Supporting drone mission planning and risk assessment with interactive representations of operational parameters

Balita Rakotonarivo, Nicolas Drougard, Stéphane Conversy, Jérémie Garcia

Supporting drone mission planning and risk assessment with interactive representations of operational parameters

Balita Rakotonarivo[1], Nicolas Drougard[2], Stéphane Conversy[3] and Jérémie Garcia[4]

Abstract— **Drone missions in urban areas or at long range offer new opportunities for drone operators but require approval from the authorities due to the potential risks. Obtaining authorization is complex and time-consuming since operators must produce and often iterate on a concept of operation and risk analysis documents to accommodate the authorities' expectations. Our goal is to support the drone mission planning process to make it more efficient so that more and safer operations can be designed and authorized. In this paper, we describe our work designing and assessing interactive representations of operational parameters on maps to enhance thinking and accelerate the process from early concept definition to mission execution. We first collaborated with an operator during a longitudinal study that enabled us to refine and explore our concepts and prototype with real-world use cases. We then collected the feedback from authorities to evaluate the ability of our prototype to match the needs and requirements beyond our first study. Our results indicate that visually representing the concept of operations makes its description more accurate and easier to understand. We also found that exploring the impact of the operational parameters on safety actively supports risk identification and the formulation of adequate mitigation. We believe that our work can inspire the design of future safety support systems and may also contribute to supporting the collaborative process between operators and authorities needed for drone operations in the Specific category.**

I. Introduction

Drone operations, like any aeronautical activities, present risks that can have dramatic consequences for property and people [1]. The safety regulations applicable to drones have two main objectives: ensuring the safety of other airspaces users by reducing the risk of mid-air collision and ensuring the safety of people and goods on the ground by limiting the risk of crashes.

Since January 1, 2021, a European regulation on Unmanned Aircraft Systems (UAS) is applicable in all European Union Member States, as well as in Iceland, Liechtenstein, Norway, and Switzerland. The approach used to ensure the safety of drone missions is to identify the risks and provide mitigation means to reduce them below acceptable thresholds. For example, the risk induced by the proximity of a parachute flight zone could be mitigated by carrying out the mission in question at a time when the probability of encountering a parachutist is very low; or by requesting a zone temporarily reserved for the drone alone. Typical scenarios, whose risks have already been characterized, have been described in the appendix of the EU drone regulation (EU Regulation 2019/947) [2]. They will allow operators to prepare and carry out missions that correspond to these scenarios by submitting an operational declaration of compliance to their national aviation safety agency [3]. However, many operations do not correspond to any of these typical scenarios: long-range missions during which the drone covers several kilometers (e.g. railroad surveillance), missions conducted out of sight of the remote pilot (also called Beyond Visual Line of Sight (BVLOS) [4]), or more generally any mission for which at least one of the constraints of the scenarios pre-analyzed by the European regulation cannot be respected. Such operations require operational authorization from the authorities to be executed [2].

Prior work studying professional drone practices identified that operation preparation is one of the most important and time-consuming mission phases [5]. For missions that require operational authorization, this becomes even more important. Operators must collaborate with several entities, like the national aviation safety agency, public administration, or air traffic controllers. They also need to produce several documents and certificates following methodologies such as the Specific Operations Risk Assessment (SORA) methodology [6]. The risk assessment phase and the application for the authorization are time-consuming and challenging for operators that frequently have to revise their plans to get the authorization [7]. Prior work for supporting the safety of drone operations focused on providing tools for the mission execution or the flight plan definition but neither for the initial design nor the operational safety analysis [8]. Existing safety tools such as Samwise [9] provides online forms to accelerate the process but does not much focus on enhancing safety.

Our goal is to support the safety of drone operations from the early design phases to the authorization request and the mission execution. In this paper, we present our work on the design of interactive tools for supporting the mission design and risk assessment phase for operations that necessitate operational authorization. We describe our concept and prototype for representing the mission operational parameters on a map and providing adequate interaction to explore their impact on safety. We then detail the results from a seven-month design study with a drone operator in

This work was partially funded by the Defense Innovation Agency (AID) of the French Ministry of Defense (CONCORDE Project N°2019 65 0090004707501).

[1]Balita Rakotonarivo is a PhD student at the French Civil Aviation University, Toulouse, France balita.rakotonarivo@enac.fr

[2]Nicolas Drougard is an Associate Professor at the National Higher French Institute of Aeronautics and Space, Toulouse, France nicolas.drougard@isae.fr

[3]Stéphane Conversy is a Professor at the French Civil Aviation University, Toulouse, France stephane.conversy@enac.fr

[4]Jérémie Garcia is an Associate Professor at the French Civil Aviation University, Toulouse, France jeremie.garcia@enac.fr

which we iteratively assessed and refined our prototype to match his needs. We also report on a focus group study with regulators to gather additional feedback on our work and to generalize our findings. We conclude with a discussion of our results' contributions, their validity, and future research directions.

II. Related Work

Our work builds on mission planning, safety support of drone operations, and geovisual analytics.

A. *Mission planning*

Mission planning is usually done within a Ground Control Station (GCS) provided by drone manufacturers [10], [11] or autopilot providers [12]. Within such tools, operators can specify the waypoints of the intended paths, or the areas to be surveyed, before sending instructions to the drone. These tools already include safety features such as sense-and-avoid, transponder traffic awareness, automatic altitude limitation, or geofencing, useful near sensitive areas such as airports. Haque et al. enhanced a GCS with additional layers of data including weather and no-fly zones information [13].

Several online tools aim at speeding up the process of operation declaration to the authorities when no authorization is required. DroneKeeper [14] and Unifly [15] are presenting drone operations on maps with several layers of ground and aeronautical data such as drone restriction zones or airports boundaries. Operators must generally input areas in which the drone will fly and fill in several fields to specify the operation. Such tools are often associated, as in the case of Clearance [16], with a regulation expert system that helps determine the necessary steps before carrying out the operation, based on the rules of the regulatory framework. Tools like PansaUtm [17] also provide links with the registration services as a remote pilot or the management of a fleet of drones. US Federal Aviation Administration *Low Altitude Authorization and Notification Capability* [18] provides advanced functionalities to automate authorization requests with airport managers, and real-time Air Traffic Controller and drone pilot communication. Unfortunately, existing tools mostly focus on operations that do not require waivers, "further coordination" in USA, or an "operational authorization" in Europe. Also, safety support features mostly cover the flight execution phase but not the preparation phase that has been identified as very important for professional drone pilots [5] and mandatory for operations requiring a complete safety analysis to be approved by authorities [7].

B. *Safety support during drone operations planning*

In a systematic literature review on safety support for drone operations [8], we identified several existing approaches for supporting the safety of drone operations, from aircraft integrity to path planning, safety assessment, cybersecurity, or Human-Computer Interaction. They also identified that the preparation and authorization requests phases were poorly covered by the surveyed literature which strengthened the motivation for this work.

For preparation phases, existing work proposed to support fleet management and automate flight plan generation [19], [20], [21], [22], as well as to alert during operations when a potential accident may occur [19]. These approaches are valuable to accelerate mission definition and planning, but there is no explicit support for conducting safety assessments before the generation of flight plans.

Current safety analysis tools often rely on formal methods that provide outputs in the form of diagrams or tabular data but are not fitted to maps [8]. For instance, Rothwell et al. [23] made verification and validation tools more operational by using a graphical user interface for specifying and validating high-level mission objectives based on a formal model checker. A user study demonstrated that using their tools improved mission performance, safety, and predictability, but is more time-consuming for users, perhaps due to the complexity of authoring patterns and rules in textual form. Similarly, Samwise [9] proposes the online realization of safety studies for the Specific Operations Risk Assessment (SORA). Unfortunately, it is based on textual data and requires operators to use and produce maps illustrating the flight zones and the risks.

Existing work investigated the use of risk maps in case of a crash by taking into account the drone's characteristics, the environment, and the weather [24], [25]. Such visualizations can help operators understand the risks associated with their operations. The use of these maps, not only after all mission parameters have been defined, but also during the development of the concept of operation (denoted by Conops), could be very valuable.

C. *Geovisual Analytics*

Maps and cartograms are visual representations heavily used during both flight preparation and execution for flight monitoring. According to Lohse et al. [26], "Maps are symbolic representations of physical geography. Maps differ from cartograms in that cartograms superimpose quantitative data over a base map". Compared to other visualizations, maps excel at showing spatiality, are easy to understand, are attractive, and offer a good balance between showing the parts or the wholeness of a situation while giving a lot of information [26]. For cons, they are static and less efficient to show the temporal evolution.

In the cartography discipline, "Spatial decision support means computerized assistance to people in the development, evaluation, and selection of proper policies, plans, scenarios, projects, or interventions where the problems have a geographic or spatial component" [27]. In practice, this field also lacks tools. Geographic Information Systems are often unable to deal effectively with the specificity and complexity of real-life problems, forcing users to narrow their problems to fit the capabilities of the tools [27]. Andrienko et al. proposed the concept and research field of "Geovisual Analytics for Spatial Decision Support" for the cross-disciplinary research that looks for ways to provide computer support to solving space-related decision problems through enhancing human capabilities to analyze, envision, reason, and deliberate" [27].

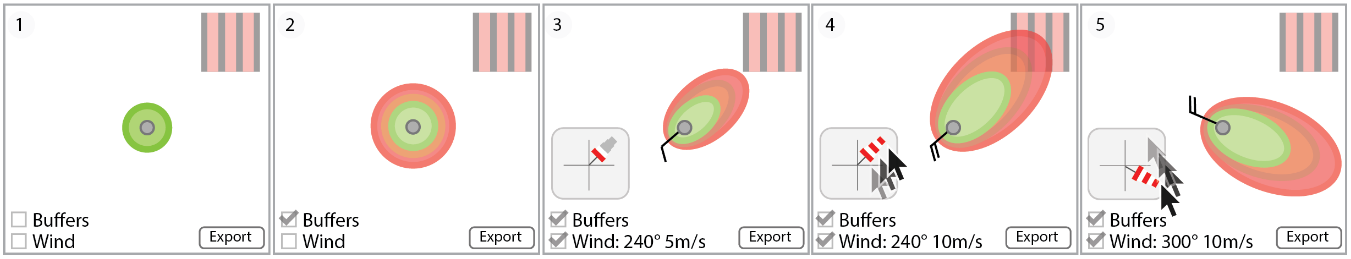


Fig. 1. Assessment of wind impact on safety buffers: 1) the operator places the remote pilot, and the nominal area is automatically plotted in green; 2) displaying the required buffers zones; 3) displaying the wind impact on the buffers with a windsock appearing illustrating the direction and speed of the wind; 4-5) manipulating the windsock updates the zones in real-time for determining acceptable wind conditions for which a flight should not be conducted, as the safety buffers overlap or not the "no-fly zone".

III. Design Concept

To support the safety of drone operations during the preparation phase, we propose to model the operational parameters (OP) of a mission as variables on a map, make them manipulable with feedback quickly visible to assess the risks, and share the results with other stakeholders. In this section, we detail and illustrate our concept.

A. Rendering Operational Parameters on a map

Assessing the safety of a drone operation requires an adequate representation on a map. Prior research based on interviews of drone operators performing moderate risks missions found that a mission can be described by its OP [7]. These can be classified from external and non-controllable parameters up to those the operator can choose and adjust.

Examples of external and non-controllable parameters are weather, the regulatory framework, geography, and airspace characteristics. Examples of fixed parameters are the drone system features like its class (regarding EU regulation [28]), automation level, Maximum Take-Off Mass, maximum speed, or maximum radio range. Examples of adjustable parameters are the planned trajectories, the height above ground, the speed, the take-off and landing zones, the time of flight, the chosen safety mitigation, the selection of crew members, and so on.

The described list of OP is not exhaustive and some missions will require additional parameters that are relevant to the mission at hand. Some of these OP can be geospatial data, like areas and buffers, trajectories, and crew members' positions. Geospatial data require special tools and methods to take full advantage of them [29]. It is likely that providing data in a spatial context will facilitate analysis and subsequent decision making, as opposed to tables or text-based descriptions [30].

B. Providing feedback on safety and interactions for adjusting Operational Parameters

We propose that operators must be able to manipulate the OP of their operations and have immediate feedback on the risks or safety issues these changes might pose. This principle builds on geovisual analytics to support spatial decision-making by combining the processing power of the computer to render graphics accurately according to well-defined given parameters, and the creativity and expertise of the user to analyze the situation and explore solutions [27]. For maximum effectiveness, "the user should be able to interact with the computational models and get immediate feedback in an appropriate form"[27].

We also argue that interaction using Direct Manipulation [31] of operational parameters is adequate for such tasks. Direct Manipulation is a style of interaction in which the user manipulates objects of interest directly and gets immediate feedback on its operations as with a drag and drop in a file and folder system.

Direct Manipulation has several advantages in our context. First, it allows quick, reversible, and incremental actions on the map, with immediately computed and visible results. Immediate feedback and Reversibility foster exploration as the operator can try and adjust different solutions multiple times. Second, they use metaphors of the natural objects with which the drone operators usually work, and facilitate learning and use of the tool. This allows recognition rather than recall, i.e. the operator has less cognitive workload as he/she sees information about what he/she is doing rather than remembering what the parameters are or where they are. This should also allow her/him to allocate more cognitive resources to risk assessment. Finally, Direct Manipulation can offer a "What you see is what you get" approach to the description of the Conops that may not only help convey the Conops to not only the operator but also the other stakeholders such as the clients or the regulators.

C. Example scenario

Figure 1 illustrates a scenario where an operator must survey an area that is often windy. The nominal area where the flight can normally occur is green. The safety buffers are in orange for the contingency area and red for the emergency area. There is a "no-fly zone" on the top right.

To find the range of possible operational parameters for the operation, the operator starts by manipulating the wind strength and direction with mouse drag interaction on the windsock. This interaction updates the safety and contingency buffers to assess the impact of the wind on the buffers and the possible overlap with restricted areas.

IV. Method

We first conducted a longitudinal study with a drone operator in order to explore and characterize our concept in a real-world context. We then conducted a focus group study with stakeholders involved in the first study and regulators to validate and generalize our concept to other possible operations and to identify future research directions.

A. Longitudinal study

To explore and assess our concept, we ran a longitudinal design study with a drone operator. He was working on a Conops to perform Instrument Landing System maintenance with the drone instead of a truck and human operators. The operations involved flying the drone within the airport perimeter and to communicate with both air traffic controllers and the maintenance team. Given the risks posed by flying a drone within an airport, the operator needed to define the Conops, coordinate with stakeholders and obtain operational authorization from the authorities. We offered to use our prototype to provide support for planning the operation and exploring safety issues.

a) Participant: Our participant (P1) is a certified remote drone pilot and a drone system engineer with a background in control systems and flight dynamics.

b) Apparatus: We started with a basic prototype consisting of an online web application that features a map on which the operational parameters are drawn and manipulated as illustrated in Figure 2. The first version allowed the operator to see a zone around the safety pilot and safety buffers that were computed from the wind strength. We used the Leaflet library[1] to build the map, and external sources of data from public repositories to provide additional layers of data such as the airport's limits and a street map background.

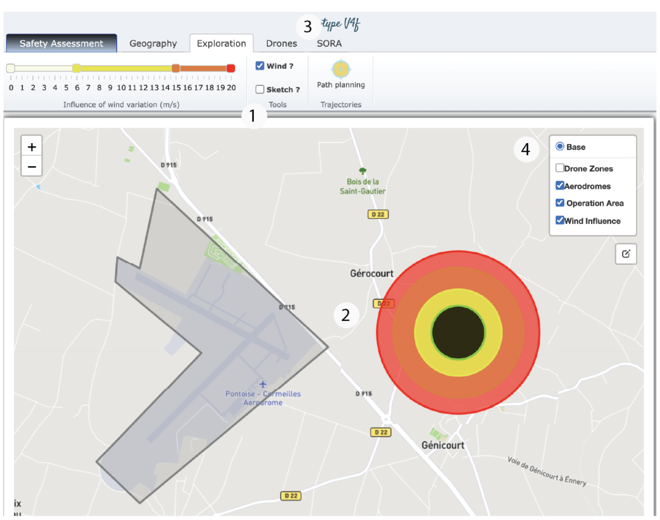


Fig. 2. The starting map: wind variator (1), which influences the buffers displayed on the map (2), other controls for safety analysis like trajectory definition, Geography and Drones tab (3), and the layers control with a small set of aeronautical data (4).

c) Iterative Design process: We started with an initial meeting to understand P1's goals and capture initial requirements to adapt our prototype to the planned operations. We then iteratively designed and assessed our prototype using participatory design techniques [32] such as co-designing representations on low-fidelity mockups or doing experience maps, a synthesis of a user's experience used to identify issues and ideate on possible solutions [33]. From the first version, the prototype was provided to the operator as a technology probe [34] so that he could use it on his own over a longer time. Our goals were to better understand his needs, evaluate our technologies and gather new directions for future research.

d) Data collection and analysis: We video recorded our meetings and asked P1 to provide comments and screenshots of the applications when he felt that the representation or interaction could be improved. Before the end of the project, we used a break-off letter inspired by cultural probe [35]. The technique consists in asking the participant to write a break-off letter with the software to record his feelings and inspire ideas. We expected to discover the strengths of our prototype, its limits, the opportunities remaining to be explored, and the experience of P1 about our work, in his own words. We then analyzed the results using qualitative coding of the data to classify our findings in themes [36].

B. Focus Group study

After the real-world longitudinal study, we wanted to consolidate our findings and concept with other stakeholders, and to get the perspective of regulators that grant operational authorizations. We thus conducted two focus groups to further explore and validate our concept. Both focus group sessions were performed remotely, video recorded, and transcribed for analysis.

a) Participants: The first focus group included stakeholders involved in the operations carried out in our design study. In addition to P1, three air traffic controllers and their team leader at the airport participated. The second focus group involved six members of the French Drone regulation team that are responsible for verifying and validating the operational authorization requests.

b) Process: The focus group started with a brief introduction to our goals and a demonstration of the prototype for P1's scenario. We also demonstrated additional prototypes illustrating two different scenarios to foster discussion beyond a specific case. The first scenario covered the automated survey of an area, and the second one the tracking of a long-range convoy in populated areas. We then asked them to react to our concept and think about the strengths and limitations of this approach. We asked them questions on how such a concept could facilitate collaboration before and during operations to accelerate the authorization request process and enhance safety. For the second focus group, we also asked questions about their process and the tools they used for performing validation of operational authorization requests.

V. Longitudinal Study Results

The longitudinal study allowed us to explore and assess our concept from the early stage of the operation design to the production of documents for obtaining the authorization, and flight tests with the envisioned hardware. We explored

[1] https://leafletjs.com/

several interactions and operational parameter representations to facilitate P1's work. Using our prototype, P1 was able to design and describe the Conops, perform risk assessment, and export data to be used within the authorization request. Figure 3 presents the final version of the prototype including data from P1's operation. In this section, we report our findings according to specific tasks that we identified during our analysis.

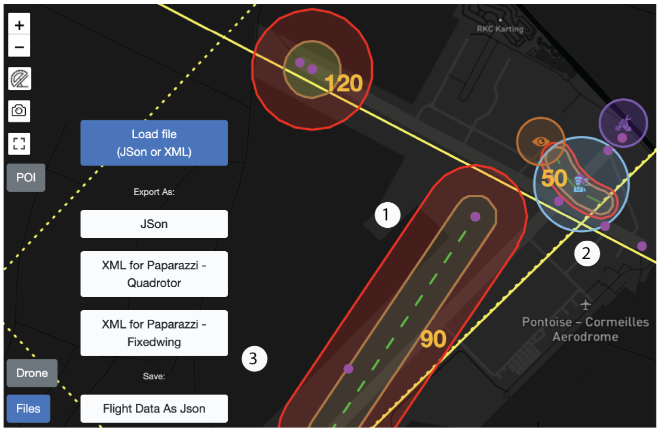


Fig. 3. The final prototype: trajectories with their safety buffers (1), actors in place (2), and the Files import/export panel opened (3).

A. Representing and inputting operational parameters

We started by identifying the operational parameters that would be required for defining the operation. P1 explained that he had to describe trajectories given by the maintenance team of the airport to record data for calibrating the Instrument Landing System. He also explained that the air traffic controllers wanted the operation to remain within the boundaries of the airport and to have direct communication with the head of operations.

Our prototype displays the airport boundaries by retrieving data from online services. Following suggestion from P1 we also included data representing the aircraft take-off and landing trajectories as specified in international aviation visual charts for additional context about air operations. We then designed interaction for defining named points within our prototype, either with point and click on the map or by specifying geographical coordinates. After selecting a point, P1 could define a trajectory from this point.

We created four possible trajectories: hover to remain still over a point, vertical motion over a point, moving from point A to point B, and orbiting around a point with a specific angle and distance. For each trajectory, P1 asked to edit the altitude using forms to set the values in numerical format. For instance, to specify a translation along the runway, P1 needed to select the starting point, then select the "GOTO" trajectory operation on a button of the interface, before clicking over the target point. Once the interaction is complete, a form appears to define the altitude and additional safety parameters as illustrated in Figure 4.

For the "ORBIT" trajectory P1 wanted to specify them using a point for the center of the circle and an angle around

Fig. 4. The "GOTO" panel where buffers are automatically computed when height is changed (1), the nominal trajectory (2), and the resulting contingency and emergency buffers once displayed (3).

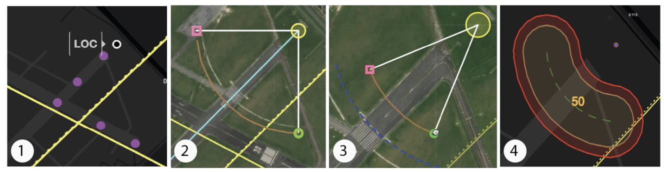


Fig. 5. Specifying an ORBIT trajectory: 1) P1 chooses the point of interest which to orbit around (LOC). 2) P1 adjusts the half-angle relative to the runway axis. 3) The resulting trajectory is visible on the map and can be adjusted with the graphical handles. 4) The prototype displays the safety buffers.

a symmetry axis such as the runway. Figure 5 illustrates how he specified such a trajectory using the runway axis and the Instrument Landing System Localizer point as required by the specification given by the maintenance team.

P1 explained that he wanted to represent the position of stakeholders on the map to check their ability to get visual feedback of the drone during the operation. These included the air traffic control tower, the head of operations, the ground maintenance team, the remote pilot, and possible external observers. We added movable icons using colors matching their description in the Conops to make them visible on the map with an editable radius to describe their visual field of view as presented in Figure 6.

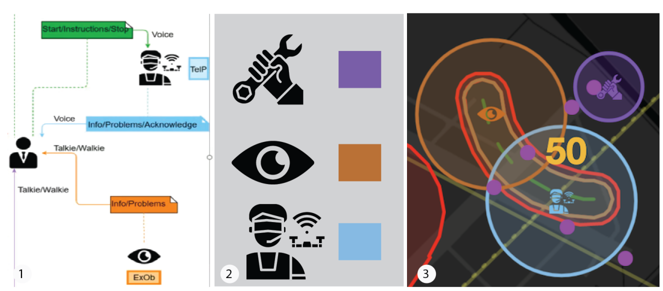


Fig. 6. The colors and icons of the entities, which are detailed in (2), are consistent in the application document (1) and on the map (3). The remote pilot and one external observer work together to keep the drone in sight even if it goes farther than each other's range.

In the break-off letter, P1 stated that the representation of the Operational Parameters was really helpful to understand the complete situation and produce descriptive documents for other stakeholders.

B. Visually Exploring Safety

P1 explained that he needed to define contingency and emergency buffers around the trajectory, and make sure these buffers remain within the airport boundaries as there were roads around the airport. From the flight profiles, we displayed buffer zones in orange for contingency and red for emergency as visible in Figure 4. The safety buffers can be specified manually using a form or computed automatically according to a predefined formula that uses the height of the drone above the ground. According to the regulation, the height of the flight determines a minimum buffer around the trajectory. By visualizing the buffers and the intersection with the airport boundaries, P1 was able to adjust the altitude of the trajectories to minimize the risks. He explained that he adjusted the altitude of a trajectory until it fitted with the airport perimeters displayed on the map. He also used the buffer representation to decide that some trajectories involving high altitude would not be possible given the actual constraints.

For the buffers, he explained that having a 3D visualization of the motions would be very valuable to better understand orbiting motion and to document his Conops for the authorization request. We thus added a 3D visualization over a 2D map as illustrated in Figure 7. P1 explained that adjusting the viewpoint helped him better understand the operation and provided clear illustrations to create the required safety risk assessment and mitigation elements.

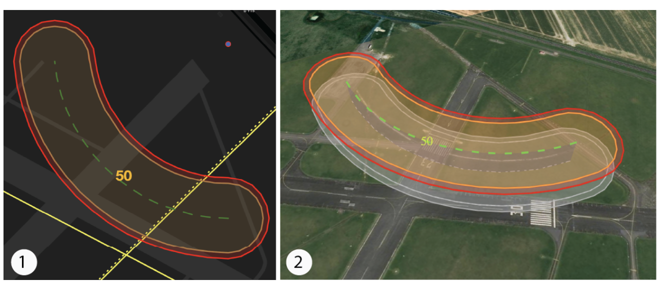


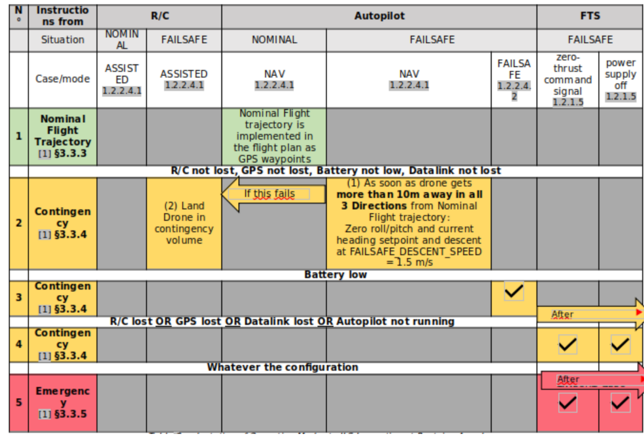
Fig. 7. Synchronization of two dimensional (1) and three dimensional (2) views.

P1 stated that the manipulation of the visual elements representing the stakeholders' positions on the map (Figure 6) was valuable to describe his Conops and assess whether an obstacle might be present between the pilot and the UAS. For specific long-range motions beyond 200 meters from the remote pilot, he placed an additional observer to cover the full trajectory, hence ensuring a permanent Visual Line of Sight with the drone.

C. Exporting and integrating with other tools and platforms

To produce the authorization request document, P1 wanted to describe the intended trajectories, positions of stakeholders, and the use of buffers as safety mitigation techniques. We added features to export screenshots of the application but also all data from the application including the trajectories and the safety buffers as JSON[2] files that might be imported into other software applications. Since he wanted to use the Paparazzi GCS and autopilot [12] for the operation, we also added support for exporting the data as valid Paparazzi flight plan.

[2]Javascript Object Notation



N°	Instructions from	R/C		Autopilot			FTS	
	Situation	NOMINAL	FAILSAFE	NOMINAL	FAILSAFE		FAILSAFE	
	Case/mode	ASSISTED 1.2.2.4.1	ASSISTED 1.2.2.4.1	NAV 1.2.2.4.1	NAV 1.2.2.4.1	FAILSAFE 1.2.2.4.2	zero-thrust command signal 1.2.1.5	power supply off 1.2.1.5
1	**Nominal Flight Trajectory** [1] §3.3.3			Nominal Flight trajectory is implemented in the flight plan as GPS waypoints				
	R/C not lost, GPS not lost, Battery not low, Datalink not lost							
2	**Contingency** [1] §3.3.4		(2) Land Drone in contingency volume	← If this fails	(1) As soon as drone gets **more than 10m away in all 3 Directions** from Nominal Flight trajectory: Zero roll/pitch and current heading setpoint and descent at FAILSAFE_DESCENT_SPEED =1.5 m/s			
	Battery low							
3	**Contingency** [1] §3.3.4					✓	After →	
	R/C lost OR GPS lost OR Datalink lost OR Autopilot not running							
4	**Contingency** [1] §3.3.4						✓	✓
	Whatever the configuration						After →	
5	**Emergency** [1] §3.3.5						✓	✓

Fig. 8. The piloting modes and the autopilot policy are configured according to the areas where the unmanned aircraft evolves. The colors are consistent on the map and in the application document. Green is the nominal flight trajectory, yellow is the contingency buffer and red is the emergency buffer where Flight Termination System would be instantly activated.

In the Conops, several autopilot modes were defined to match specific situations such as entering within the emergency area, low battery, or lost radio events as presented in Figure 8. We added the autopilot behaviors according to specific rules when exporting the flight plan. More precisely, we linked the fail-safe mode for entering a contingency buffer or the kill mode if the drones enter the emergency buffer. We also built a server listening for messages from the Paparazzi ground control station to retrieve and display the drone within our prototype during the actual operation as illustrated in Figure 9. Using Paparazzi, P1 was able to perform tests on an aerodrome with a dedicated area for model aircraft flights. The drone conformed well to the nominal plan as well as to the forecast for emergencies, *i.e.* GPS loss, datalink loss, control loss, and geofence violation, as specified within our prototype.

Fig. 9. The mission can be exported to the paparazzi GCS (2) with the safety buffers. During the operation, the position of the drone can be monitored on the map (1).

P1 explained that the seamless integration with the Paparazzi autopilot and ground control station accelerated the process from the design of the operation, the safety analysis, and the production of documents for the authorization request to the actual tests, either with the Paparazzi simulator or with a real drone in a dedicated airfield.

VI. Focus Group Results

After we presented our prototype and the scenarios visible in Figure 10, all participants expressed excitement and had very positive feedback on our concept. Both groups expressed their interest to try the tool directly for their work to further explore its possibilities. Below we describe the results from the workshop highlighting the opportunities of our concept for a variety of operations and the possible impact on the support of the collaboration between stakeholders.

Fig. 10. 1) Excerpt from the tracking use case, in which the drone has to fly over a populated area. The map displays the population density and the planned trajectory. 2) Excerpt from the survey use case, in which an automated survey of a limited area has to be performed.

A. Operational parameters representation on a map

The Air Traffic Controllers explained that the flight profiles displayed on the airport map were easy to understand. One of them stated that *"it makes the operation very clear"* since he knew perfectly the airport and could see the trajectories over it. Regulators mentioned that providing the 3D view also clarified specific trajectories and their possible impact on safety. Surprisingly, for the group of regulators, the trajectories were not paramount. Instead, they were more interested in how the safety was managed regarding those trajectories and their environment. They indicated that the representation of the buffer zones was very useful and was making the link with the material required by the SORA methodology.

The regulators indicated that they were using various map applications to assess the risks of all the submitted flight intents. They noticed that some important data layers were already present, like population density and computed buffer zones (Figure 10). To quote one member of the regulator unit: *"Indeed, on your software, having the combination of a satellite and a base map views, roads, population density..... I admit that this is something I'm quite fond of! I recognize that it could simplify our life."* They also indicated some missing aeronautical data for their work such as the International Civil Aviation Organization 1:50000 Visual Chart.

B. Supporting safety assessment

Air traffic controllers found that the tool was clear and accurate for estimating the level of safety. They expressed that the buffer zones and the link with autopilot policy were very valuable additions to the flight plans they usually had during previous drone operations conducted on their site. One air traffic controller said that: *"We never went that far for the level of the details (...). I wonder if it could become a model for future risk assessments."*. The air traffic controllers asked about the possibility to use the tool during future experimental operations they were hosting to monitor the drone's location while it is flying and its distance to the safety buffers. They indicated that they had no tools to assess safety during the preparation phase nor situation awareness of ongoing operations on their field during execution except direct visual feedback and phone call with remote pilots.

During the second focus group, we focused on how regulators assessed and validated the safety of the operations they had to review. They explained that they were using mostly maps and that our concept seemed very relevant to their work. They explained that they frequently switch between different software applications for getting or processing geographical data to achieve their tasks. They found it very effective to unify all applications with many data sources and dedicated interaction. One of the team members stated that *"the software is like a combination of our tools so it would ease our life"*. Regarding the safety buffers, they appreciated that the computation formula for the buffer zone was editable as they often use different formulas to investigate possible risks.

The regulators suggested several possible improvements to support the production of safety-related content within the application. For instance, one of them suggested adding a module for computing SORA risk levels based on the operational parameters. He explained that: *"For instance, if I place where I want to fly, at which speed, my trajectory and wind conditions. The application would tell you what the Ground Risk is"*. Another regulator wanted to add an interaction for reviewing the formulas used by the operators to compute the buffers' dimensions.

When discussing automated risk mitigation approaches such as systematically creating buffers or suggesting flying during weekends to avoid populated areas, the regulators doubted that this would be relevant. They explained that drone operators are genuinely creative when they have to determine mitigation for risk and frequently come up with new or unexpected solutions. One of them commented that *"as there is a wide diversity of possible Conops, a wide diversity of solutions for the mitigation can also be proposed."*. The head of the regulator unit explained that *"the difficulty of the mitigation comes from the fact that the process is qualitative (...), especially on mitigation intended to reduce the number of people at risk on the ground. So in theory, the operator could propose everything as a solution"*. They all emphasized that operators were responsible for the choice of the means to mitigate their risks. This implied that the tool should rather expose the situation but do not suggest mitigation means. According to the regulators, allowing to determine the feasibility of an operation is a strong contribution.

C. Information exchange

The air traffic controllers found the visualization very practical to ground their discussions on potential procedures they would have to implement during the operation. For instance, they started discussing rules to apply to the taxiing of some helicopters and general aviation aircraft during P1's operation. They also discussed and negotiated possible procedures that they would apply to keep all the simultaneous operations fluid and safe. When we asked about the possibility of sending messages or communicating via highlighting in our application during operation, they indicated that they would prefer to rely on the phone.

The regulators explained that adopting a consistent representation for the application documents would ease their work and facilitate exchanges with operators submitting authorization requests. When asked about the possibility of exchanging comments or asking for details about a request directly on the map with comments, for instance, they explained that this could be valuable but was not a priority for them. They already communicate and share files with the operators, via email, online file-sharing services, and a dedicated website. They indicated that a versioning system with adequate visualizations on the map, as a way to check and track the changes between different meetings or requests with an operator would be more important. As the regulator's team head insisted: *"Being an authority, I prefer when a submitted document is not modifiable. The reason is that our operational authorization relies on some mitigation means which are recorded in a document whose version is official and frozen"*.

VII. Discussion

Our longitudinal work with a drone operator and the follow-up focus groups helped us explore and characterize our concept. In this section, we discuss our work strengths and limitations to support drone operations safety.

A. Supporting safety with geovisual analytics

As demonstrated during our work, our concept of representing and manipulating a mission's operational parameters on a map proves successful at planning operations and assessing the safety of one real-world operation. The results of the focus groups with professional air traffic controllers and regulators also indicate that our approach could also serve as a basis for the assessment and visualization of larger and more complex operations. We also gathered evidence that our concept is valuable to support understanding of the operation and support discussion among various stakeholders about the possible impacts of operational parameters on safety.

The geovisual analytics [27] approach was particularly appreciated by P1 and the participants of the focus group. They all expressed that adjusting operational parameters to have a view of the intended flights and estimate their impact on operational safety could accelerate the process and make it safer. P1 appreciated the specific interaction for inputting trajectories usually found on ground control stations while benefiting from various layers of data and relevant information on his specific context or operation. The geovisual analytics approach also fits well with the SORA methodology which is an accepted means of compliance to perform a risk assessment for drone operations in the Specific category. In the semantic model of SORA [37]), the determination of ground and air risks takes into account flight geography, contingency and emergency volumes, and adjacent areas which are all spatial data. Thus visualizing and exploring safety-related information directly on a map can reduce the workload by avoiding back and forth between spatial and textual data.

The possibility of extending our concept to additional operational parameters is large as our prototype can accept data from most online or offline sources. The main challenge is to make the data visible and manipulable with relevant visual parameters and adequate interaction so that safety can be visually assessed. To facilitate the process of extending our tool, we included generic interaction to manipulate shapes and points over the map including positioning, scaling, color changes, or adding tooltips. We also included tools that compute intersections or overlap between shapes or distances between elements to add new safety-related features according to the use case considered.

B. Transitioning from early description to authorization and execution

During our longitudinal work with P1, our prototype allowed him to express and think about the operation he needed to implement. The visual elements related to safety such as airport boundaries and buffers helped him specify operational parameters such as the altitude or the trajectories. Interaction for exporting screenshots with colors corresponding to existing figures and documents in his Concept of Operations Document facilitated the elaboration of the documents for obtaining operational authorization.

The participants in the focus group noted the ability of our prototype to make the Conops easily understandable to other stakeholders and that it could provide a unified format for sharing drone operations with safety elements.

However, both the air traffic controllers and the regulators did not prioritize having a communication channel through the map. They explained that this would pile up with their existing tools such as email or phone.

While the regulators did not want to work with operators on a shared document as they required static versions to work with, we believe that there are opportunities to support collaboration with other authorities and stakeholders.

We also integrated with Paparazzi [12] an existing drone autopilot and its Ground Control Station to facilitate tests and execution of the operation. Overall, our prototype can support the whole drone operation life cycle from Conops description, operational safety assessment with corresponding autopilot policy and files required for authorization request in the specific category of operations, export of flight intentions and flight plans, real-time flight monitoring, and flight data saving for post-flight analysis or incident reporting.

C. Limitations and research perspectives

We focus on a unique user which might have led the exploration of our work in very ad-hoc directions. However, having considered other scenarios and gathered feedback from other professional stakeholders gave validity to the proposed concept. We are interested in pursuing our work with additional drone operators to evaluate the ability of our concept and prototype to adapt to other requirements and design new relevant interactions. We are also interested in conducting more formal experiments with several users planning a similar operation with and without our prototype to better evaluate its ability to support safety. This will allow us to collect qualitative and quantitative data for consolidating the validation of the concept.

Of all the ideas that have emerged from this research, some could not be put in the prototype as either they did not serve our use cases or they were discarded during the workshops for technical reasons. In a few cases, were not able to compute the impact on the safety of some operational parameters. For instance, the impact of the wind on safety buffers was very dependent on the drone used and required adequate models that we could not find. Using existing tools providing ground risks according to operational parameters such as Drosera [25] could considerably expand our prototype. Regarding the validity of our data, we acknowledge that a focus group is not a user test. There are differences between what people say and what they do, more direct observations would consolidate the validity of the concept for other use cases. Although the stakeholders recognized the value of the tool and the effectiveness of the concept exposed in this article, user tests are the next step for thorough validation. Considering the positive feedback from the operator and the other stakeholders, the first step of validation is reached but further experimentation is needed.

Our approach focused on geovisual analytics. However, the SORA methodology can not be fully conducted on a map only. Some elements do not have a geographic component like drone design verification or pilot training. Integrating textual and spatial data with consistent color coding and possibly direct links between textual and spatial data is also a perspective of our work to provide a unified workspace to plan drone operations and assess their safety.

VIII. Conclusion

We presented our work aiming at supporting the preparation and risk assessment of drone operations requiring authorization before being executed. We introduced our concept consisting of representing the operational parameters on a map and allowing their manipulation to facilitate the description of the Conops and assess its safety. During a longitudinal study with an operator and two focus groups with air traffic controllers and regulators, we explored our concept and evaluated its ability to accelerate the mission preparation and risk assessment phase. We found that our approach can accelerate the planning and authorization request steps while improving risk identification and mitigation, thus supporting safety. We also found that it can facilitate information sharing with other stakeholders and be used from early design to the actual execution of the mission, thus providing a unified environment for safer drone operations. Future work will focus on studying additional use cases, integrating additional safety features like ground risk, and conducting more controlled experiments with more drone operators and pilots in order to gather statistics for quantitative validation. Finally, the integration of this concept into a holistic Unmanned Traffic Management System is also a research avenue.

Acknowledgments

We thank Jim Sharples and Jules Nabon for their implication during this research.

References

[1] G. Wild, J. Murray, and G. Baxter, "Exploring civil drone accidents and incidents to help prevent potential air disasters," *Aerospace*, vol. 3, no. 3, 2016.

[2] The European Commission, "Commission implementing regulation (eu) 2019/947 of 24 may 2019 on the rules and procedures for the operation of unmanned aircraft," 2019.

[3] European Union Aviation Safety Agency, "Easy access rules for unmanned aircraft systems (regulation (eu) 2019/947 and regulation (eu) 2019/945)," 2021.

[4] L. Davies, R. C. Bolam, Y. Vagapov, and A. Anuchin, "Review of unmanned aircraft system technologies to enable beyond visual line of sight (bvlos) operations," in *2018 X International Conference on Electrical Power Drive Systems (ICEPDS)*, 2018, pp. 1–6.

[5] S. Ljungblad, Y. Man, M. A. Baytaş, M. Gamboa, M. Obaid, and M. Fjeld, *What Matters in Professional Drone Pilots' Practice? An Interview Study to Understand the Complexity of Their Work and Inform Human-Drone Interaction Research*. New York, NY, USA: Association for Computing Machinery, 2021.

[6] European Union Aviation Safety Agency, "Annex I to ED Decision 2019/021/R - Acceptable Means of Compliance (AMC) and Guidance Material (GM) to Commission Implementing Regulation (EU) 2019/947," 2019.

[7] B. Rakotonarivo, N. Drougard, S. Conversy, and J. Garcia, "Safety first! an interview study of drone mission development to guide system design supporting safety analyse and authorization requests," in *33e Conférence Francophone sur l'Interaction Homme-Machine (IHM '22)*, Namur, Belgique, Apr. 2022.

[8] ——, "Systematic Literature Review of Safety Support for Drones Operations," in *32nd Francophone Conference on Human-Computer Interaction*, Apr. 2021.

[9] E. Italia, "Samwise: online risk assessment for drone operations," https://www.online-sora.com/, 2019, accessed: 2021-10-22.

[10] Delair, "Delair ux11 - the smartest mapping drone," 2021, https://delair.aero/delair-commercial-drones/professional-mapping-drone-delair-ux11/.

[11] DJI, "Dji improves geofencing to enhance protection of airports across asia-pacific," 2019, https://www.dji.com/newsroom/news/dji-improves-geofencing-to-enhance-protection-of-apac-airports.

[12] Gautier Hattenberger, "Paparazzi uav blog," 2021, https://blog.paparazziuav.org/.

[13] S. R. Haque, R. Kormokar, and A. U. Zaman, "Drone ground control station with enhanced safety features," in *2017 2nd International Conference for Convergence in Technology (I2CT)*, 2017, pp. 1207–1210.

[14] Innov'ATM, "Dronekeeper : préparation de mission pour télépilotes et données drone," https://www.dronekeeper.com/, 2021, accessed: 2021-10-22.
[15] Unifly, "Unifly," https://www.unifly.aero/, 2021, accessed: 2021-10-22.
[16] Clearance, "Préparation de missions drone et demandes d'autorisation - clearance," https://clearance.aero/, 2017, accessed: 2021-10-22.
[17] Pansa, "Pansa utm," https://www.pansa.pl/en/pansautm/, 2021, accessed: 2021-10-22.
[18] F. A. Administration, "Uas data exchange (laanc)," https://www.faa.gov/uas/programs_partnerships/data_exchange/, 2019, accessed: 2021-10-22.
[19] X. Wang, J. Zhang, P. Feng, D. Yu, and Z. Wu, "A safety monitoring system for unmanned aerial vehicles," in *Proceedings of the 2nd International Conference on Computer Science and Application Engineering*, ser. CSAE '18. New York, NY, USA: Association for Computing Machinery, 2018. [Online]. Available: https://doi-org.gorgone.univ-toulouse.fr/10.1145/3207677.3278103
[20] J. A. Besada, A. M. Bernardos, L. Bergesio, D. Vaquero, I. Campaña, and J. R. Casar, "Drones-as-a-service: A management architecture to provide mission planning, resource brokerage and operation support for fleets of drones," in *2019 IEEE International Conference on Pervasive Computing and Communications Workshops (PerCom Workshops)*, 2019, pp. 931–936.
[21] H. Goudarzi, D. Hine, and A. Richards, "Mission automation for drone inspection in congested environments," in *2019 Workshop on Research, Education and Development of Unmanned Aerial Systems (RED UAS)*, 2019, pp. 305–314.
[22] J. A. Besada, L. Bergesio, I. Campaña, D. Vaquero-Melchor, J. López-Araquistain, A. M. Bernardos, and J. R. Casar, "Drone mission definition and implementation for automated infrastructure inspection using airborne sensors," *Sensors*, vol. 18, no. 4, 2018.
[23] C. D. Rothwell and M. J. Patzek, "An interface for verification and validation of unmanned systems mission planning: Communicating mission objectives and constraints," *IEEE TRANSACTIONS ON HUMAN-MACHINE SYSTEMS*, vol. 49, no. 6, pp. 642–651, DEC 2019.
[24] S. Primatesta, A. Rizzo, and A. la Cour-Harbo, "Ground risk map for unmanned aircraft in urban environments," *JOURNAL OF INTELLIGENT ROBOTIC SYSTEMS*, vol. 97, no. 3-4, pp. 489–509, MAR 2020.
[25] N. Raballand, S. Bertrand, S. Lala, and B. Levasseur, "DROSERA: A DROne Simulation Environment for Risk Assessment," in *Proceedings of the 31st European Safety and Reliability Conference*. Angers, France: Research Publishing Services, Sept. 2021, pp. 354–361.
[26] G. L. Lohse, K. Biolsi, N. Walker, and H. H. Rueter, "A classification of visual representations," *Commun. ACM*, vol. 37, no. 12, p. 36–49, dec 1994.
[27] G. Andrienko, N. Andrienko, P. Jankowski, D. Keim, M. Kraak, A. MacEachren, and S. Wrobel, "Geovisual analytics for spatial decision support: Setting the research agenda," *International Journal of Geographical Information Science*, vol. 21, no. 8, pp. 839–857, 2007.
[28] European Union Commission, "Commission delegated regulation (eu) 2019/945 of 12 march 2019 on unmanned aircraft systems and on third-country operators of unmanned aircraft systems," 2019.
[29] M. Nöllenburg, *Geographic Visualization*. Berlin, Heidelberg: Springer Berlin Heidelberg, 2007, pp. 257–294. [Online]. Available: https://doi.org/10.1007/978-3-540-71949-6_6
[30] A. Dennis and T. Carte, "Using geographical information systems for decision making: Extending cognitive fit theory to map-based presentations," *Information Systems Research*, vol. 9, pp. 194–203, 06 1998.
[31] B. Shneiderman, "Direct manipulation: A step beyond programming languages (abstract only)," in *Proceedings of the Joint Conference on Easier and More Productive Use of Computer Systems. (Part - II): Human Interface and the User Interface - Volume 1981*, ser. CHI '81. New York, NY, USA: Association for Computing Machinery, 1981, p. 143.
[32] D. Schuler and A. Namioka, *Participatory design: Principles and practices*. CRC Press, 1993.
[33] Adobe, "A Guide to Experience Mapping for UX Design," 2020.
[34] H. Hutchinson, W. Mackay, B. Westerlund, B. B. Bederson, A. Druin, C. Plaisant, M. Beaudouin-Lafon, S. Conversy, H. Evans, H. Hansen, *et al.*, "Technology probes: inspiring design for and with families," in *Proceedings of the SIGCHI conference on Human factors in computing systems*, 2003, pp. 17–24.
[35] B. Gaver, T. Dunne, and E. Pacenti, "Design: cultural probes," *interactions*, vol. 6, no. 1, pp. 21–29, 1999.
[36] A. Strauss and J. M. Corbin, *Grounded theory in practice*. Sage, 1997.
[37] Joint Authorities for Rulemaking on Unmanned Aircraft Systems, "JAR doc 06 SORA (package)," march 2019, http://jarus-rpas.org/content/jar-doc-06-sora-package.