

Performances of Some Autonomous Assets in Maritime Missions

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ABSTRACT: The paper deals with key features of some autonomous assets, i.e., unmanned aerial and underwater vehicles used for marine surveillance and reconnaissance missions. Firstly, performances of Airbus Zephyr S HAPS (Solar High Altitude Pseudo-Satellite), Tekever AR5 Life Ray Evolution and the AR3 Net Ray medium altitude unmanned aerial vehicles (UAVs) have been analysed. Then, ECA Group A18 and A9 autonomous underwater vehicles (AUVs) features have been presented. The strengths, weaknesses, opportunities and threats (SWOT) approach is applied to position appropriately these UAVs and AUVs in the context of maritime security operations. The need for further investigation in the field is revealed as well. The analysed vehicles are assets deployed with the European Commission's (EC) COMPASS2020 project and tested over European seas.

1 INTRODUCTION

Unmanned aerial vehicles (UAVs) and autonomous underwater vehicles (AUVs) are being increasingly used for numerous purposes in both military and civilian areas. Today's applications of these systems include surveillance, reconnaissance, remote sensing, target acquisition, border and marine patrol, infrastructure monitoring, communications support, aerial imaging, industrial inspection and emergency medical support. The UAVs and AUVs have capacities of sensing and perceiving the environment, processing the sensed information, communicating, planning and decision making, as well as acting autonomously by using control algorithms and actuators [5]. The UAVs and AUVs presented in this paper are deployed within EC Horizon 2020 COMPASS2020 (Coordination Of Maritime assets for Persistent And Systematic Surveillance) project. This project has a goal to use unmanned aerial and underwater vehicles in operational coordination with

manned oceanic patrol vessels used by European Maritime Safety Agency (EMSA), to enhance current marine border surveillance operations, with a particular focus on the detection, monitoring and control of irregular migration and narcotics smuggling. The project has been conceived to assist authorities in handling the pressure put on European external borders by the vast amount of irregular border crossings observed in recent years. Besides struggling with irregular migrants, Europe has a problem with other incidents of the most disperse nature such as the long lasting issue of narcotics trafficking [11]. Aiming to address these two big challenges, the project proposes the development of an unified system based on open standards that will enable the combined operation of multiple unmanned assets, manned platforms currently used for marine surveillance and the future accommodation of other platforms and services with minor integration efforts [7;8;18].

This article concerns key performances of the UAVs and AUVs at a high level of abstraction, used within COMPASS2020, and it is organised as follows: Section 2 deals with UAVs: Airbus Zephyr S HAPS, Tekever AR5 Life Ray Evolution and AR3 Net Ray; Section 3 considers AUVs: ECA Group A18 and A9 assets; Section 4 gives a SWOT analysis of examined UAVs and AUVs, which can be considered as an original contribution of the article; while the last Section 5 gives conclusion and indicates directions for further investigation in the field.

2 KEY FEATURES OF SOME UNMANNED AERIAL VEHICLES

In this section general features of UAVs as Airbus Zephyr S HAPS, Tekever AR5 Life Ray Evolution and AR3 Net Ray have been given. The inspiration for selecting these particular UAVs is found, as it is already noted, in recently set up EC Horizon 2020 COMPASS2020 project.

2.1 Airbus Zephyr S HAPS

The Zephyr is the first unmanned aircraft capable to fly in the stratosphere, harnessing the sun's rays and running on a combination of solar cells and high-power lithium sulphur batteries (solar-electric power) above the weather and conventional air traffic. It is a High Altitude Pseudo-Satellite (HAPS) [18;21] capable to fly for almost a month at a time combining the persistence of a satellite with the flexibility of an UAV (Figure 1). As HAPS, the Zephyr uses high-definition electro-optical and infra-red cameras to produce real-time visuals in any lighting. It costs around 5 million US\$, while an orbital satellite costs between 50 and 400 million US\$ [22], so it is considerably cheaper than a satellite. At the moment, Airbus possesses two types of the Zephyr, designed to accommodate a variety of payloads. The production model Zephyr S has a wingspan of 25 m and weighs less than 75 kg. It is able to carry see, sense and connect payloads. Presently, the larger Zephyr T, which is under development, has a wingspan of 33 m and a Maximum Take-Off Weight (MTOW) of 140 kg [2].



Figure 1. Airbus Zephyr S HAPS in stratosphere (Source: Airbus)

The Airbus Zephyr S has been firstly launched on 11 July 2018 in Yuma, Arizona, USA. Previously, it was transported from Farnborough, UK. It had a

small ground infrastructure. This was a historical take-off, when after eight hours Zephyr reached the stratosphere. Its lower altitude was 18 km, and the highest 23 km. This was, at the time, the longest flight without refueling, lasting 25 days, 23 hours and 57 minutes [1]. Unfortunately, on 15 March 2019, the Zephyr aircraft crashed near its launch site in Wyndham, Western Australia [19]. This was caused by severe adverse weather. Luckily, it happened in an extremely remote location and caused no injuries or property damage. Work on the Zephyr improvements is continued and it is to be expected that the Zephyr's mechanical launcher will be tested soon.

Zephyr sees clearly, senses efficiently, and connects precisely. It is able to revolutionise missions all over the world, including defence, humanitarian, security and environmental operations. It shapes the future of connectivity. Zephyr delivers new services, new business models and new opportunities to the connectivity market. It is flexible, scalable and connects beyond. Zephyr detects and tracks vessels in all weather through High Altitude Radar Persistent Imagery (HARPI) within the range of 35 nm (Figure 2). It is suitable for adaptive missions planning at distances greater than 100 nm (Figure 3). In addition, it cues other air assets to investigate; provides situational awareness to maritime agencies; enables maritime network evolution; adds security and resilience to the network, in a way to integrates it with existing IP networks and like.

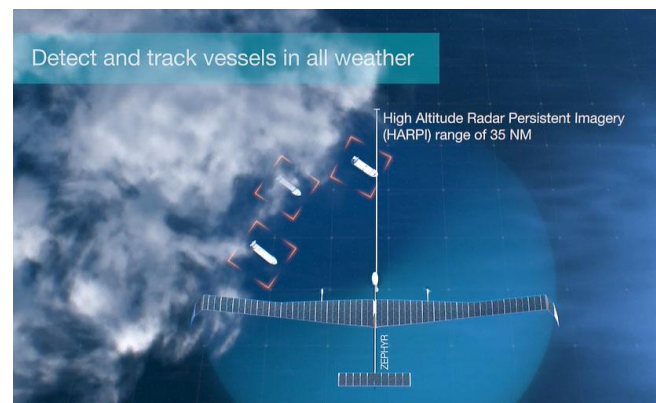


Figure 2. Zephyr vessels' tracking by HARPI (Source: Airbus)

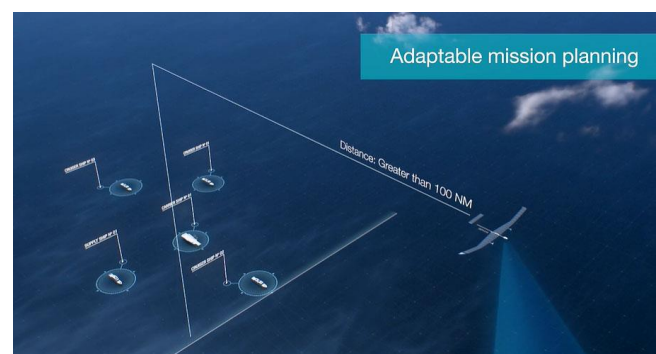


Figure 3. Zephyr adaptive mission planning (Source: Airbus)

The Zephyr was conceptually integrated in the proposed COMPASS2020 architecture, as a valuable asset for future concepts of operation. Due to its potential of acting as a high altitude platform capable

of performing early detections and providing the respective warnings to the system, it is considered to bring added value to the solution, by providing persistent surveillance and the first detection of potential events of interest. The goal of the project is to develop the solution in such a way that it will be possible and simple to integrate the Zephyr (both physically and in terms of data processing) within the overall system, once this platform has reached a development maturity that allows it to become fully operational [7;8].

2.2 Tekever AR5 Life Ray Evolution

The AR5 Life Ray Evolution is a medium-endurance and medium-altitude fixed wing UAV (Figure 4). It is designed for wide area land and maritime surveillance, pollution monitoring, fisheries inspection and communication relay [10]. The AR5 Life Ray Evolution has advanced on board capacities in terms of data processing. It can simultaneously process Electro-Optical/Infra-Red (EO/IR), radar and AIS data [17].



Figure 4. Tekever AR5 Life Ray Evolution (Source: Tekever)

The AR5 Life Ray Evolution is sub-tactical UAV dealing with 180 kg MTOW. It allows high speed beyond line of sight (BLoS) satellite communications (SATCOM). It also provides high precision video, imagery and sensor data in real time. Its features include a flexible architecture, supporting multiple types of payloads and datalinks. Moreover, this platform complies with the highest production standards as the first European-wide UAV-based maritime surveillance system, which is International Traffic in Arms Regulations (ITAR) free [13]. As an UAV that requires a runway for take-off and landing, its automatic take-off and landing capabilities, as well as the fact that it can use short and unpaved airstrips, are great advantages. The AR5 Life Ray Evolution has a cruise speed of 100 km/h and a standard endurance of approximately 16 hours. The available payload capacity is up to 50 kg, wingspan 7.3 m and length 4.0 m. It is equipped with a three axis multi-sensor gyro-stabilised gimbal, capable of supporting the integration of multiple types of payloads. This includes AIS transceiver, multiple EO/IR sensors, Emergency Position Indicating Radio Beacon (EPIRB), radar, etc [24;27].

Within COMPASS2020, the AR5 Life Ray Evolution UAV plays an important role as a middle layer platform, which is able to provide wide maritime area surveillance, complementing the operational gap between the wider coverage but lower resolution capabilities of the Zephyr, and the lower altitude and more localized situation

monitoring provided by the AR3 Net Ray, which will be presented in the following sub-section [6;8].

2.3 Tekever AR3 Net Ray

The AR3 Net Ray is a ship-borne UAV designed to carry out several types of maritime and land-based missions (Figure 5). These missions include: intelligence, surveillance, target acquisition and reconnaissance (ISTAR) actions, pollution monitoring, infrastructure surveillance and communication support operations. This UAV is capable of delivering an endurance up to 10 hours, which makes it an ideal solution to carry out both maritime and land based missions. The payload capacity is 4 kg and it includes: multiple options for EO/IR sensors, near-infrared to long-wave infrared (LWIR) sensors, laser illuminators, communication relay systems, AIS transceivers and EPIRB. It provides real time collection, processing and transmission of high definition video. Its communication range is up to 80 km within radio Line of Sight (LoS), cruise speed is 85 km/h, MTOW is 23 kg, launch is conveyed via catapult, recovery via parachute and airbags (for land based operations) or using a net system (for maritime based ship-borne operations). The AR3 dimensions are 3.5 m of wingspan and a length of 1.7 m [26].



Figure 5. Tekever AR3 Net Ray taking-off (Source: Tekever)

The AR3 Net Ray UAV will be included in the COMPASS2020 surveillance ecosystem as an organic asset of the oceanic patrol vessels operated by the maritime authorities. This UAV will be operated (launched, piloted and recovered) from the vessel to provide the tactical teams with enhanced real time information to help decision making. The AR3 will cover a surveillance level below the AR5, providing a more localised monitoring of events and situations of interest [6;8].

3 KEY FEATURES OF SOME UNDERWATER UNMANNED VEHICLES

In this section, crucial features of AUVs as ECA Group A18 and A9 are briefly presented. The inspiration for selecting these particular UAVs is like in the previous case of UAVs found within EC Horizon 2020 COMPASS2020 project. These assets are robots-drones that travel underwater without

requiring input from an operator. They are autonomous platforms, without cable, integrated their own energy. In other words, they execute missions autonomously. They are capable to follow a programed pattern with very accurate positioning, while navigating close to the seafloor with very good stability. They provide high resolution images in order to improve survey efficiency. These drone systems are used for underwater mine warfare, homeland security, crucial infrastructure protection, harbor and coastal surveillance and protection, rapid environmental assessment (REA), search and rescue (SAR) operations, intelligence, surveillance, and reconnaissance (ISAR), commercial applications (offshore), and deep water survey and inspection. They are launched and recovered via robots [14].

3.1 ECA Group A18-M

The A18 is a configuration of ECA Group AUVs family (Figure 6). Its applications for the defense and security sector encompass: (i) Rapid Environment Assessment (REA); (ii) Intelligence, Surveillance and Reconnaissance (ISR); (iii) organic underwater mine warfare: mine countermeasures mission module for large multipurpose vessel and mission module for oceanic mine warfare, and (iv) conventional underwater mine warfare: detection and classification. The system can be delivered with a Launch And Recovery System (LARS) allowing automatic underwater recovery. Data post processing can be made with Triton imaging applications. It performs autonomous missions up to 300 m depth, and is easily transportable by plane for overseas missions. Due to its large endurance, very high area coverage rate (2km²/hour) and payload capacity, it is able to host high performance payloads according to the mission's requirements as Synthetic Aperture Sonar (SAS), Conductivity, Temperature and Depth (CTD) sonde, video, forward looking sonar (FLS), multi-beam echo sounder, and others [23]. For navigation, it uses Inertial Navigation System (INS), Doppler Velocity Log (DVL), military global navigation satellite system (GNSS) and Global Positioning System (GPS) periodically, after resurfacing. It can communicate via WiFi, Ethernet, Iridium and/or acoustic wireless communication channel. Its average speed is 3-5 knots (while the maximum is 6 knots). It withstands harsh environmental conditions and offers a greater stability when encountering heavy turbulence from waves. The high degree of stability enables this AUV to capture high-resolution images. The information obtained by the platform is processed to the command centre [15;9].

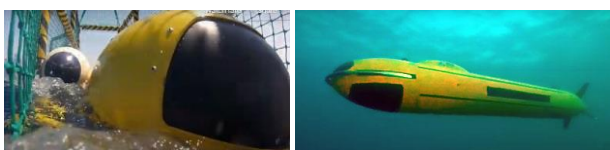


Figure 6. ECA Group A18 launching and underwater mission (Source: ECA Group)

3.2 ECA Group A9

The A9 is a member of ECA Group UAVs family for environmental monitoring (Figure 7). In addition to the seabed image acquisition, the A9 AUV can record bathymetric data as well as environmental information such as water turbidity, conductivity, temperature, fluorescence, dissolved oxygen and/or pH. Mission planning and monitoring are done through user friendly software which allows operator to follow the vehicle at any time during its mission. This underwater drone has been designed to meet STANAG 1364 requirement; as such, its acoustic and magnetic signatures are minimised in order not to trigger any underwater mines when doing the mine warfare survey. As part of early trials for the SWARM project, ECA Group A9 fitted with the interferometer sidelooking sonar demonstrated ability to conduct surveys in a shallow water of 13-20 m depth. It uses a phase differencing bathymetric sonar that increases area coverage by close to 200% over conventional multi-beam echo sounders in shallow water [16]. For navigation, it uses INS, DVL, GPS and for communication purposes radio (UHF), WiFi, Ethernet and the acoustic wireless communications. Its payload consists of, but it is not limited to: Interferometer Side Scan (ISS) sonar, video, CTD, and environmental sensors (turbidity, pH, fluorescent Dissolved Organic Matter (fDOM) / waste water discharge).



Figure 7. ECA Group A9 (Source: ECA Group)

Within the COMPASS2020 project plans, the AUVs are to be deployed from the offshore patrol vessel into a strategic location that is coincident to the traffickers' typical routes. The AUVs are programmed to follow circular trajectories in the area of interest, navigating underwater at low depth in order to remain undetected from the smugglers and at the same time staying closely enough to the surface in order to optimise the possibility of detecting the target. The AUVs carry sets of hydrophones that enable detecting speed boats and localise dumped cargo (cases or bags with narcotics). After detection of the target, the AUVs can communicate to the Zephyr, which is used as a communication relay in the system [11].

4 SWOT ANALYSIS

This section deals with some basic positive and negative factors connected with previously introduced UAVs and AUVs. These factors are summarised through a SWOT analysis (Table 1). In accordance with SWOT principles, strengths, weaknesses, threats and opportunities of the considered UAVs and AUVs are highlighted. Current solutions for analysed UAVs and AUVs are in development and/or testing phases [12]. Therefore, it was not possible to conduct surveys due to their strengths, weaknesses, threats and opportunities among potential endusers such as European maritime and coastal authorities. Developers and researchers involved in the project have created their own internal documentation, which is treated as the

intellectual property of the project. Therefore, the following SWOT analysis is based mostly on secondary literature resources [3;4;20;25] and some information upon the results of the field experiments recently being carried on. However, used references are sound and promise quality of conducted study. Through further investigation the examined features of UAVs and AUVs can be assessed within the specific context, which might be different from the analysed one – European coastal areas monitoring and combat against narcotic smugglers by the maritime authorities. Apart from this, at the current stage of the research in the field, the following SWOT is at high level of abstraction and only partly anchored to the afore mentioned project and its setting.

Table 1. SWOT analysis of the UAVs and AUVs

Strengths	
UAVs	AUVs
<ul style="list-style-type: none"> - Lightness. - Manual launching or reduced logistics footprint. - Low energy consumption. - Lower acquisition price in comparison to satellites. - Better quality of information in comparison with satellites. - Lower operational costs in comparison with manned aircrafts used for the same mission profiles. - Ability to fly for more hours continuously in comparison to manned aircrafts, as there is no need for aircraft downtime for pilot rendition. - High seeing, sensing and communication capacities. - Capacity of both LoS and BLoS operations. - Large coverage and durability of flight without recharging. - High level of automation. - Possibility to be safely integrated with commercial aviation. - Capacity to support high risk activities. - Capacity to reach areas inaccessible for humans. 	<ul style="list-style-type: none"> - Capacity to support high risk activities. - Capacity to reach areas inaccessible for humans. - Capacity to explore unexplored marine habitats. - Capacity to monitor and repair underwater constructions, pipelines and cables. - High level of autonomous navigation, collecting data and coming back to the seasurface vessel. - Silence operation and consequently not disturbing the environment and being imperceptible to potential foes. - Being tight and waterproof. - Having shape that mimics sea creatures (fishes, crabs, turtles, beetles and snakes). - High appropriateness of kinetic and dynamic properties for underwater environment. - Capacity of delivering with a Launch And Recovery System (LARS). - Navigation with combination of Inertial Navigation System (INS), Doppler Velocity Log (DVL), military global navigation satellite system (GNSS) and Global Positioning System (GPS) periodically. - Possessing advanced sensors like: Synthetic Aperture Sonar (SAS), video, forward looking sonar (FLS), multi-beam echo sounder and like. - Communications via acoustic, radio and optical (light and laser) waves.
Weaknesses	
UAVs	AUVs
<ul style="list-style-type: none"> - Complexity of the UAVs makes them more vulnerable. - Requirements for highly skilled personnel for designing, creating, operating-controlling, maintaining and upgrading the UAVs. - Lack of law regulations at a wider scale. - Lack of management and operational knowledge at different levels of the UAVs operation. - Lack of common communication capacities between the UAVs and other vehicles within integrated traffic and transportation system. - The link between the UAVs and ground control stations. - Maneuvering and obstacles' avoidance algorithms and features are under development. - Computer vision is also still until development. 	<ul style="list-style-type: none"> - Better adaptive control using neuro-fuzzy techniques is needed. - More accurate localising using improved INS non-linear Kalman filters, cooperative localization (swarm intelligence), artificial intelligence vision and object detection, odometry, are to be developed. - Underwater wireless communications are to be improved, particularly at the longer distances. - High-density battery power supply is necessary. - Energy harvesting methods are to be improved.
Opportunities	
UAVs	AUVs
<ul style="list-style-type: none"> - Increasing safety and security at sea and in general. - Reduction of traffic congestion in areas with high density traffic. - Approaching up to now inapproachable areas. - Approaching areas of high risk for humans. - Gathering more information on distance areas, 	<ul style="list-style-type: none"> - Increasing safety and security at sea and in general. - Approaching up to now inapproachable corners of seabed. - Approaching areas of high risk for humans. - Gathering more information on distance areas, aquatic flora and fauna, constructions. - Lower ecological footprint.

- entities, constructions.
- Lower ecological footprint.
- Developing 3D path planning with obstacle avoidance.
- Developing potentials of autonomous systems.
- Further development of artificial super-complex UAV systems.
- Developing 3D path planning with obstacle avoidance.
- Developing potentials of autonomous systems.
- Further development of artificial super-complex AUV systems.

Threats

UAVs AUVs

- | | |
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| <ul style="list-style-type: none"> - Collapse of the UAVs due to severe weather conditions/harsh environments. - Negative effects of external factors as natural forces and cosmic impacts. - Losing human control over the crafts. - Unsafe landing and recovering. - Internal disturbances and faults in the systems as super-complex ones. - Over-reliance on technology, i.e., UAVs in the analyzed context; - Unauthorized malicious intrusion into the system (hacking); - Scarcity of the cost-benefit analysis; - High investment risks; - The lack of readiness of entrepreneurs to support further development of UAVs; - Uncertain revenue of investments; - Users' reluctance to accept high risk investments in the UAVs innovations; - Questionable innovation acceptance success, etc. | <ul style="list-style-type: none"> - Losing human control over the crafts. - Unsafe Launch And Recovery System (LARS). - Internal disturbances and faults in the systems as super-complex ones. - Over-reliance on technology, AUVs in the analysed context. - Unauthorised malicious intrusion into the system (hacking). - Scarcity of the cost-benefit analysis. - High investment risks. - The lack of readiness of entrepreneurs to support further development of AUVs. - Uncertain revenue of investments. - Users' reluctance to accept high risk investments in the AUVs innovations. - Questionable innovation acceptance success. |
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5 CONCLUSION

A review of the UAVs and AUVs within the context of the COMPASS2020 project has been given. The Zephyr, the AR5 and the AR3 UAVs and A18 and A9 AUVs have been described through pointing out their key features. Based on the findings from secondary literature resources and experiences from the project up to now, some strengths, weaknesses, opportunities and threats of the considered UAVs and AUVs have been highlighted.

The future research in this area should provide a deeper insight of compatibility of the UAV and AUV systems with the existing and well established manned and unmanned crafts used for the same or similar purposes. Common communication schemes and algorithms among (un)manned, aerial, seasurface and underwater craft are currently under further development.

There is a strong argument in favour of increasing initiatives for testing, validating and integrating unmanned systems within current surveillance infrastructures (both land and maritime based), as these assets can assist current surveillance and monitoring capabilities of authorities in a cost-effective way. However, the so-called blind-belief in technology, including the analysed UAVs and AUVs, should be critically reviewed. The willingness of various involved parties to develop, implement and adopt such advanced systems should be investigated with the aim to provide their innovation implementation success in military, civil, industry and other errands.

Such advanced systems can be used as subjects of further research work and base for applying for research funds not only in developed, but also I developing countries as South Africa. The scope of the analysed craft can be broaden beyond patrolling

and combat missions in European seas. For instance, the South African Operation Pakhisa programme inspired by blue economy can enrich its scope by investigating possibilities of optimal deploying the UAVs and AUVs within the national context, in accordance with the actual needs and preferences in maritime.

ACKNOWLEDGMENT

This article has been inspired by European Commission's Horizon 2020 COMPASS2020 Project (Grant Agreement No: 833650). The author is an external expert at the Project.

REFERENCES

- [1] Airbus. 2018. "Zephyr – Zephyr S turning dreams into reality on its maiden flight". [Online]. Available at: <https://www.airbus.com/defence/uav/zephyr.html>. [Accessed: 12 November 2019].
- [2] Airbus. 2019. "Zephyr – Pioneering the Stratosphere". [Online]. Available at: <https://www.airbus.com/defence/uav/zephyr.html>. [Accessed: 12 November 2019].
- [3] Alop A. 2019. "The Main Challenges and Barriers to the Successful Smart Shipping". *TransNav – International Journal on Marine Navigation and Safety of Sea Transportation*, 13(3): 521-528. [Online]. Available at: https://www.transnav.eu/Article_The_Main_Challenges_and_Barriers_Alop,51,925.html[Accessed: 06 December 2020].
- [4] Andrews E. 2016. "The Sinking of Andrea Doria". [Online]. Available at: <https://www.history.com/news/the-sinking-of-andrea-doria>. [Accessed: 9 December 2019].
- [5] Becerra VM. 2019. "Autonomous Control of Unmanned Aerial Vehicles". *Electronics*, 8(4): 452. [Online]. Available at: <https://www.mdpi.com/2079-9292/8/4/452/htm>. [Accessed: 6 December 2020].

- [6] Bauk S., Kapidani N., Sousa L., Lukšić Ž. and Spuža A. 2020. "Advantages and disadvantages of some unmanned aerial vehicles deployed in maritime surveillance". Proc. of the 8th International Conference on Maritime Transport, 17-18 September 2020, Barcelona, Spain, pp. 301-310.
- [7] Bauk S., Kapidani N., Luksic Z., Rodrigues F. and Sousa L. 2019. "Autonomous marine vehicles in sea surveillance as one of the COMPASS2020 project concerns". Journal of Physics: Conference Series, 1357 (1). [Online]. Available at: doi: 10.1088/1742-6596/1357/1/012045. [Accessed: 6 December 2020].
- [8] Bauk S. et al. 2020. "Aerial Segment of the COMPASS2020 Project: Review of Main Constituencies". The 24th International Conference on Information Technology (IT), Zabljak, Montenegro, 2020, doi: 10.1109/IT48810.2020.9070718.
- [9] Bauk S. et al. 2020. "Key features of the autonomous underwater vehicles for marine surveillance missions". Proc. of the 1st International Conference Maritime Education and Development, 23-24 November 2020, Durban, South Africa (to appear).
- [10] Bold Business. 2017. "Maritime Surveillance, Newest Task for Drones". [Online]. Available at: <https://www.boldbusiness.com/communications/drone-maritime-surveillance/>. [Accessed: 25 November 2019].
- [11] COMPASS2020. Coordination of Maritime assets for Persistent And Systematic Surveillance, Project internal documentation (Boosting the effectiveness of the Security Union, H2020-SU-SEC-2018-2019-2020): 1-70.
- [12] Chavaillaz A., Wastell D. and Sauer J. 2016. "System reliability, performance and trust in adaptable automation". Applied Ergonomics, 52: 333-342.
- [13] Digital Guardian. 2019. "A definition of ITAR compliance". Digital Guardian's Blog. [Online]. Available at: <https://digitalguardian.com/blog/what-itar-compliance>. [Accessed: 25 November 2019].
- [14] ECA Group. 2019. "A9, A18, A27: ECA Group's AUV range for UMIS drone system". [Online]. YouTube. Available at: <https://www.youtube.com/watch?v=u7ka4SmDako> [Accessed: 7 January 2021].
- [15] ECA Group. n.d. "A18-M/AUV/Autonomous Underwater Vehicle, Data Sheet". [Online]. Available at: <https://www.ecagroup.com/en/solutions/a18-m-auv-autonomous-underwater-vehicle>. [Accessed: 12 April 2020].
- [16] ECA Group. n.d. "A9-E/AUV/Autonomous Underwater Vehicle, Data Sheet". [Online]. Available at: <https://www.ecagroup.com/en/solutions/a9-e-auv-autonomous-underwater-vehicle>. [Accessed: 12 April 2020].
- [17] FLIR. 2019. "What is EO/IR?" [Online]. Available at: <https://www.flir.com/discover/rd-science/what-is-eoir/>. [Accessed: 25 November 2019].
- [18] Gonzalo J., Lopez D., Dominiguez D., Garcia A. and Escapa A. 2019. "On the capabilities and limitations of high altitude pseudo-satellites". Progress in Aerospace Science, 89: 37-56.
- [19] Jones, H. 2019. "Ministry of Defence's Zephyr drone crashes in Australia". [Online]. Available at: <https://ukdefencejournal.org.uk/ministry-of-defences-zephyr-drone-crashes-in-australia/>. [Accessed: 14 April 2020].
- [20] Kapidani N., Bauk S., Davidson I.E. 2020. "Digitalization in Developing Maritime Business Environments towards Ensuring Sustainability". Sustainability, 12(2), 9235, <https://doi.org/10.3390/su12219235>.
- [21] Kramer J. 2018. "What Are Pseudo-Satellites and What Do They Mean for Aerospace and Aviation?" [Online]. Available at: <https://blog.v-hr.com/blog/what-are-pseudo-satellites-and-what-do-they-mean-for-aerospace-and-aviation>. [Accessed: 24 November 2019].
- [22] Metcalfe T. 2018. "This 'pseudo-satellite' drone can fly 70,000 feet up in the sky - Zephyr could replace some spy or Earth-observing satellites in the future". [Online]. Available at: <https://www.nbcnews.com/mach/science/pseudo-satellite-drone-can-fly-70-000-feet-sky-ncna894071>. [Accessed: 8 January 2021].
- [23] Naval Technology. n.d. "A18-M Autonomous Underwater Vehicle". [Online]. Available at: <https://www.naval-technology.com/projects/a18-m-autonomous-underwater-vehicle/>. [Accessed: 9 April 2020].
- [24] Naval Technology. 2019. "Tekever AR5 Life Ray Evolution Unmanned Aerial System (UAS)". [Online]. Available at: <https://www.naval-technology.com/projects/tekever-ar5-life-ray-evolution-uas/>. [Accessed: 24 November 2019].
- [25] Sahoo A., Dwivedy S.K. and Robi P.S. 2019. "Advancement in the field of autonomous underwater vehicle". Ocean Engineering 181:145-160.
- [26] Tekever. 2018. "Brochures – AR3 Extending Your Horizon". [Online]. Available at: airray.tekver.com/ar3/. [Accessed: 24 November 2019].
- [27] Tekever. 2018. "Tekever AR5 – The European Maritime Patroller". [Online]. Available at: <https://uas.tekver.com/ar5/#:~:text=TEKEVER%20AR5%20%E2%80%93%20The%20European%20Maritime,pollution%20and%20oil%20spill%20monitoring>. [Accessed: 24 November 2019].