeguarding the AQUA*modem* Op2 from potential damage and ensuring that it remained securely in place.

The assembly of the AQUA*modem* Op2 and the stainless steel bracket was then secured to the Lander's structure using M6 bolts with prevailing torque nuts. Both the bolts and nuts were made of A4 stainless steel (Figure 20).

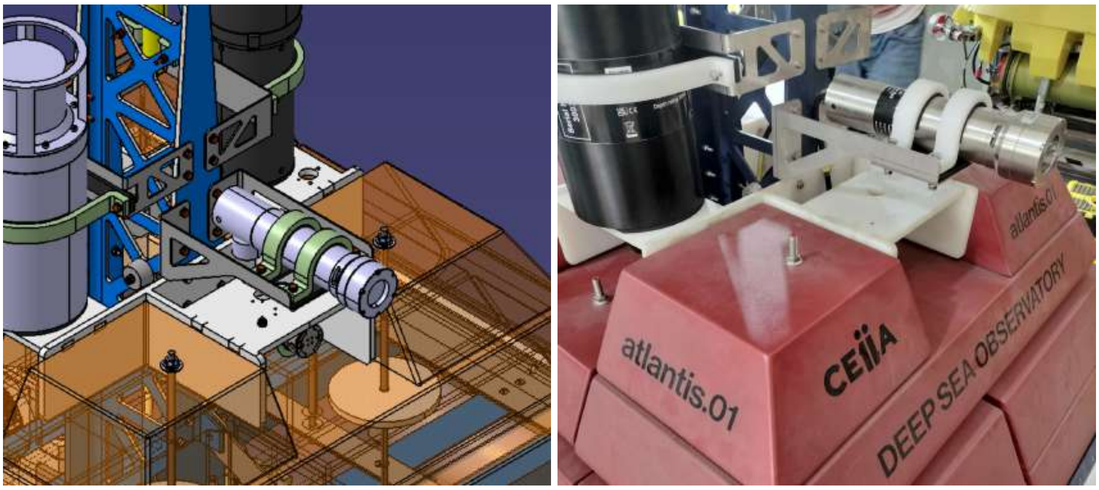


Figure 20 - AQUATEC optic modems CAD and ATLANTIS Lander integration.

c. Electrical

The AQUA*modem* Op2 requires a secure attachment to the Lander and depends on the Lander to provide the necessary power for its operation.

To achieve this, a connection was established between the sensor and the Lander's communication container. Both the power and data connections were possible through a single underwater cable with MCIL6F – MCIL6M terminations.

Internally, a 24 VDC power channel was assigned to the AQUA*modem* Op2 connection port. This channel can supply up to 2.5 A and can be controlled via software. Communication is possible via an RS-2332 interface on the onboard computer.

d. Software

As part of the integration of the AQUA*modem* Op2 optical modem with the ATLANTIS Lander, a dedicated driver was developed for the onboard software. This driver was created in accordance with the specifications provided by AQUATEC and shared with EDGELAB so they can test the entire communication.

The main key feature of the software integration is the ability to provide a seamless interface between the user and any subsea instrumentation via an RS232 serial interface. This interface allows data download between our lander and a mobile asset, *e.g.* a ROV or AUV.

The modem installed in the ATLANTIS Lander, even in sleep mode, is always listening. When it receives a ping from the modem on the mobile asset, it wakes up and can send files from a pre-defined folder, as requested by the mobile asset.

While sending files, the software divides the files into data chunks to send one at a time and always after receiving the acknowledgment of the previous message. The size of the chunks and the transfer rate can be configured during the activity. The software is also prepared to retry sending a message a number of configurable times.

6. AUV Docking System (EDGELAB)

a. Overview

The AUV docking system developed by EDGELAB (Figure 21) serves as a purpose-built structure designed to address two critical aspects during the operation involving the ATLANTIS Lander and the AUV: collision prevention and precise guidance. Its primary function is to facilitate the exchange of data between optical modems, one installed on the CEiiA Lander and the other on the EDGELAB AUV.

The docking station's design incorporates a distinctive LED ring positioned on the structure's largest diameter. This LED ring plays a pivotal role in enhancing the visibility of the docking structure underwater and helps the AUV operator during the approach and docking manoeuvres. It ensures that the AUV operator can effectively navigate and align the vehicle with the docking station. This LED ring doesn't have an impact on optical communication.

To establish a connection with the Lander, the docking station features a cable equipped with a female connector, specifically the MCBH8F. This is used to power the LED ring.

Figure 21 - AUV docking station.

b. Mechanical

The secure fixation of the docking system is achieved using M6 bolts paired with prevailing torque nuts. Both the bolts and nuts are constructed from high corrosion resistant A4 stainless steel.

The lower part of the docking system structure was designed with holes that align with the pre-existing holes on the Lander structure (Figure 22). For the upper part of the docking system, new holes were drilled on the Lander's main structural bar. These newly integrated holes serve the purpose of fastening the docking station's tie rods, further enhancing the structural integrity and stability of the docking system.

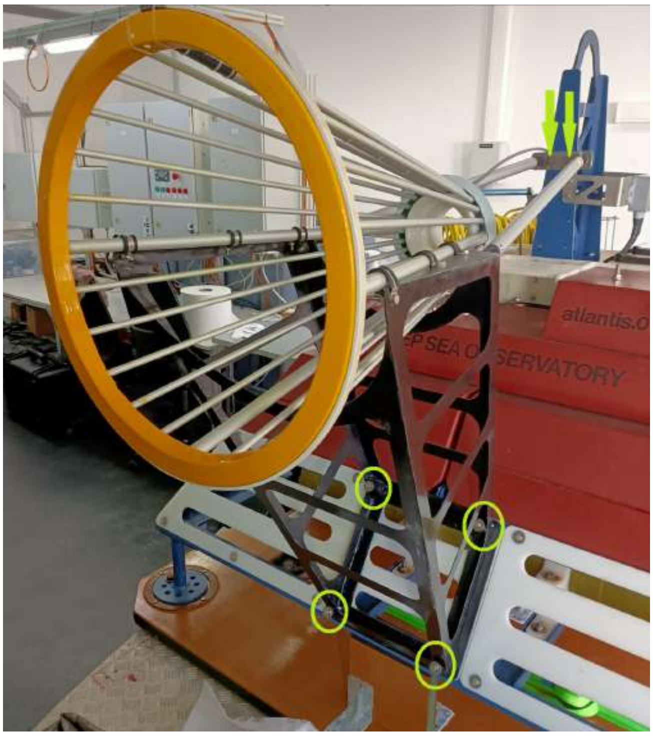


Figure 22 - AUV docking station points of assembling in ATLANTIS Lander.

This mechanical configuration ensures a robust and reliable connection between the AUV docking system and the Lander, reinforcing the capability to operate effectively in challenging underwater conditions.

c. Electrical

The docking system depends on the Lander to provide the necessary power to light the LED ring. The connection was established between the system and the Lander's communication container through an underwater cable with MCBH8F – MCIL8M terminations.

Internally, a 24 VDC power channel was assigned to the docking system connection port. This channel can supply up to 2.5 A and can be controlled via software. This channel is the same that is used by the AQUA*modem* Op2, so total power is shared between the two systems.

d. Software

No software integration was required for this system. However, as mentioned above, power can be controlled via a pre-existent software feature. Power is enabled on the docking system at the same time it is on the optical modem, as described in a previous section.

V. ATLANTIS LANDER - NAUTILOS CONFIGURATION

In this section, we present the configuration of the ATLANTIS Lander, a CEiiA platform, integrated with NAUTILOS sensors and payloads from Aquatec and UL-FE. Additionally, the docking system from EDGELAB is incorporated in this configuration.

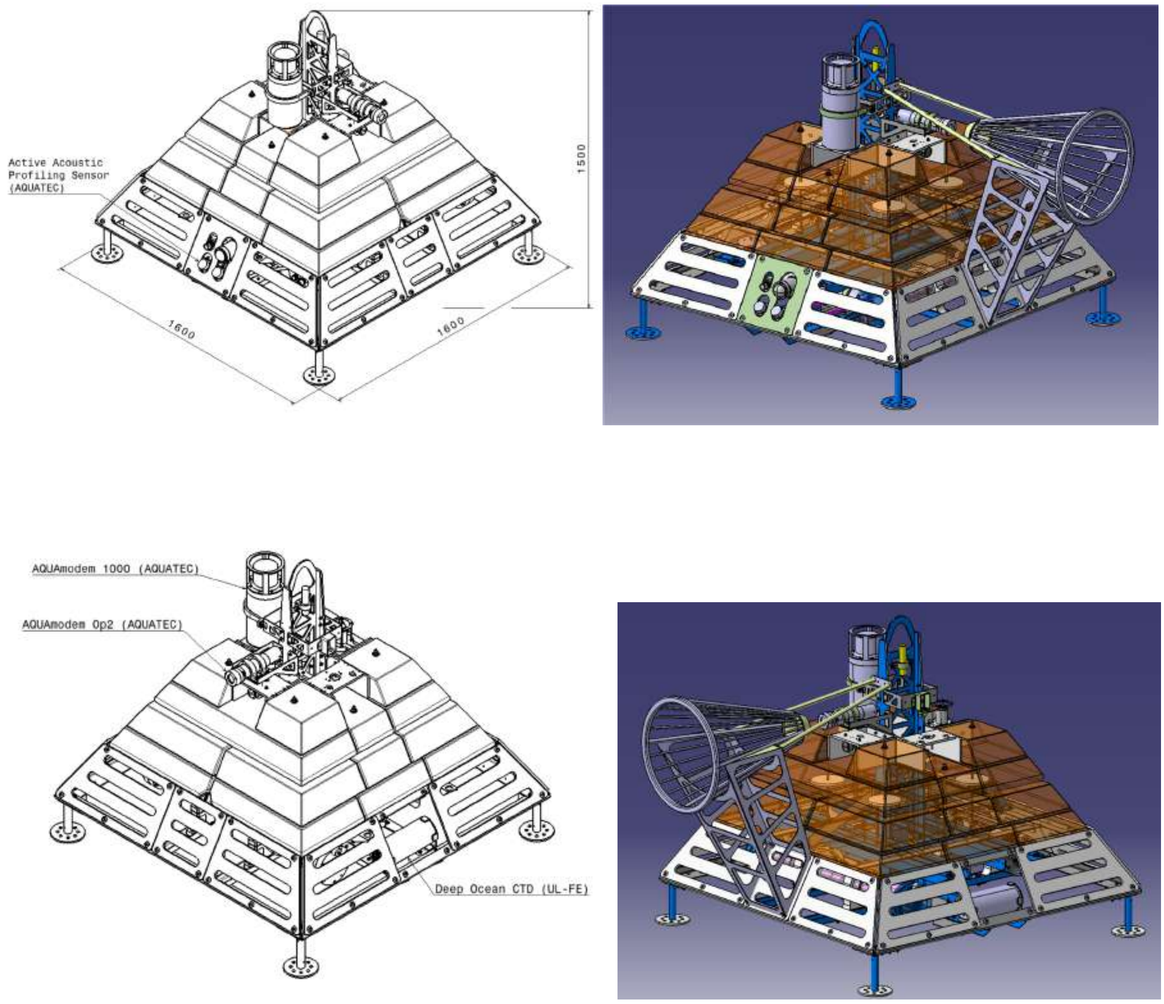


Figure 23 - ATLANTIS lander platform provided by CEiiA with NAUTILOS sensors and payloads from AQUATEC and UL-FE (schematic and CAD images).

As previously outlined, upon finalizing the configuration of the ATLANTIS Lander with the complete integration of all sensors and essential payloads, a series of global analyses must be conducted. These analyses are vital to guarantee the accurate deployment, functioning, and retrieval of the Lander during the missions outlined in WP6 and WP7. Key aspects to be rigorously assessed include: 1) structural analysis; 2) Weigh and Buoyancy.

a. Structural analysis

The initial step in our comprehensive analysis is the structural analysis. This critical examination is indispensable for confirming that the existing structure can withstand all operational loads (Figure 24). Additionally, it provides valuable insights into safety considerations during transportation, including factors such as maximum allowable speed.

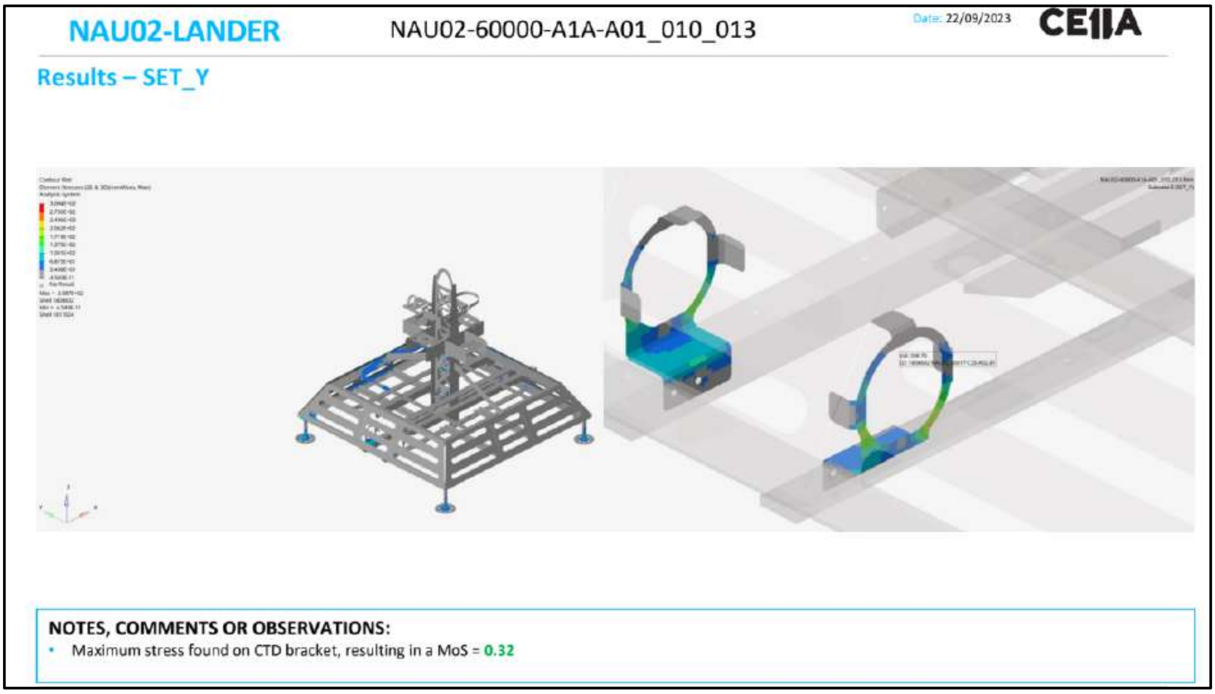
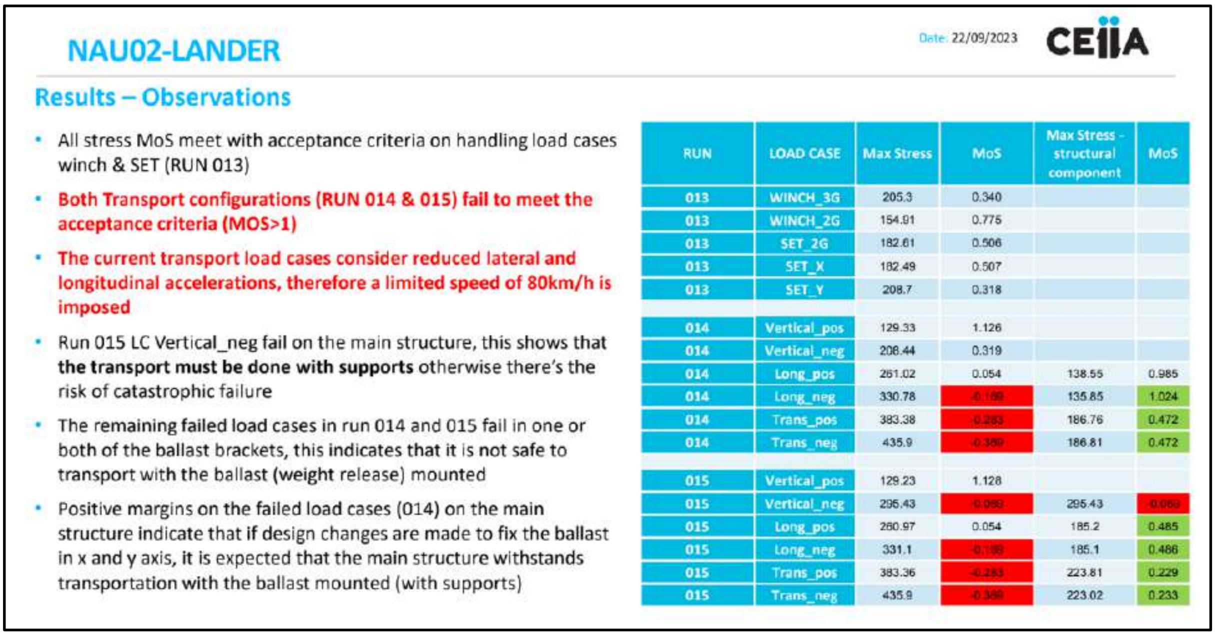


Figure 24 - Extract from the ATLANTIS Lander structural analysis - in detail for UL-FE Deep Ocean CTD.

This study considers 3 load cases (load case 13, load case 14 and load case 15). All of them consider the same payload (described above), however they vary in terms of all the efforts requested during several moments of operations (transport, winch operation and deployment on water) (Figure 25).



RUN	LOAD CASE	Max Stress	MoS	Max Stress - structural component	MoS
013	WINCH_3G	205.3	0.340		
013	WINCH_2G	154.91	0.775		
013	SET_2G	182.61	0.506		
013	SET_X	182.49	0.507		
013	SET_Y	208.7	0.318		
014	Vertical_pos	129.33	1.126		
014	Vertical_neg	208.44	0.319		
014	Long_pos	261.02	0.054	138.55	0.985
014	Long_neg	330.78	-0.169	135.85	1.024
014	Trans_pos	383.38	-0.283	186.76	0.472
014	Trans_neg	435.9	-0.369	186.81	0.472
015	Vertical_pos	129.23	1.128		
015	Vertical_neg	295.43	-0.069	295.43	-0.069
015	Long_pos	260.97	0.054	185.2	0.485
015	Long_neg	331.1	-0.169	185.1	0.486
015	Trans_pos	383.36	-0.283	223.81	0.229
015	Trans_neg	435.9	-0.369	223.02	0.233

Figure 25 - Extract from the ATLANTIS Lander structural analysis - Major conclusions.

Major conclusions indicate that load case 13 presents a positive MoS (margin of safety). On the other hand, load cases 14 and 15 present small negative MoS. All of them are related to road transportation. To address this concern, two pivotal measures are instituted: the implementation of a robust structure for the ATLANTIS Lander during transportation (aiding the support of critical regions of the Lander in transit, as presented in Figure 26) and strict adherence to guidelines, limiting transportation speed to never exceed 80 km/h.

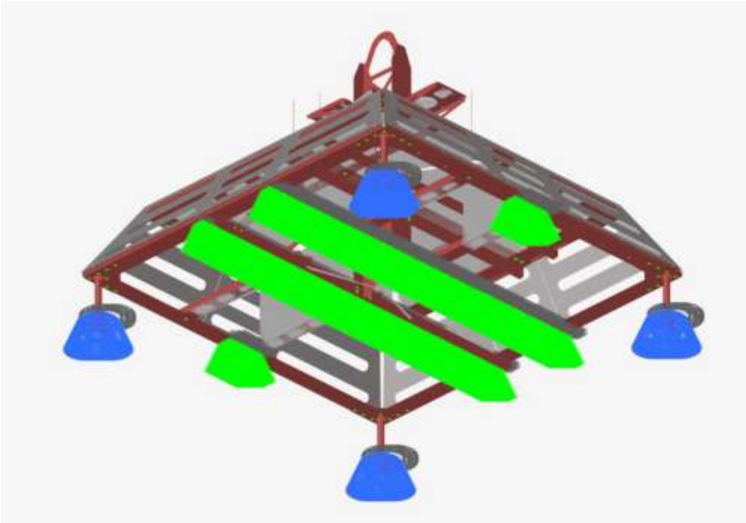


Figure 26 - Lander regions that need to be supported (green) or fixed (blue) during road transportation.

b. Weight and Buoyancy

As previously discussed, Weight and Buoyancy analysis was also performed. These analyses aim to quantify the Lander's operational weight-buoyancy status, which in turn determines its descent and ascent speed (before and after the operation period, respectively), as well as its attitude underwater and at the surface (when it is ready for being deployed or recovered), which is critical for determining the demanded logistical efforts.

In certain scenarios, refinements may be necessary as minor adjustments to equipment placement, the inclusion or removal of buoyancy elements (such as syntactic foams), and the addition or removal of weight (utilizing trim steel plates) may be undertaken to optimize the Lander's performance. These efforts contribute to fine-tuning the Lander's weight-buoyancy configuration for enhanced operational efficacy.

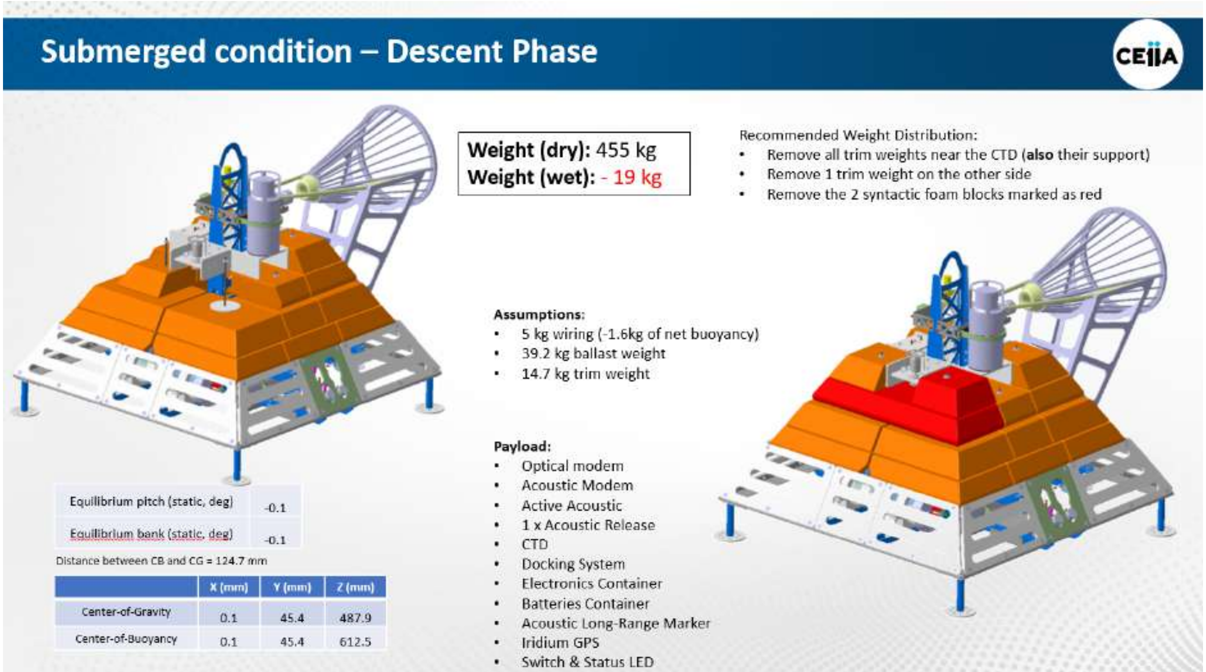


Figure 27 - Extraction from ATLANTIS Lander stability analysis.

Based on the current analysis of the NAUTILOS payloads, two significant adjustments are deemed necessary:

1. Trim Weights Removal:
   - **Change:** Remove all trim weights located near the CTD.
   - **Rationale:** This modification is essential to optimize the weight distribution and buoyancy of the Lander in a manner that aligns with operational requirements, improving the Lander's attitude while submerged and on the surface.
2. Syntactic Foams Blocks Removal:
   - **Change:** Remove 2 synthetic foam blocks marked in red.
   - **Rationale:** This adjustment aims to fine-tune the buoyancy characteristics of the Lander, ensuring optimal weight-buoyancy dynamics during deployment and recovery, to prevent an overwhelming ascent speed.

These changes are crucial for enhancing the overall performance and stability of the Lander in various operational scenarios (Figure 27 and Figure 28).

Figure 28 - ATLANTIS lander platform provided by CEiiA with NAUTILOS sensors and payloads from AQUATEC and UL-FE (real image).

VI. DEVIATIONS

The integration of the Deep Ocean low-level radioactivity sensor, developed by HCMR, initially for inclusion in the ATLANTIS Lander provided by CEiiA, encountered deviations based on several considerations.

The primary concern revolved around the radioactivity sensor having volatile memory. This means that if we were to power off the lander for a sleep period, all the stored data within the sensor would be irretrievably lost. To prevent this undesirable data loss scenario, the lander would need to remain in a constant powered on state. Although the Lander ATLANTIS theoretically met the sensor's requirements, this continuous power requirement significantly impacts the endurance and mission duration of the lander. As a result, the decision was made to shift the integration of this sensor to the HCMR platform.

Notably, this shift facilitated the following key criteria:

1. Risk Assessment and Testing: Multiple tests were made feasible by the platform change, namely in Greece. These tests aimed to assess the sensor's risk of data loss and gain confidence in its performance during actual data collection campaigns.
2. Increased Field Missions: Integration into HCMR platforms allowed for an expanded number of field missions involving this sensor, a crucial step in enhancing its technological maturity.
3. Intervention and Data Recovery: Ownership of both the developed sensor and the integration platform by HCMR ensured ease of intervention in case of accidents or data loss.

To summarize, the deviation in sensor integration was driven by a proactive approach to maximize the sensor's utility, minimize risks, and expedite its technological development. The integration of this radioactivity sensor in a water sampler on a R/V is documented in the D5.2 report, titled "Report on Integration of Sensors on Unmanned Vehicles/Platforms."

Additionally, Commercial Off-The-Shelf (COTS) sensors from HCMR, initially intended for installation in the CEiiA Lander, were requested to be regularly deployed in the Cretan Sea and are installed on the POSEIDON E1m3A obs (description added in D5.2).

VII. SUMMARY

As we conclude this report, "D5.7 – Report on Integration of Payloads/Sensors on Lander Platform," within the ambit of the NAUTILOS project, we reflect on the achievements that have been realized. The integration of an array of sensors, payloads, and cutting-edge communication systems has been meticulously detailed. The integration process, from mechanical configurations to software development, was successful and demonstrate a resolute commitment to durability and reliability. Partners involved in the work (CEiiA, UL-FE, AQUATEC and EDGELAB) demonstrated a remarkable adaptability and a commitment to optimizing the integration process that required careful planning and execution to ensure optimal conditions for data collection, and the physical integrity of the installed sensors and other payloads, and the platform itself.

With the closure of all integration of sensors and payload on ATLANTIS Lander provided by CEiiA (an adaptable modular platform designed to function at depths of up to 2000 m), this team is ready for the next challenges: field missions expected in WP6 and WP7, and thus to foster the deep-sea observation and the monitoring of both chemical and biological data, in addition to various other physical variables of the deep ocean environment.

VIII. APPENDIX 1: REFERENCES AND RELATED DOCUMENTS

ID	Reference or Related Document	Source or Link/Location
D4.5	Report on development and laboratory tests of Deep Ocean CTD sensor	**NAUTILOS Google Team Drive**
D3.6	Report on initial laboratory tests of Active Acoustic Profiling Sensor	**NAUTILOS Google Team Drive**