Review of Unmanned Aerial Systems for the Use as Maritime Surveillance Assets

Sanja Bauk, Nexhat Kapidani, Žarko Lukšić, Filipe Rodrigues, Luís Sousa

***Abstract* - The paper presents key features of Unmanned Aerial Systems (UASs) deployed within the H2020 project Coordination Of Maritime assets for Persistent And Systematic Surveillance (COMPASS2020). The project has been conceived to enhance maritime safety, search and rescue at sea, as well as controlling and monitoring irregular migration and securing the European maritime borders from narcotics smuggling by means of the seamless integration and coordination of several manned and unmanned vehicles, specifically suited for these purposes. In this paper only the aerial segment has been considered, i.e., the Zephyr pseudo-satellite, as well as the AR3 Net Ray and the AR5 Life Ray Evolution crafts. Comparative advantages and disadvantages of these systems are presented, along with their info-communication roles within the project. Also, some directions for further research in the field are specified.**

I. Introduction

The COMPASS2020 project is an EU co-funded project under Horizon 2020 programme that aims to demonstrate a mature solution to enable a seamless integration and coordination of manned and unmanned platforms to augment the capabilities of Authorities under the Maritime Surveillance domains. In particular, the focus is to provide a solution to assist European governments and EU agencies to monitor and efficiently deal with a rising number of various incidents and threats, including piracy and smuggling of goods and narcotics, as well as irregular migration and marine pollution. The Search and Rescue (SAR) operations are part of these actions [1]. The project has been conceived to address a wide range of challenges currently faced by Authorities in the maritime domain, and will be demonstrated in a large-scale exercise that will cover two dimensions: (a) the SAR missions connected with irregular migration, and (b) seizing narcotics smugglers. For the successful achievement of these goals, the following assets are considered within the project infrastructure: (1) an Oceanic Patrol Vessel (OPV) handled by the Portuguese Maritime Authority, conceived and constructed as a multi-mission vessel; (2) the AR3 Net Ray Unmanned Aerial Vehicle (UAV), a fully autonomous UAS with uninterrupted flying capacity of up to 10 hours and a communications span of up to 80 km, launched by catapult and recovered by parachute and airbags (standard recovery option for land-based operations) or with a net system (specifically designed for maritime operations); (3) the AR5 Life Ray Evolution, a medium-altitude and medium-endurance, fixed-wing UAS conceived and constructed for supporting SAR tasks, long range intelligence observations and marine combat patrol (up to 16 hours of flight duration and a communications span of 100 km using Radio Line-of-Sight (RLoS) means, or unlimited using satellite communications (SATCOM)); (4) the Zephyr UAS, a High Altitude Pseudo-Satellite (HAPS) that co-operates among satellites, manned aircraft and UASs with an operating altitude of about 21 km; and (5) the A18-M, an Autonomous Underwater Vehicle (AUV), which can be blasted off from the OPV, capable of conducting autonomous tasks up to 300 m depth and within an area of 2 km^2 per hour. It is easily displaceable by plane for overseas actions and it is commonly deployed for different defense and security operations [2].

Within this article, we will give review of aerial segment of the project assets: the Zephyr, the AR5 and the AR3. Since they are relatively new systems, their key features will be presented and mutually compared. In addition, their roles within the project in terms of info-communication services they provide will be described. Finally, directions for further research shall be given.

II. Selected Aerial Systems

A. *The Zephyr*

The space in which Zephyr operates is the stratosphere. The stratosphere is a layer of Earth's atmosphere placed between troposphere and mesosphere. Its lowest part is around 10 km above the Earth's surface at middle latitudes. Its top has an altitude of around 50 km. The lower boundary of the stratosphere is called tropopause, while its upper one is named stratopause (Figure 1). The temperature raises upward through the stratosphere, vice versa the behavior in the troposphere, where temperature falls down as the altitude becomes higher. This temperature stratification ensures low level of turbulence and allegation in the stratosphere and the layers of air there are more stable [3].

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S. Bauk is with the Administration for Maritime Safety and Port Management of Montenegro, Montenegro & the Maritime Studies, Faculty of Applied Sciences, Durban University of Technology, SA (corresponding author e-mail: bsanjaster@gmail.com).

N. Kapidani & Ž. Lukšić are with the Administration for Maritime Safety and Port Management of Montenegro, Montenegro (e-mails: nexhat.kapidani@pomorstvo.me & zarko.luksic@pomorstvo.me).

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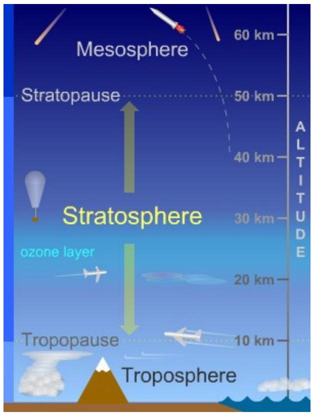

Figure 1. Layers and altitudes of stratosphere (Source: [3])

The Zephyr is a HAPS [5], able to fly merging the stubbornness of a satellite with the resilience of an UAV, or UAS. It uses high-definition and infra-red cameras to produce real-time visuals in any lighting. The Zephyr unit costs around 5 million USA$, while an orbital satellite costs between 50 and 400 million USA$ [6;7].

The Airbus' Zephyr S has been firstly launched on 11th July 2018 in Yuma, Arizona, USA. Previously, it has been transported from Farnborough, UK. It used to have a small ground infrastructure. It was a historical take-off, when after eight hours Zephyr reached the stratosphere [8;9].

Unfortunately, on 15th March 2019 the Zephyr aircraft with 25 m wingspan and mass of less than 75 kg has crashed near its launch site in Wyndham, Western Australia. 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 in 2020.

Under the context of the project, the Zephyr is capable of performing early detections and providing the respective warnings to the system. It brings added value to the solution, by providing persistent surveillance means and the first detection of potential events of interest. Based on this, the operators are able to request to the other platforms (medium and low altitude flying platforms) to inspect with more detail certain areas of interest.

Figure 2. Zephyr on its flight (Source: [9])

B. *The AR5 Life Ray Evolution*

The AR5 Life Ray Evolution was chosen by the European Maritime Safety Agency (EMSA) in an international tender to be the first European wide UAS to act as a maritime patroller. It is a medium-endurance and medium-altitude fixed wing UAS. It has been designed for wide area surveillance, in particular in the maritime domain, pollution survey, fisheries monitoring and communication convey [10]. The AR5 has advanced on board capabilities in terms of data processing.

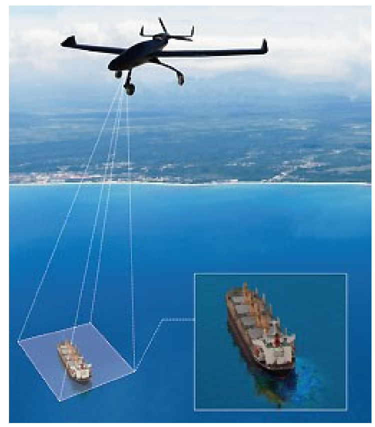

Figure 3. The AR5 mission at sea (Source: [12])

The AR5 complies with the highest production standards as the first European-wide UAS-based maritime surveillance system, which is International Traffic in Arms Regulations (ITAR) free [13]. Its huge advantages are automatic take-off and landing whilst using short and unpaved airstrips [14].

The AR5 has a three axis multi-sensor gyro stabilized gimbal, capable of supporting the integration of multiple types of payloads. This includes, for example, (Satellite) Automatic Identification System ((S)AIS) transceiver, multiple Electro-Optical+Infra-Red (EO+IR) sensors, Emergency Position Indicating Radio Beacon (EPIRB), Radar, etc.

The AR5 has being considered in the project as the middle aerial layer surveillance platform to complement the operational gap between the wide surveillance (low resolution) capabilities of the Zephyr, and the more localized actuation of smaller platforms such as the AR3 Net Ray UAV. Launched and recovered from land through a runway, this platform will be connected simultaneously to the land base station and the system onboard the OPV, in order to provide the data acquired by its sensors to the end-users at both operational and tactical levels. Therefore, this platform has been integrated in the concepts of operation defined in the project, taken into account to develop the system's architecture (considering the implementation of NATO Standardization Agreement (STANAG) 4586 as the communication protocol), and will be used during the final demonstration of the project.

C. *The AR3 Net Ray*

The AR3 Net Ray is a ship-borne UAS designed to carry out several types of maritime and land-based missions. These missions include: intelligence, surveillance, target acquisition, and reconnaissance actions, pollution monitoring, infrastructure surveillance, communication support operations and like. It delivers endurance up to 10 hours (mission dependent) that makes it perfect to fit to both maritime and land-based missions. It can provide real time collection, processing and transmission of high definition video. The AR3 can load EO, near-infrared (NIR) to long-wave infrared (LWIR) sensors, laser illuminators, communication relay system and like [17;18].

Figure 4. The AR3 Net Ray catapult (Source: [18])

Within the project, the AR3 covers the surveillance needs at a lower level than the previous assets, i.e., at a lower altitude and with capability to provide more localized data regarding the monitored situations. In that sense, this platform will be operated (launched, piloted and recovered) from the OPV to provide the tactical level with enhanced real time information to help decision making. This will imply the integration (both mechanically and in terms of data flows through the implementation of STANAG 4586 communication protocol) with the OPV. In addition, the AR3 was also considered during the development of concepts of operation, definition of the system's architecture and will be part of the project's final demonstration. On top of that, this platform will be also used for two improvement activities as: (i) enhancement of the feasibility of the recovery system by feeding its autopilot with simulated optimized paths based on computational fluid dynamics analyses; and (ii) tested against harsh environmental conditions according to MIL-STD-810G.

III. MULTIPLE LAYERED APPROACH

One of the main innovative aspects proposed in the project is the complementary approach to cover different surveillance levels, using different types of unmanned platforms to enhance the current capabilities of maritime authorities. These assets, as mentioned previously, have different features that support this complementary approach. Table 1 provides a comparison of some basic technical features of the Zephyr, the AR5 and the AR3.

As can be noticed from Table 1, these platforms operate at distinct altitudes and have different payload capabilities.

When designing the solution, the project's team took advantage of this complementarily (from high altitude unmanned aerial platforms to unmanned underwater platforms), capable of providing data to the operators at different stages of the missions and with distinct level of detail. Following this approach, it allows the authorities to accommodate the performing of missions in a coordinated and effective way with the already existing platforms, enhancing the situational awareness and thus the time of response to such incidents.

TABLE I
COMPARISON OF ZEPHYR, AR5 AND AR3 KEY FEATURES

Feature	COMPASS UASs		
	Zephyr	***AR5***	***AR3***
Wingspan	25 – >32 m	7.3 m	3.5 m
Flight height	21 km	915 m	305 m
Cruise speed	42 km/h	100 km/h	85 – 140 km/h
Communication range	1000 km	100 km (RLOS) Unlimited (SATCOM)	80 km (RLOS)
MTOW	55 - 140 kg	180 kg	23 kg
Payload capacity	5 kg	50 kg	4 kg
Endurance	900 h	20 h	10-16 h
Recovery	Belly-landing	Automatic take-off, unprepared airstrip	Parachute or Net System
Launch	Manual	Automatic landing, unprepared airstrip	Catapult

Note: Different sources provide different information, i.e., the data vary for different UAS types. Therefore, in Table 1 are given approximate data. (Source: Own)

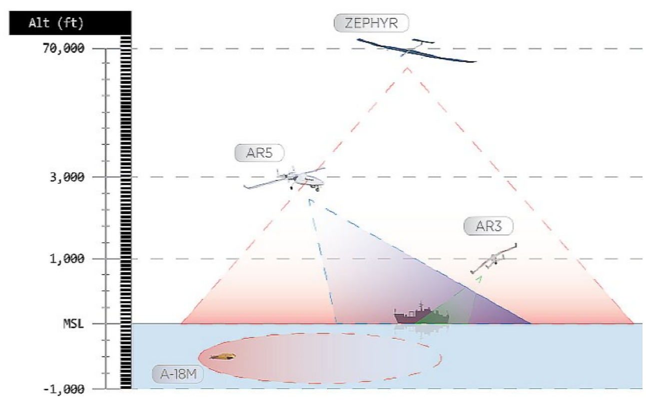

Figure 5. Multiple layer approach to UAS-based maritime surveillance (Source: Own)

IV. THE UASS ROLES DURING THE MISSIONS

The purpose of the project is twofold, as it has been stated earlier: (a) dealing with irregular migrations and (b) preventing narcotics smuggling. When it comes to search and rescue operation with focus on an irregular migration situation, a craft carrying irregular migrants is in a distress state and emits EPIRB signal to alert the European marine authorities. When it receives the EPIRB signal, the Zephyr immediately sends this information to the operational commander working from the Maritime Operations Center (MOC) through the Mission System (MS) replica onboard the OPV. Then, the OPV launches and the AR3 ready to gather all data on the vessel in distress, enhancing in such way the situational awareness of European marine authorities. The AR3 can provide better awareness about the event through OE, NIR and LWIR sensors [1;2]. Afore described data flow is schematically presented in Figure 6.

In the second case of interception of narcotics smugglers, the OPV, the Zephyr and the A18 M are in operation along the border area. The Mission System (MS) is operating onboard the OPV and it is constantly connected to its replica at Maritime Operations Center (MOC). The Zephyr is launched from MOC, which is land based, and its task is to collect a picture of the area being surveyed. Besides, an AUV has been previously released from the OPV into a strategic location connected to the traffickers' typical routes. Once when it detects the target, the AUV can communicate to the Zephyr used as a communication relay.

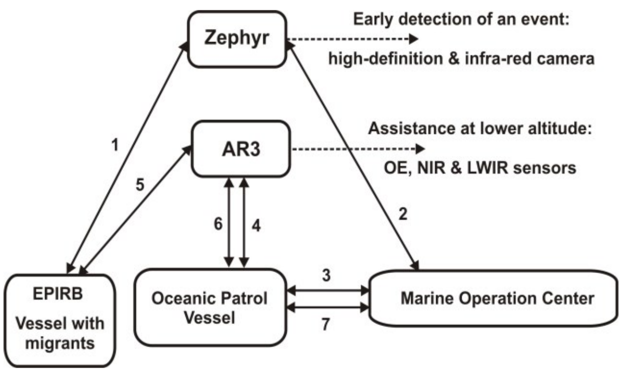

Figure 6. Irregular migration mission data flow (Source: Own)

After that, the Zephyr transmits automatically an alert to MS onboard OPV and its replica in the MOC. Once the MOC receives the alert, the officers proceed with the deployment of an AR5 platform. The AR5 task is to approach the vessel closer and collect more information through (S-)AIS transponder, EO+IR sensors, EPIRB and Radar. Thanks to this information, the officer onboard OPV can decide how to intercept the threat and work effectively. In the case that smugglers try to get rid of the cargo, the AUV has capacity of finding it out by means of side scan sonar [1;2]. The scheme of key information flow in the second case of action is drawn in Figure 7.

Presently, the experts' team within the project is designing algorithms for seamless data acquisition, analysis, storage and presentation. This is based on the experts' knowledge and also experiences acquired thanks to several realistic case studies and recent test-beds in Mediterranean Sea. Following research work should target harmonizing actions of all involved man and unmanned crafts and optimizing relevant data/information flow algorithms [19]. The schemes for improving bidirectional communication links between all relevant stakeholders in the case of alert are to be explored in some more detail, as well.

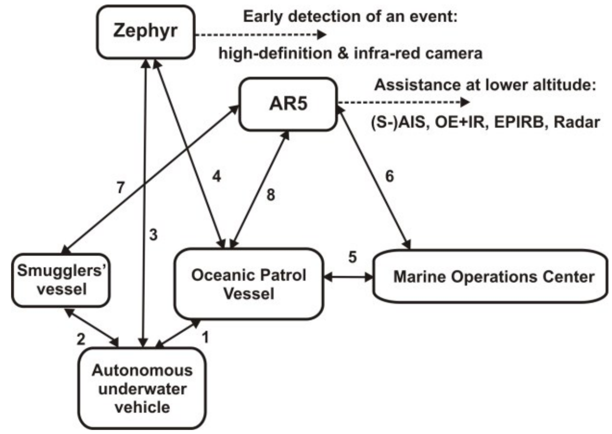

Figure 7. Interception of narcotics smugglers (Source: Own)

V. Conclusion

An overview of the UASs within H2020 COMPASS2020 project has been given. The technical features of the Zephyr, the AR5 and the AR3 UASs have been presented. The purposes for which they can be used: maritime surveillance, narcotics smugglers interception and illegal migrants SAR actions have been highlighted, including their comparative (dis)advantages. Main advantage of the systems is that they can be used in dangerous circumstances and unfavorable weather conditions, without direct human involvement on the spot. However, these systems are new and complex and as such they might be connected to numerous risks [20]. For instance: losing human control from the ground, systemic errors, crashes in populated and built environments, etc. Besides, the risk of investments in such innovative systems is not negligible (e.g., Zephyr crash in Wyndham in 2019). The future research in the filed should deal with all previously mentioned concerns and provide deeper insight of compatibility of these systems with the existing and well established (un)manned vehicles used for the same or similar purposes. Also, harmonizing and rationalizing information flow and communication protocols between all assets involved within the considered project should be taken into in-depth consideration.

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