Learning from Aeronautics - Materials and Acoustics
New Challenges of Oil & Gas Exploration

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Abstract

The oil and gas industry is under major developments and changes with the discovery of new oil and gas repositories in the south Atlantic and the exploration of subsea environments.

This work presents two case studies that evaluate two different concepts developed over the years for aerospace applications that are used to help to overcome the existing challenges in subsea exploration: underwater acoustics, essentially on data transmission and acoustic positioning, and materials under severe conditions, essentially in terms of the evaluation of ageing and design approaches. Attending to each technology's applications, limitations, technological overview and foresights a discussion is performed, in a risk governance basis.

In the first case the main limitations concern to the range of operability of acoustic equipments. The acoustical positioning systems present, for example, a broad scope of ranges, starting with a few centimetres (less than 10cm) to several kilometres (up to 6km). The frequency bands used can also vary from a few kHz to hundreds kHz though the deeper the frequency can reach, the less accurate the measure is.

For the second case study, composite materials, such as fibre-glass and carbon-fibres, change their mechanical behaviour abruptly showing changes in the Young modulus and tensile and flexural properties after 1 week of exposure to salt water (fibre-glass tested at around 350bar.) Evidence of total degradation of materials (glass and carbon fibres) when exposed do hydrocarbons gases as been observed in literature related to the oil and gas exploration.

The two technologies have been further assessed in terms of their application in an existing ROV operated by the EMEPC, in Portugal (i.e. the ROV Luso). Analysis to the limitations and ranges of operability are presented of the acoustic systems (mainly positioning) and to the existent composite materials.

Keywords: Aerospace; Oil & Gas; Risk Governance; Acoustic communications; Composite materials; ROV

1. Context

The aerospace sector has developed new goods, services and frameworks that can fulfil consumers' needs and improve the quality of life, not only aerospace related but also in several other industries and sectors. The aerospace industry has introduced many technologies in the world, creating and enabling products from the ARPANET (internet predecessor) to improved imaging to breast cancer detection. It is, therefore, expected and necessary that the aerospace sector continues to play an important role in society [1].

The deep sea exploration sector is under continuous change and interested in technology that may help to increase levels of productivity and efficiency and to minimise challenges and risks [2]. The new locations of oil wells on the Brazilian offshore, the pre-salt discoveries, are an example of a challenge that the industry of sea exploration must handle.[3]

The development of technologies in aeronautics, as for example in areas like composite materials, electronics, control systems, numerical analysis methods (aerodynamics, structural, hydrodynamics), communications and several others, as also, working frameworks to deal with the increase uncertainty, are resulting in having better performances and lower costs. These developments are being adapted to other industries like the deep-sea offshore oil and gas in which technological trajectories [2] there is an exceptional need for radical and innovative solutions

2. Research Problem and Outline

This thesis aims to identify two specific aerospace technologies, acoustical communications and composite materials, gather knowledge on concepts and limits of operations in order to understand how they are helping the deep-sea offshore oil and gas industry in this new paradigm of challenges.

For the underwater acoustics one decided to focus on the ranges of applicability and operation of underwater positioning systems and communications. For materials are specified characteristics like ageing and design approach under extreme conditions, presenting also the limits of applicability of such materials to the deep sea. For both cases are also appointed applications and possible further connections to the aeronautical sector.

The field work, presented in the last chapter, integrates the knowledge gathered in the other chapters and makes possible to understand the occurrence and the limitations of these phenomena in the reality, in the Portuguese ROV, Luso. The discussion and further work are also presented at the end.

3. Methodology

3.1. Case Study Definition

The selection of the case studies and the process of inducting theory using these cases follows a framework already tested and validated [4, 5].

The process for working case studies has several steps: defining the research questions, specify the population in case, select more than one data collection methods, have multiple investigators to combine different data, overlap data and opportunistic data collection, analysing data, comparison with conflicting literature and reaching closure.[4]

This theory is applied to science when there is enough data to overlap and to get to real conclusions, as in this case. All the theory must then be evaluated, though it must be: parsimonious, testable and logically coherent [6].

After the selection of the cases studies and the gathering of extensive data from literature and interviews one entered a phase of conclusions that follow a framework by IRGC, explained afterwards, but that consists of the selection of the major benefits, risks and recommendations (technological issues and also some extra considerations that are important for the evaluation of their importance for the industry) and then a brief conclusion is drawn (for both case studies).

Technology foresight analysis has no direct effect on the methodology of this thesis but is worth mentioning as the criteria to choose future options for the deep offshore oil and gas industry, and also aeronautical, regarding the information already available, must follow a correct thought methodology. The term "foresight" has been used to describe how to deal with long-term issues essentially in new policy tools to deal with problems in science, technology and/or innovation systems. While a few tools and techniques have been developed, they represent an unprecedented diffusion of forecasting, planning and participatory approaches to long-term issues.[7]

The strategic importance of technology in delivering value and competitive advantage to the companies and to the industrial networks in which they operate. These issues are becoming more critical as the cost, complexity and rate of technology change increases, and competition and sources of technology globalize (as for example the search for technologies in different areas as in this thesis). The management of technology must ensure that exists technological potential to solve the needs, now and in the future of a company and sector, in addition, the impact of changes in technology needs to be assessed, in terms of potential threats and opportunities, including disruptive technologies.[8]

There are several ways to evaluate whether a technology may or may not have a positive impact to solve the existing challenges like technology roadmapping, which represents a powerful technique for supporting technology management and planning, especially for exploring and communicating the dynamic linkages between technological resources, organizational objectives and the changing environment [8]. The work here presented tries to be a part of that process on both case studies has one evaluate the limitations and risks of use of such technology in the exploration of deep sea.

3.2. Risk Governance - International Risk Governance Council

The aim of a risk governance analysis and framework is to help experts and academia, in various countries and different context conditions, to design policies, regulatory frameworks and industrial strategies to maximize the benefits of a technology improvement and a new design approach to the deep-sea offshore oil and gas industry, regarding the know-how provided by the evolution in the aerospace sector and the development of disruptive technology with an aeronautical insight basis.

In the attempt to prevent inequitable distribution of risks and benefits between countries, organisations and social groups, differing approaches to assessing and managing the same risk, excessive focus on high profile risks, to the neglect of higher probability but lower profile risks, inadequate consideration of risk trade-offs, failure to understand secondary effects and linkages between issues, cost inefficient regulations, decisions that take inappropriate account of public perception and loss of public trust, risk governance must ensure a comprehensive approach comprising: pre-assessment; appraisal; characterisation and evaluation; management and communication.

These general categories, when interconnected and correctly applied to the different problems, provide a thorough understanding of a risk and options to deal with them.

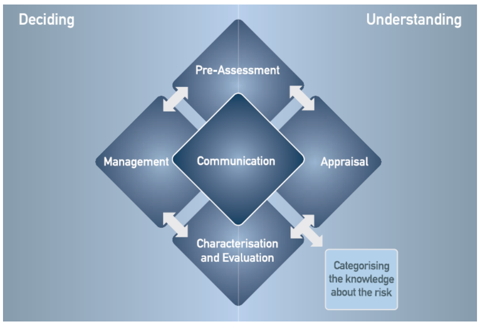

Figure 1: IRGC Framework (source: [9])

When referring to technology-related risks one must understand the existence of three major categories of that are worth mention: risks with uncertain impacts - uncertainty associated with technology and science innovation; risks with systemic impacts and risks with unexpected impacts [9].

Complexity of the new technological systems can encompass and/or influence many of the IRGC's risk factors as: scientific unknowns, loss of safety margins, positive feedback, varying susceptibilities to risk, conflicts of interests, values and science, social dynamics, technological advances, temporal complications, communication, information asymmetries, perverse incentives, malicious motives and acts. [9]

4. Underwater Acoustics

A large portion of Earth is inaccessible to electromagnetic waves, the underwater is one of the environments where that is true. Water, especially salt water, exhibits strong conductivity, meaning a higher degree of dissipation. This dissipation translates in an attenuation of the electromagnetic waves rapidly, limiting their use and range.[10] Acoustic waves are the most used way to transport information and data in the underwater environment.

As one may know, today there are available several solutions and applications that utilize the acoustic waves. Not only as radars and radio waves in the atmosphere and in space (lower performances) but also to:

- Detect and locate obstacles and targets;
- Measure different characteristics (later examples);
- Transmit signals (later further information on this topic).

The values for both frequency and wavelength can vary a lot and it depends on the characteristics of the medium, which influence the different physical processes behind the acoustic wave properties. The main constraints on the frequencies are:

- Dampening of sound waves in water (effect increases with frequency);
- Size of sound sources (increases with lower frequencies);
- Difficult selection of directivity of the acoustic sources and receivers (improving with frequency);
- Acoustic response of the target (comparison between the target size with the wavelength).

There are several applications of sound properties though the existence of limitations. One of the most important applications of acoustic technology is data transmission which, similarly to other modern transmission systems, underwater acoustic data transmission is performed using digital signals. The data are coded as binary symbols, each type of symbol being transmitted with different acoustic signals. The design of acoustic digital data transmission systems can therefore benefit from the powerful techniques developed in telecommunications. However, today's international standard for underwater telephones uses an analogue modulation around an 8-kHz carrier frequency (poor quality).

Underwater acoustic data transmission presents some problems that are difficult to avoid. The first is the achievable data rate: the frequencies usable are a few tens of kHz at most, to get acceptable ranges. The available bandwidths are thus reduced, and therefore the amount of information that can be transmitted. And the vagaries of propagation strongly degrade the quality of the signals transmitted, in particular through multiple paths and reverberation, as well as rapid amplitude fluctuations due to interference and scattering. The performance of a given system will therefore depend a lot on its conditions of use.

To counter propagation effects, one uses directive antennas, decreasing the effects of multiple paths and reverberation. The signals transmitted must be optimised to counter certain processes; the same signal can be transmitted at different frequencies to decrease the risks of fading; successive signals can be transmitted at time intervals in excess of expected spread of multiple paths, etc. It is also possible to code digital signals, in order to detect and correct a posterior some transmission errors. Finally, there are many techniques of signal processing that can be applied at reception.

The performance and degree of sophistication of each system is highly variable, depending on the application and the techniques used. Data transmission towards automated systems (UMVs) requires total reliability, despite an often complex acoustic environment, but it does not require high transmission rates. In favourable conditions of propagation, such as vertical transmission at large depths, it is possible to reach rates of 10kbits/s at depths of 5.000m. [11]

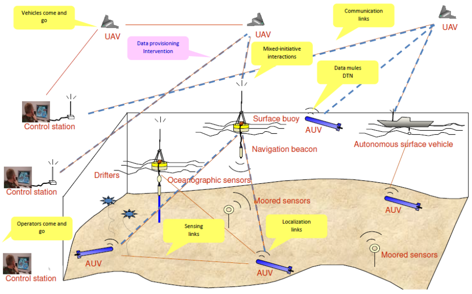

Figure 2: Network Vehicle System Concept - integration of multiple autonomous systems in marine environments (source: [12])

4.1. Risk Analysis

The benefits that can be seen from the application of these technologies is such environments and the potential gains that those can add to the industry:

- Access to places that human cannot;
- Gather information not possible otherwise, reducing costs and preventing investments that may not have the expected outcome;

The previous enumeration gives us some of the benefits of using these systems and all the specialists interviewed were convinced that the future on sea exploration must be handled by autonomous, or at least remotely operated, vehicles like ROVs, UMVs, UAVs, subseaplatforms and others.

The existence of risks must also be studied. This study is of great importance to actually understand the viability of such applications in the industry:

- Low rates of communications;
- Lack of knowledge in extreme depths;
- Errors in the control may lead to catastrophic situations - collisions;
- Lack of legislation and the existing is extremely conservative;
- Endurance perspectives are considered an obstacle that must be overcome rapidly;
- Cyber-attacks

Acoustic communications present limitations when operated underwater. The selection of which system to use depends highly on the range and accuracy intended and also on the desired application.

The main constraints found are related with the dampening of sound waves in water, attenuation of the signals transmitted, small propagation speed compared to aerial applications, perturbations of propagation due to different speeds of sound in water, deformation of transmitted signals and low rates of data transmission.

The creation of multi-systems architectures, using autonomous systems, has been proved possible and efficient [12] to overcome some of these limitations yet other risks arise, for example the lack of security on the networks, the delays on the means of communications and the testability of the robustness of the systems.

Another solution currently underdevelopment is the use of arrays to potentiate the sources of acoustical signal underwater and so diminish the losses [13].

Following the IRGC methodology for technology related risks one will check if all the pre-assessment question are answered. The potential damages and adverse effects have been highlighted with reference to the communications limitations and control debilities that may create uncomfortable situations to users and operations. The probability of occurrence is high, as the limitations are presented in all the environments and conditions. These limitations may only be reversed with further scientific and technological research, and with the creation of robust systems that can overcome the existent limitations. The benefits, opportunities and potential of these applications are referred.

Concluding this first case study the main limitations concern to the range of operability and accuracy of some equipments. The acoustical positioning systems present a large scope of operability, starting with a few centimetres (less than 10cm) to several kilometres (up to 6km). The frequency bands used can also vary from a few kHz to hundreds kHz though the deeper the frequency can reach, the less accurate the measure is.

As seen there are demanding limitations on acoustic communications that do not allow the rapid expansion of autonomous vehicles underwater, leading the technological industry to adapt solutions.

Integration of multiple sensors is therefore essential to surpass the limitations of individual equipments. The risks on the legislation and the capability to deal with cyber-attacks [14] must also be governed and new disruptive solutions for the deep sea exploration are essential to overcome these new challenges.

5. Materials Under Severe Conditions

Offshore oil production has become more and more complex. The main challenge is to provide technical solutions, reliable and safe, for the new oil field discoveries expressed before (pre-salt).

As mentioned, the search for new wells, at depths of 1500m to 3000m, the so called "hard to reach" reserves, bring along several challenges one must face: potentially degrading environments, arctic conditions and/or highly sour reservoirs.

High specific strength and stiffness are of great importance to solve some of the technical challenges and to obtain extreme high performances in the deepwater fields. Some composite materials can be created in order to not to corrode so easily, which is of supreme importance for the deep-sea offshore oil and gas industry. The only problem is to create means to understand the rate of degradation, which implies a search for new technologies to comprehend the long term degradation and/or ageing of these materials in the offshore oil and gas environments.

Subsea technology in use has a main preference for steel as the main material choice for systems that contain the flow pressure like pipes and valves, for structural elements including trawl protection, etc. Is now time to change this paradigm.

While the industry is gaining experience at the drilling at great water depths the critical factor in increasing depth is the drilling raiser. The riser must be made lighter to avoid excessive tension levels in its upper part. This may be achieved by replacing sections of the steel riser with composite material risers. Additionally, removing substantial weight from the riser, by fabricating them from composites, will proportionally reduce the topside counter balancing weight and allow current handling capacities of rigs and derricks to be used. The density of steel is 8 in air and composites are approximately 2. However in water, the densities are reduced to 7 for steel and 1 for composites. Thus composites offer a seven-fold weight reduction which reduces the capacity of handling equipment or allows larger parts when using composites. The same principle must apply to cabling, wire lines and choke and kill lines that run from the surface to the well-head. A composite riser solution is still under development and is discussed below. Additional challenges for drilling in ultra-deep water include weakness of the surface formations and the range of temperatures and pressures encountered which may vary from near 0^0C at the seabed to 150^0C+ in the formation at pressures in excess of 400 bar.

For production, the seafloor-to-surface mooring systems, umbilicals and risers have additional challenges to that of weight as described for drilling risers.

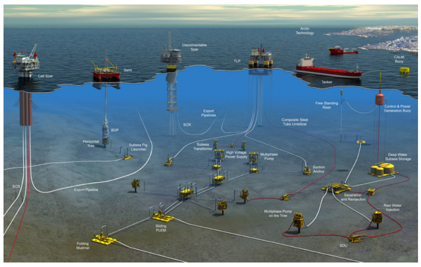

Figure 3: Big Picture of the subsea technologies with the subsea production systems and naval support equipments (Source: www.genesisoilandgas.com/our-business/subsea/Pages/default.aspx - 24th November 2014)

5.1. Technical Characteristics in Severe Conditions

To meet some of these challenges, the industry is beginning to look at new types of composite materials moving on from the established glass reinforced epoxies, used in piping, to carbon reinforced thermoplastics that offer high temperature capability, and high load capacity and stiffness. The use of unreinforced thermoplastics within the industry is not new with PVDF, PEEK, Polyamide and others being used widely for back-up rings and fluid barriers. However, the use of these thermoplastics as composites, i.e. reinforced with continuous glass or carbon fibres requires identifying which of these materials should be used for specific operating conditions.

It is important to determine any macro affects of exposure media and temperature. However, for any long term study a detailed investigation is needed into the techniques for gradual ageing starting from the surface that is exposed to the corrosive media. Hence, it is important to understand the different aspects of long term ageing and how this can be applied to a composite material in service.

It is also known that the environment can have a great influence on materials and can result in degradation. For metals, corrosion literature is in abundance that explains the creation and propagation of these effects. In composite materials and in general polymers, the environment can cause irreversible changes to the original properties analogous to corrosion. However, there is far less literature available. The process of change in properties of polymers or the fibres, or the bond between the polymer and the fibre is termed "ageing", replacing the word corrosion. For composite materials ageing can be categorized by three different primary mechanisms: physical, chemical and mechanical. These mechanisms depend on the material characteristics, for example: thickness, density, matrix; as well the type of application, environment and time of exposure.

Physical ageing will occur in polymers at temperatures below the glass transition temperature (T_g) and is based on fluid absorption. Initially, the fluid absorbs into the composite material surface and then, as time progress, a fluid content concentration gradient develops through the thickness of the material by diffusion. It is generally the first effect of ageing in non-extreme environments (i.e. concentrated acids) and can be reversible in amorphous polymers by heating it above its T_g. For composites these effects are complicated by different concentrations along continuous fibres.

Chemical ageing is an irreversible procedure and generally happens after physical ageing. It is irreversible because it affects the polymer chains through mechanisms such as cross-link creation, hydrolysis and chain scission (loss of molecular weight). It may also permanently damage the fibre or the bond with the resin. Similarly to physical ageing, it starts at the surface and continues inward. It can be characterized by changes in the T_g and mechanical properties.

Another stage of ageing is mechanical ageing when the pipes are under load, for example. This is also irreversible and affects the bulk material. It includes matrix cracking, delamination, interface degradation and all processes that are observable on the macroscopic scale. A well known type of ageing is the termed environmental stress cracking.

For future design steps to be developed, using ISO14692 [15], one can detail the design steps for composite piping systems to be designed and installed safely. The effect of ageing is added to one of the design parameters, external pressure collapse:

$$P_c = 2(\frac{1}{F})E_h(\frac{t}{D})^3 \tag{1}$$

Where P_c is the collapse pressure, F is a safety factor, E_h is the hoop modulus of the pipe, t is the average wall thickness and D is the pipe diameter.

Except for E_h, no parameters in this equation are affected by ageing (assuming no material loss). The hoop modulus is a function of the material, the lay-up and the number of plies. Knowing these variables, the hoop modulus can be calculated by the CLT.

The most used materials in pipes and offshore equipments are the FRP materials, that due to their nature of anisotropy and performance degradation the structural design makes them an unique case study. The structural design typically includes the design for internal pressure, external pressure, axial strength, bending strength, and buckling strength. Testing based methods are required in most cases in order to establish the long-term performance limits of FRP piping components, whilst the design strain based calculation may also be used along with short-term verification tests.[16]

There have been several projects investigating the use of carbon reinforced composites for risers where one of the prime motives is for lighter string in deep water applications. Composite risers may see more applications with the increase in deep water exploration.

Composite materials also offer advantages as the principal material for the body of valves and pumps, They have a proven track record in other industries where hostile fluids are handled and can be used for Acid Transfer, Brine, Chemical Processing, Corrosive Services, Water Treatment, etc. While GRP pumps and valves have better corrosion resistance compared to more expensive and highly-alloyed metals, use of carbon fibre composite further increases the durability for use with downhole and production chemicals. [17]

Rather like the aerospace industry, composite materials are becoming an enabling material to solve some of the technical challenges faced by the deep-sea offshore oil and gas industry in accessing "hard to reach" oil and gas reserves with priority on deep water production. Like in the aerospace industry, the high specific strength and stiffness are paramount to obtaining the performance for the deep water fields. However there is another significant advantage of composite materials and that is that they do not corrode. This is not entirely accurate because in the long term, composites to degrade in hostile environments and the rate of degradation needs to be understood.

While the design and engineering of composite material components for the offshore industry can learn from and use the tools in the aerospace industry, the evaluation of long term degradation or ageing in the deep-sea offshore oil and gas environments requires new technologies to be developed as the ones developed for the aerospace industry.

Ultra-Light Composites used in Advanced Aeronautics may also be used in the deep-sea offshore oil and gas industry which can bring different solutions.

The aeronautical industry, with the vast knowledge on this field of expertise, is of extreme importance for the evolution and development of the composite materials industry with applications in the O&G and subsea exploration sector.

This sector has already results in place for the behaviour of several materials like for carbon-epoxy composites. The certification for the use of composites in aeronautics obligates to identify possible occurrence of degradation by ageing, essentially regarding the thermal ageing process that affects the weight (weight loss) and a significant loss of mechanical strength and ultimate strain. [18].

The results for aeronautics, plus the existence of models to correlate the loss of mechanical characteristics of composite materials, are of great importance for the development of applications with composite materials for the offshore oil and gas and deep sea exploration sector.

5.2. Risk Analysis

The most important benefits of the use of composite materials in the deep-sea offshore oil and gas industry, and in subsea applications, for now, and the potential saves learned from the aeronautical sector are:

- Resistance to all kinds of environments (using specific materials, polymers and/or resins);
- Lighter;
- Cheaper maintenance (attending that the material has been studied extensively in the ageing performance).

After the extensive literature review and interviews with the industry, is evident that the composite materials and the testability and design of materials are one of the main developments in the technological industry with applications in this sector.

The benefits like the resistance and lighter weight are several times referred by the literature as a way also to reduce the costs of transportation and maintenance.

As seen in the all chapter the innovation in terms of materials may address some risks, essentially on the topic of the testability and reliability of these materials when compared to others that are used for far more years (metals and plastics).

The risks on the materials derive mainly from technological aspects but also from regulations and certifications:

- Technical issues like ageing (explained);
- Manufacturing;
- Selection of wrong materials and polymers;
- Lack of study of the behaviour of the materials;
- Lack of regulation on which materials are allowed and the needed certifications;
- Impacts reaction not studied.

Essentially the risks come from scientific and technical issues. This means that the further action must be centralized in the research and study of all ranges of materials and conditions. Also the legislations and certification must be seen as this industry only accepts the use of more advanced technologies after a long time of testing and proven the capability of the technology to respond correctly to every possible demand.

The use of composite materials and the use on already in use applications and in underdevelopment ones is of great interest. Not only for the industry that may add more benefits as the reduction of costs and the capability to have higher efficiency levels and to explore new horizons. The information gathered by interviews to the industry also showed that several projects of R&D are underdevelopment and that the industry is extremely interested, as shown in the OTC of 2014 and 2013.

Following the IRGC methodology for technology related risks one has to check if all the pre-assessment question are answered, essentially regarding the scientific risks constituents. The potential damages and adverse effects have been highlighted with reference to possible degradation of the materials and the possibility of existing unexpected reactions of the structures to collisions or other external factor. The probability of occurrence is high, as the limitations are presented in all the environments and conditions, but the problem is that they may just appear after several years of operation. These limitations may only be reversed with further scientific and technological research in order to understand the performance and evolution of the materials in these environments. The benefits, opportunities and potential of these applications and solutions are also referred.

Concluding, the application of composite materials may be of great interest for the deep-sea offshore oil and gas industry and on different applications. Research is needed in terms of the evaluation of the behaviour of the materials in extreme conditions. After such a thorough investigation, that has already started, major benefits may be gain with the introduction of this type of technology and scientific knowledge minimizing the risks and adding new solutions.

6. Summary

The practical case study has as main objective to make a contact with specialists in deep-sea operations in order to add more value to this work and so understand the robustness of the work here presented. The work with the EMEPC was developed at their headquarters, Paço de Arcos, and was helped by the use of data from the dives since 2008.

6.1. The ROV Luso - An application case study

To integrate the research one will present the case of the ROV Luso, the only ROV operating in Portugal, bought in 2008, by the EMEPC, and only one of eight in Europe (for the same purposes).

The ROV Luso has the capability to dive until 6000 m of depth and has as main goals the gathering of samples from the deep subsea and constitutes an advantage when accessing European and other funds in the areas of deep sea exploration.[19]

This machine has several equipments, mainly robot arms, video camera, Doppler velocity logger (DVL), CTD (conductivity, temperature, and depth sensor) for measuring oceanic properties, altimeter and acoustical positioning systems.[19] The structure of the equipment is mainly constituted by aluminium and titanium alloys.

The interest of this case study is that this technology has on board not only acoustical systems (positioning systems) but has also composite protection structures, making an ideal case for applying and understanding the behaviour of the last mentioned phenomenons, limitations and risks to an underused equipment.

To begin this analysis one will now present the conditions of operation of the Luso: depths and examples of in-dive conditions (salinity, temperature and the calculated speed of sound, respectively):

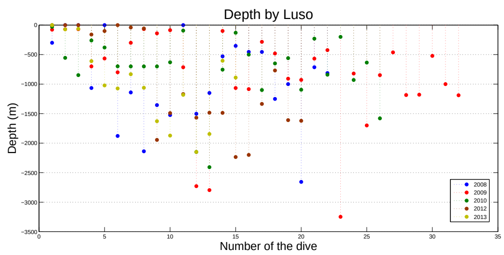

Figure 4: Depth of Luso's dives. Data from the EMEPC from 2008 to 2014, except 2011

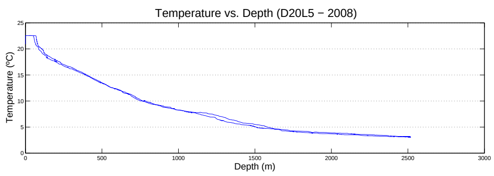

Figure 5: Temperature vs. Depth by Luso in the dive D20L5 of 2008. Data from the EMEPC

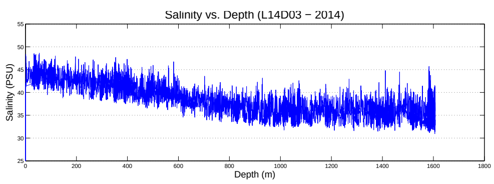

Figure 6: Salinity vs. Depth by Luso in the dive L14D03 of 2014. Data from the EMEPC

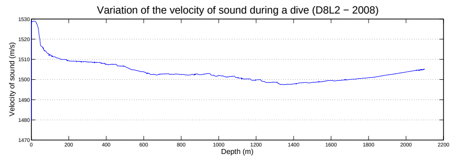

Figure 7: Variation of the sound velocity in deep waters - data from the dive D8L2 of 2008. Data from the EMEPC

To resume the conditions to which Luso is subjected one may conclude that deep-sea operations bring enormous challenges for the equipments on board.

Depths of more than 1500 m, temperature ranges that are usually around 20^{o}C and salinity maximums of 53.36 PSU are certainly extreme conditions to any system.

The speed of sound in a dive changes significantly, in this case it is possible to observe a range of speeds from 1530 m/s to speeds lower than 1500 m/s. This variation is also confirmed by the literature though for this work the important is that the variation will be limiting for the acoustical signs.

High levels of salinity added to temperature ranges bigger than 20^{o}C constrain not only the use of the acoustical sensors but also help to deteriorate the mechanical properties of the ROV's structure, essentially some specific equipments such as the umbilical.

The Luso presents several acoustic systems on board: USBL, DVL and Altimeter. For each system one will present photographs and tables gathering all the information researched *in loco* at the EMEPC.

The acoustical equipments on board of Luso serve mainly to assess the ROV location when in operation. This work aims to evaluate these equipments and try to understand how the challenging conditions of deep-sea condition affect the use of such equipments and propose solutions for the limitations.

Equipments	Ranges
Acoustic Positioning - USBL	-5 to 45^{o}C and an accuracy range of 0.4m
DVL (Doppler Velocity Log)	-5 to 45^{o}C and up to 6000m
Altimeter	Up to 6000m and starts working at 100m of the ocean floor

Table 1: Acoustic equipments on the ROV Luso

The ranges of operation and the conditions experienced by the ROV, Luso's operations do not stress the use of such equipments, though some challenges have been point out.

The Luso presents two important composite materials structures: the buoyancy structure and the umbilical.

The majority of the structure of the ROV is in aluminium and titanium alloys. The composite materials serve mainly two functions: enhance the buoyancy of the structure and to protect the interior of the umbilical, serving mainly to hold the tensions in the cable.

Equipments	Data
Buoyancy	Sintactic Foam
Umbilical	Aramid (Kevlar) and thermoplastic polyester

Table 2: Composite materials on the ROV Luso

The conditions found by the EMEPC in the Atlantic ocean are inside the ranges of operability of all Luso's equipments, as expected.

Though the requirements are met, several issues came up during the interviews. For the acoustical systems, noise and deficiencies in the transmission of signals, were the main difficulty presented as the noise from the propulsion system limited the use of the USBL.

For the composite materials the degradation of the umbilical led to the reduction of the tensile and flexural properties and the structural changes in the ROV imply the constant adaptation of buoyancy.

The need to improve the ROV for different missions, and also to upgrade to a novel generation of remotely operated vehicles, makes the integration of new materials and structures that may accommodate this last challenges.

The work developed together with the EMEPC made possible to identify some projects that may be of great importance for the future of the deep sea exploration:

1. Structures in composite materials to upgrade current generation of ROVs;
2. Adapt existing sensors towards multi-sensor integrated systems, to avoid current limitations of positioning sensors;
3. SHM mechanisms, integrating acoustic sensors and composite materials;

In conclusion, this case study made possible to understand the limitations of the oceanic environment and the challenges in the deep sea exploration.

The ROV Luso may also be used as a test bed for the development and test of further technology for the deep sea essentially regarding the technological areas presented throughout this master thesis.

6.2. Discussion

The new challenges for the deep-sea offshore oil and gas exploration, but also for the sustainable exploitation of the oceans (as both share similar challenges, as proved with the case study on the ROV Luso), are leading the technological trajectories to focus on innovative and radical solutions.

Therefore the main purpose of this thesis was to identify and understand the applications and limits/ challenges of operation for two technologies (case studies), from the aeronautic sector, in this environment: composite materials and acoustic communications.

- The analysis: learning from aeronautics:

  Acoustic communications: towards multi-sensor integration in deep-sea robotics.

  Composite materials: towards future applications in deep sea robotics for better buoyancy control;

The research presented in this work shows several references to the aeronautical sector when referring to the deep-sea offshore oil and gas technological developments. Not only with possible new applications for technology already developed for the aeronautical industry but also the scientific knowledge, the know-how in working with state of the art technology, the certification and the testability procedures used in aeronautics. This information was gathered not only in the bibliographic review but also by specialists and confirmed with the practical case study with the ROV Luso.

The Luso case study helped to gather the insights of specialists and made possible to identify a test bed for future uses. The capacity of the Portuguese industry, mainly the aeronautical sector, to enter in this industry may gain an important view and chance of testing technology by resorting this equipment.

- Application: ROV Luso: a test bed for future exploitation;

The practical case study served to identify clearly the environmental conditions in the deep-sea and also to understand the practical limitations of the acoustical equipments and the degradation of the composite materials on board.

The need to develop innovative solutions to overcome such challenges is the primary goal of the creation of the International Observatory of Global Policies for the Sustainable Exploration of Atlantic, which is an implication of this thesis. This platform will allow the opportunity to develop and further study all the sea related technologies, making possible to assess and explore new engineering for the deep-sea offshore oil field services for the South Atlantic, allowing the managing of the risks.

- Implications: The need for an Observatory, to assess and explore new engineering for the offshore oil field services for the South Atlantic.

6.3. Further Work

The most important barriers to this thesis were the little readiness of individuals to engage in systematic and interdisciplinary thinking and sharing valuable insights and time constraints.

In terms of further work all chapters may be further studied, not only in terms of interviews, but also in terms of literature review and experiments to prove the phenomena here presented.

This thesis is a first impression on a comparative study between two technologies from the aerospace sector and their limitations in the deep-sea offshore oil and gas industry. In terms of scientific knowledge is important to continue to gather more information on the topics and understand what are the main projects undergoing on both sectors.

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