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Selected Operational Problems and Challenges for the Unmanned Aircraft Systems

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ABSTRACT: Scientific and technological developments mean that Unmanned Aircraft Systems (UAS) play a key role in industry, business, science and education and rescue. This is due to ongoing research, the implementation of the results of deployment projects, and the plans and forecasts of international organisations. In the literature, there are three main groups of factors determining the development of technology in the aviation sector: user/user expectations, technical capabilities, legal basis. The cooperation of actors integrates the aviation environment and creates an interdisciplinary jigsaw of systems: navigation, air traffic management, safety, communication, flexibility and efficiency and airspace capacity, surveillance and radiolocation. As a result of experiments and the operational use of unmanned systems, e.g. during rescue and firefighting operations in the Biebrza National Park in 2020, it was found that the prerequisite for the safe and precise performance of a task by an UAS is the initial and direct navigational preparation. The experience gained and conclusions made it possible to develop a concept of navigational preparation for UAS. The above issues integrating the approach of security studies and safety engineering disciplines are presented in the article.

1 INTRODUCTION

Scientific and technological advances make unmanned systems play a key role in industry, business, science, and education and rescue. This is due to the conducted research, implementation of the results of implementation projects as well as plans and forecasts of international organizations. The results obtained from scientific experiments and flight tests carried out in 2015-2024 made it possible to specify and present in the paper selected problems related to the operational use of dedicated unmanned systems. Aviation experience is also important, participation in the work of the NATO C3 Board Navigation Committee, CNS/ATM Sub Committee, conducting projects (SHERPA, HEDGE, EGNOS Introduction in Eastern Europe) of the Polish Air Navigation Services Agency, organizing conferences, DRONTECH WORLD MEETING workshops since 2016, conducting lectures and workshops organized by CEPOL, participation in search and rescue operations and operational UAS activities during exercises: fire brigade, the police, border guards and crisis management of Katowice International Airport. At that time, there was also an opportunity to get acquainted with unmanned air, land, oversea and underwater systems [1].

At the outset, it is also important to note the classification of UAS. The NATO UAS classification is presented in table 1, but in the event the UAS is armed, the operator should comply with the applicable [2] and the system will need to comply with applicable air worthiness standards, regulations, policy, treaty, and legal considerations (for example Strike/Combat in table 1). Unmanned Aircraft System (UAS) that have a maximum energy state less than 66 Joules are not likely to cause significant damage to life or property, and do not need to be classified or regulated for airworthiness, training, etc (for example Micro in table 1) purposes unless they have the ability handle hazardous payloads (explosive, toxins, chemical/ biological agents, etc.).

For civilian purposes, the classification of drones in the European Union includes five classes, which are defined based on weight and dimensions [3]:

- C0: Drones weighing less than 250 g that cannot fly faster than 19 m/s.
- C1: Drones with a mass of 250 to 900 g that cannot fly faster than 50 m/s.
- C2: Drones between 900g and 4kg that cannot fly faster than 80 m/s.
- C3: Drones with a weight of 4 to 25 kg.
- C4: Drones weighing more than 25 kg.
- C5 and C6: Drones are dedicated to the specific category in STandard European Scenarios (STS).

The implementation of the above projects required the appointment of a team of interdisciplinary specialists and they pointed to the necessity of: having certified equipment, determining the position based on RTK DGNSS (Real-Time Kinematic Differential Global Navigation Satellite System), developing appropriate European and national legal and technical conditions, developing appropriate properties (flight function, dimensions, weight, fuel supply, number of engines, strength, stability, operational potential, operational potential for maintaining UAS airworthiness, controllability, restorability) and properties (functionality (usable, maintenance, maintenance of airworthiness), value, storage, technical and operational readiness, economic durability, reliability, safety, ergonomics, service life, durability – service life, serviceability, adequacy, effectiveness, testability, resistance to environmental conditions/damage and wear as well as corrosion, fatigue of operating materials, provision of service, appropriate theoretical and practical preparation for operational activities.

The aim of the research is to develop the navigation concept for preparation for UAS, which will ensure their safe and precise use in special actions, such as rescue and firefighting operations. The research also aims to characterize the challenges and problems associated with the widespread operational use of UAS, as well as at integration of technical, utility and legal requirements for safety flights.

2 METHODOLOGY

The article decomposes and reconstructs (taking inspiration from the reverse engineering method) the process of navigational flight preparation. A mixed approach was used, combining: qualitative research (case studies – Wildfire in Biebrza National Park, Poland 2020) and quantitative research (field experiments, UAS operational data analysis/logs, flight planning). It took into account user/pilot expectations, technical capabilities, legal basis. Literature review and analysis of documents (operational documentation, reports, projects deliverables) on planning and preparation for flights were made. The research did not include determining or measuring mission performance indicators (e.g., arrival time, location accuracy, radio link stability) or factors that increase the ergonomics of the pilot's work.

Table 1. NATO UAS Classification

Class	Category	Normal Use	Normal Operating Altitude	Normal Mission Radius	Example Unmanned System
III above 600 kg	Strike/Combat1	Strategic/National	Up to 65 000 ft	Unlimited (BVLOS)	Reaper
	HALE	Strategic/National	Up to 65 000 ft	Unlimited (BVLOS)	Global Hawk
	MALE	Operational/Theatre	Up to 45 000 ft MSL	Unlimited (BVLOS)	Heron
II 150 kg – 600 kg	Tactical	Tactical Formation	Up to 18 000 ft AGL	200 km (LOS)	Hermes 450
I below 150 kg	Small above 15 kg	Tactical Unit	Up to 5 000 ft AGL	50 km (LOS)	Scan Eagle
	Mini below 15 kg	Tactical Subunit (manual or hand launch)	Up to 3 000 ft AGL	Up to 25 km (LOS)	Skylark
	Micro below 66 J	Tactical Subunit (manual or hand launch)	Up to 200 ft AGL	Up to 5 km (LOS)	Black Window

Source: [1] BVLOS - Beyond Visual Line of Sight, LOS - Line of Sight, AGL - Above Ground Level.

Table 2. Checklist before TAKE-OFF and after LANDING

BEFORE TAKE-OFF	YES/NO	AFTER LANDING	YES/NO
Airspace analysis - is the flight to be performed outside a controlled space or flight restriction zone not subject to State Fire Service?		Shutting down the engines	
Analysis of meteorological conditions – KP index, wind, precipitation - do conditions match Unmanned Aerial Vehicle (UAV) capabilities?		Switching off the UAV	
Analysis of potential hazards at the flight site - is the flight site free of obstacles that could prevent safe flight execution?		Drive train temperature monitoring	
Securing the take-off and landing site - is it possible to secure the landing site?		Switching off Ground Control Station/Remote controller	
Power source health check - are the batteries operational and charged?		Communication to the Air Operations Coordinator that flights have been completed	
Ground Control Station/Remote controller - is it operational and charged?		Notification of the end of flights at Drone Tower.	
Pre-launch check of aircraft: propellers, gimbal lock, SD card, condition of engines, general condition of structure, launch, calibration - are they operational and ready to fly?		Inspection of the general condition of the UAV	
Setting Failsafe parameters (e.g. Return To Home) and specifying maximum UAV distances from the Ground Control Station/Remote controller (geofencing) - is it set?		Securing the aircraft and preparing for transport	
Use of ICT tools and systems to enhance security (e.g. [6], [7], [8])		Arrangement of take-off and landing sites	
Obtaining approval for flights, agreement with Air Operations Coordinator - if required		Downloading data from SD card	
Checking the UAV's response to commands from Ground Control Station/Remote controller - is the drone responding?			
Communication to the Air Operations Coordinator that flights are ready to begin			

Source: [5]

3 PREPARATION FOR OPERATIONAL WORK OF A UAS PILOT

State Fire Service units, like other uniformed services subordinate to the Ministry of the Interior and Administration, are entitled to request the establishment and activation of DRA and R flight restriction zones. This is done using the 'Dynamic Safety & Security - Services' information system of the Polish Air Navigation Services Agency (PANSA) [4]. It enables state institutions to quickly submit electronic requests for immediate and temporary airspace restrictions in connection with rescue, public order or state security operations. DRA zones limit the flights of unmanned aircrafts, R zones both manned and unmanned aircrafts.

The application for creation of DRA zone is made by a firefighter from the provincial command station (in Provincial Headquarters of the State Fire Service) at the request of the pilot. The application shall specify, inter alia, the date of commencement, date and time of termination of the zone, the shape of the zone, the lower and the altitude limit of the zone, as well as possible exemptions to its validity (e.g. unmanned aircraft flights below a certain take of mass are allowed). The application shall be subject to review by PANSA (fig. 1).

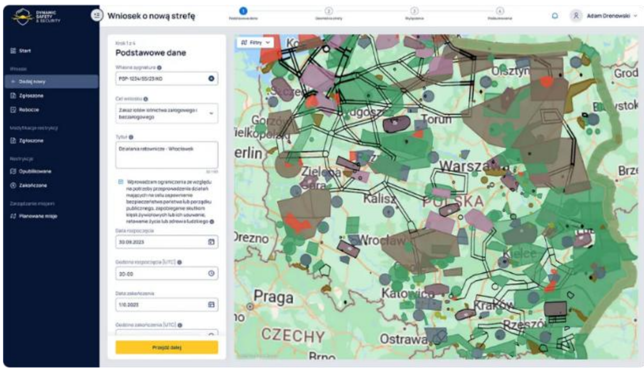

Figure 1. View of the Dynamic Safety & Security - Services' system interface. Source: [4]

Before take-off, each pilot is required to complete the checklist activities (table 2) included in the Operational Manual "Use of UAS in the activities of organisational units of State Fire Service" [5]. The Operational Manual has been developed by the Drone Team of the Chief Commandant of the State Fire Service to develop directions for development and working out changes in documents in the field of the use of Unmanned Aircraft in the State Fire Service.

In the case that there is more than one aircraft (State Fire Service or other entities) in the area of ongoing air operations, or aircraft have been dispatched to the site of operations, an Air Operations Coordinator (AOC) is appointed. It is permissible to entrust this task to a representative of another entity. The Air Operations Coordinator is also authorized to manage the flight restriction zone (Zone R or DRA) and may grant permission to fly in the zone to other entities (including entities and persons outside the uniformed services) if they request such permission. The Air Operations Coordinator (table 3) is not responsible for the manner in which UAV pilots perform their flights in the zone managed by him. His priority task is to organize the airspace in such a way as to provide the best possible conditions for UAV flights and make the best possible use of the available airspace in terms of time and space.

In order to coordinate the flights of several UAVs, also inside separate zones, it is necessary to conduct pre-flight briefing. A pre-flight briefing is performed to ensure flight safety, coordinate flight parameters, ceilings, assign sectors and establish mission objectives.

Table 3. Recommended BRIEFING elements (e.g. for Air Operations Coordinator)

GENERAL	
1.	Allocation of a separate radio channel for Drone Teams.
2.	Identify and write down the codenames of the Drone Teams
3.	Establish a safe area for drone flights, safe for manned aviation, coordinated with manned flights (southern section of the forest, north side of the runway)
4.	Provide the teams with the necessary documentation, approvals
5.	Set time slots - if applicable
6.	Characterise sites of action
7.	Check and document current and forecast weather (visibility, fog, air temperature, possibility of icing, humidity, wind direction and speed, wind gusts, Kp index, precipitation and sudden weather changes forecast).
8.	Check airspace - restrictions, boundaries, zone activity, heights, buffers (e.g. [9], [7], [6], [10], [11])
9.	Other (e.g. navigational hazards)
MISSION	
1.	Establish 'go' - 'no go' criteria - if applicable
2.	Division into sectors/flight areas - ABCD method, dial method
3.	Mission profile (examples): Building fire; Grass/forest fire; Landfill fire; Traffic accident; SAR/missing person search (open area); Missing person search (debris); HAZMAT; LNG; Flooding; High-risk facility event; Mass event; Security; Dike monitoring; Post-fire inspection; Monitoring of firefighters' work.
4.	What are we doing? What is the objective, what information can we provide to the rescue action commander and staff? How do we want to achieve this?
5.	Threats to the success of the mission and flight, on-site risk analysis,
6.	Questions - what possibly could go wrong?
CREW	
1.	Division of duties in Drone Teams (pilot i data analyst/camera operator/observer)
2.	Checklists
3.	Reports - upon reaching the combat section you report: "WARSAW DRONE TEAM on site, I begin preparations for take off"; before flight 'WARSAW DRONE TEAM ready for take off' and waiting for approval from the Air Operations Coordinator, you report landing 'WARSAW DRONE TEAM has landed'.
4.	Avoiding information noise
5.	Rehearsal of radio communication - calling the Drone Teams one by one
EMERGENCY PROCEDURES	
1.	Procedures in case of DroneTower failure, lack of wireless network coverage, image transmission interference
2.	Procedures in case of loss of radio communication with the Staff
3.	The "see and avoid" method
4.	Emergency procedures: failure of anti-collision sensors, loss of GNSS; loss of vision; loss of radio link; drone "breaking"; power off in flight, no connection to camera
5.	Emergency response plan
6.	Critical (emergency) situations

Source: [5]

When it comes to risk analysis, it is necessary to take into account the key elements, as: concept of the operations, number of Unmanned Aircrafts (UA) and their altitude, operating environment, threats, type of operation VLOS (Visual Line of Sight) or BVLOS (Beyond Visual Line of Sight), estimation of human/bystander density in the operational area, airspace occupancy, adjacent spaces, birds presence, etc.). Various methods of risk analysis for drone flights are helpful in this regard, for example SORA (Specific Operations Risk Assessment), EPSP (Equipment, People, Environment, Procedure), ERA (Easy Risk Assessment) [20].

It is recommended that a de-briefing be conducted after the flight, where the flight crew (drone teams members) shares factual information about the flight. This information can include weather conditions, aircraft issues, and other relevant details. This type of information allows you to increase flight safety, avoid repeating mistakes, minimize risks during subsequent missions, and consolidate good habits and practices. They can also be used as input to reports after rescue operations (table 4).

Table 4. DEBRIEFING after rescue operations

GENERAL
1. Realization of mission objectives - YES / NO
2. Receiving reports from crews/teams
3. What difficulties occurred? What happened? What went wrong?
4. What could be expedited/eased/do better?
5. What was good?
6. What unexpected situations occurred?

Source: [5]

4 NAVIGATION PREPARATION OF UAV TO THE OPERATIONAL ACTIVITIES OF FIRE SERVICES

The development of UAS techniques and technologies for the needs of fire brigades, First Responders (FR) was the subject of scientific and research projects: ASSISTANCE [12], FIRE-IN [13], ResponDrone [14], FASTER [15]. The results obtained indicated the need to introduce navigational preparation, during operational UAS flights, which were used for the first time in 2020, during a large-scale fire of meadows, forest areas, reeds and peat bogs in the Biebrza National Park (Fig. 2). Firefighting activities were carried out from 19.04 to 26.04, 348 firefighters, 6 patrol and firefighting planes, 5 helicopters, and 4 UAS participated. The total area of the fire was 5280 ha [16].

Figure 2. The front of the fire marked on the site photo and satellite photo

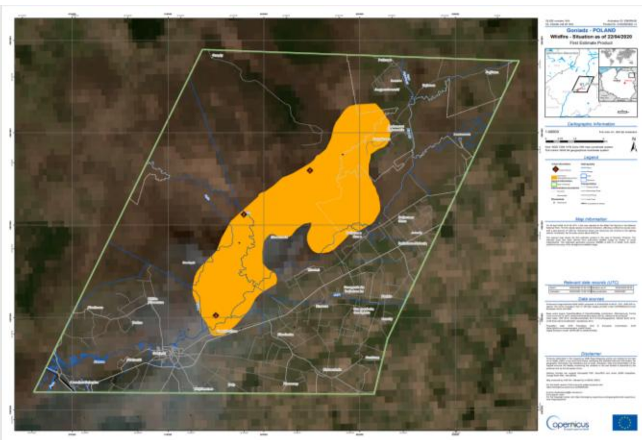

Figure 3. Image of the Copernicus satellite reconnaissance with the area affected by the fire in the Biebrza National Park. Source: [17]

Over the area affected by the fire, the following airspace zones were taken into account: restricted - EPR23 (BIEBRZA NATIONAL PARK, active H24, altitude from GND to 4000 ft AMSL), DRAR - Drone Airspace Restriction U-space.

In order to coordinate forces and resources, the Command Post of the Commander-in-Chief of the Fire Service was established and the European Disaster Response System COPERNICUS was launched, obtaining satellite imagery of the fire area (Fig. 3).

The experience and conclusions gained during rescue and firefighting operations in the Biebrza National Park enabled the development and for the first time the use of a method of initial and direct navigator preparation for flights, suitable for UAS. It was necessary for the safe and precise performance of the assumed tasks. The option of a polygonal UAS mission was used, defining the area of drone flights using the ladder method (Fig. 4).

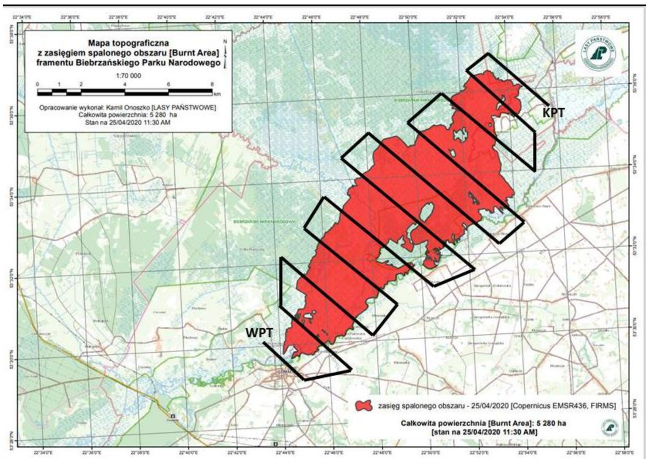

Figure 4. Ladder method, monitoring the fire site in the Biebrza National Park.

The flights were performed by UAS of the following types: DJI Matrice 210, Yuneec H520, which monitored firefighting activities, terrain, precisely identified individual outbreaks and fires, and enabled control of fires after the end of firefighting operations. The effectiveness and precision during the performance of tasks (fig. 5, fig. 6) resulted from the initial and direct navigator preparation developed and introduced for UAS.

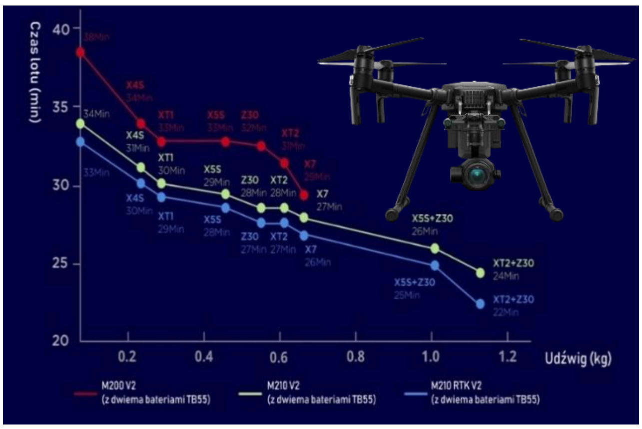

Figure 6. DJI Matrice 210 and flight times in its individual configurations [18]

Table 3. Sample logbooks necessary during the operational use of drones (filled in for the flight route along the front of the fire)

UAS (drone)					Wind parameters (direction, speed)				
Operator/pilot					True air speed (TAS)				
Flight dates 22.04.2020					Flight altitude 80 m				
Preliminary calculations				Route	Direct calculations				
Magnetic course	S	TAS (Vr)	t		KB	t	Ground Speed GS (W)	KM	KZ
of the WPT				0					
2400	0,7 km	30 km/h	1,4 min	1					
3100	0,7 km	30 km/h	1,4 min	2					
300	0,7 km	30 km/h	1,4 min	3					
600	0,8 km	30 km/h	1,6 min	4					
3300	1 km	30 km/h	2 min	5					
300	1 km	30 km/h	2 min	6					
450	1km	30 km/h	2 min	7					
od KPT									
SUPPORT NOTES									
Flight endurance - 11,8 min									
Fuel Quantity/Number of Batteries -									
Safe flight altitude – 80 m									
Deviation +7° 4'									
Dawn -					Nightfall -				
Alternate landing sites for the unmanned aerial system:									

Figure 3. Unmanned aerial system: ST16S Ground Station control unit and Yuneec H520 UAS with E90 camera [19].

Navigational UA preparation for flight is compliance with the established rules for developing a map and preparing a flight plan for a specific route. It has a decisive impact on the successful, safe execution of the UA flight. On the other hand, the graphic development of the map (Fig. 8) consists in taking into account: the flight route (Fig. 7) and its description, entering the flight time for each segment, taking into account all zones (D - danger, R - restricted, P - prohibited) above the flight area (e.g. EPR23 zone), marking natural and artificial obstacles (marking the height above the terrain and above sea level), marking the highest hill in the route strip in the form of rectangles, marking the direction and speed of the wind with a vector, recording the value of declination in the flight area. Navigator preparation for flights is performed at the moment of receiving the task and is divided into: initial and direct.

Figure 7. Route of monitoring the fire site (on the left) and data on the value of magnetic declination for the locality GONIĄDZ

It is worth noting that for the purposes of the study, "operational use of UAS" was defined as their use by state services, inspections and guards and other uniformed formations, aimed directly at combating and/or minimizing threats to human life and health, property, infrastructure or the environment, animals (in the case of the State Fire Service, these will be rescue and/or firefighting operations). These activities are characterized by the need for rapid decision-making, under time pressure, with the rapid influx of a large amount of information in a short period of time, sometimes in unfamiliar terrain, difficult, dynamic, prolonged and unpredictable conditions.

Figure 8. Fire front with a designated route on the map (left) and a route prepared during the initial navigational preparation with marked flight parameters (right)

After the preliminary navigational preparation, the prepared parameters for the UAS flight are entered in Table 3 and the direct navigational preparation is carried out and the obtained data are also placed in

Table 3. The direct navigational preparation is carried out before the UAS flight, as the wind speed and direction must be taken into account. This preparation includes: analysis of the meteorological situation, up-to-date information of the air traffic service on the navigational situation in the area of flight performance and the performance of direct flight calculations, which are performed on the basis of updated flight conditions based on meteorological data (wind speed and direction, temperature, pressure). The corrected parameters, taking into account drift angles and True Air Speed and Ground Speed caused by wind parameters, are also entered in the table on the right. Checking the aircraft's navigation equipment. During the operational use of UAS in Poland, meteorological data contained on the Institute of Meteorology and Water Management - National Research Institute website are necessary: General Aviation METeorological Information (GAMET) - forecast weather in the area and information on hazardous weather phenomena, AIRman's METeorological Information (AIRMET) - textual description with the use of applicable abbreviations, observed or forecast occurrences of significant meteorological phenomena on the flight route, Significant Meteorological Information (SIGMET) - concise description of occurring or forecast significant meteorological phenomena on the flight route affecting safety (forecast development of these phenomena in time and space is given), maps: turbulence, icing, storm maps. Taking into account the time intervals for issuing meteorological reports, it is reasonable to use mobile meteorological stations (capable of measuring at least: temperature, wind speed and direction, humidity) located either close to the place of events and deployment of forces and resources, or on the vehicles of drone teams.

5 CONCLUSIONS

The research required an interdisciplinary approach, integrating the methodological achievements of security studies and safety engineering. Analysis of real-life UAS use cases (e.g., a rescue operation in Biebrza National Park) has shown that pre-navigation preparation of operators and systems is crucial to mission success. Operational experiences led to the creation of the UAS navigation preparation concept, which can be training and procedural framework for future operations.

In the operational operation of unmanned systems, the international UTM (Universal Transverse Mercator) grid is used in the WGS-84 reference system. Presentation of the navigational preparation algorithm for operators of unmanned systems/platforms, enabling safe and optimal performance of assumed tasks, undertakings during commercial, operational activities.

In the course of the analysis, it was reasonable to characterize the following challenges and problems of operational preparation for flights:

– the need for a drone operations management platform, enabling real-time visualization of the position and altitude of the UA involved in the operation,
– wireless, reliable image transmission from the scene to headquarters, image analysis,
– inclusion in the training programs of UA pilots aspects of the operation of flight management software and management of flight data/logs, creation of orotofotomaps,
– training of firefighting pilots from different mission profile (examples): Building fire; Grass/forest fire; Landfill fire; Traffic accident; SAR/missing person search (open area); Missing person search (debris); HAZMAT; LNG; Flooding; High-risk facility event; Mass event; Security; Monitoring of dams, embankments, Post-fire inspection; Monitoring of firefighters' work,
– study of optimal parameters for flight planning, thermal imaging camera settings,
– constant analysis of atmospheric conditions, having a mobile weather station,
– analysis of reasonableness of docking station deployment/placement to enable drone takeoffs and landings, remote battery replacement,
– UA, cameras and RC stations should be resistant to adverse weather conditions (at least IP 55), equipped with anti-collision systems, additional locators/trackers,
– use of checklists by drone teams for briefing and debriefing.

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