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Low Level RPAS Traffic Identification and Management

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Abstract
This paper analyses safety and security issues raised by the low level operations of remotely piloted aircraft systems (RPAS) and discusses possible mitigation solutions, regarding the structure of the airspace, the required information and communication network, the candidate supporting systems and the role of the human actors to monitor and to manage the RPAS traffic in uncontrolled airspace. It then describes the architecture of a RPAS traffic identification and management system, composed of onboard cooperative devices and of a ground processing unit and display. Results from simulation trials and preliminary flight tests demonstrate the feasibility of the proposed solutions.

1. Introduction

In 2015, the EU Commission published a communication stressing that “RPAS are becoming a reality and will soon be commercially available on a European scale. The RPAS market poses a real opportunity to foster job creation and a source for innovation and economic growth for the years to come”.
This statement highlights the importance of enabling the routine use of remotely piloted aircraft systems (RPAS) in Europe in the very short term: RPAS operators are indeed eager to make possible routine missions especially at low altitude, from 0 to 500 feet AGL, in an airspace that is mostly uncontrolled when far from airport and controlled in the airport vicinity. However, having many air vehicles flying there raises two important concerns; one related to the safety of the other airspace users, the second related to the security of the population and ground assets as these systems can be used unlawfully, whether intentionally or not.

Regarding safety, flying in the lower layer of the airspace would require detect and avoid capabilities, which are still not available, and help from controllers which are not present in many locations, so that drones are currently not allowed to operate routinely.
In order to solve this, specific accommodations can be put in place, such as segregated airspace or restricted areas. However these measures are hampering the operations of manned aircraft that have been the legacy users of the low levels layers of the airspace for decades, having made their operations safe thanks to a compliance to the commonly agreed rules of the air and to the use of the basic ‘sense and avoid’ principle with which drones cannot currently comply due to a lack of appropriate technologies. It is indeed an unsolved challenge to define an efficient and reliable detect and avoid system, small and light enough to be installed on-board a small RPA. The alterative to an on-board detect and avoid system is to create a ground system able to manage the RPAS traffic and make it friendly for the other airspace users.
Regarding security, several governments are currently defining rules that would make mandatory for most RPAS to register before flight and to be equipped with a device broadcasting a set of identification data enabling a ground system to identify and track them.

Both safety and security concerns share a common necessity, the need for any RPAS to be electronically visible from the ground. In order to avoid having to carry multiple devices on a small drone and having an undue duplication of systems, research is underway to find out solutions giving a satisfactory response to both security and safety needs, with an adequate redundancy to reach a proper reliability.

This paper analyses the issues raised by the low level operations of remotely piloted aircraft systems (RPAS) both for safety and for security. It then discusses some possible regulatory solutions and a concept of operations to mitigate these issues, regarding the structure of the airspace, the required information and communication network, the candidate supporting systems and the role of the human actors to monitor and to manage the RPAS traffic in uncontrolled airspace. It then describes the architecture of an RPAS traffic identification and management system, implementing the technical functions of the concept of operations and composed of onboard cooperative devices and of a ground segment for use by the remote pilot, by an RPAS traffic manager or by a security officer. Results from simulation trials and preliminary flight tests demonstrate the feasibility of the proposed solutions.

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2. Issues of low level RPAS operations

Large benefits and business opportunities are expected from routine operations of RPAS at low level [1]. These operations raise issues both for flight safety and for security, which are frequently highlighted by the medias in the current situation and will become more acute as the number of RPAS rapidly increase, as envisaged for instance by the SESAR outlook study [2].
The Warsaw declaration of the European commission indeed ‘called for a swift development of a UAS ecosystem that is simple to use, affordable, commercially and operationally friendly, yet capable of addressing all societal concerns such as safety, security, privacy and environmental protection’ [3].
Low level RPAS operations may actually affect the safety of other airspace users and the security of the population or ground installations. Also specific measures such as segregated airspace, flight restrictions including no-drone zones are already adopted to solve these issues, such accommodations are not appropriate to enable routine operations of RPAS at a large scale. A concept of operation is indeed required for low level RPAS Traffic Management, addressing safety as well as efficiency, capacity, societal or environmental aspects. Several organizations are making efforts in this direction [4][5][6].
Similarly, some of these issues and a concept of operations are developed in [7], a synthesis is proposed below.

2.1 Safety issues

2.1.1 Airspace structure considerations for low level flight

Airspace has been structured in several classes, A to G (Figure 1). Classes A to E constitute the so-called “controlled airspace”, whereas classes F and G are called “uncontrolled airspace”, meaning that the traffic flying there is neither monitored nor controlled by air traffic controllers.

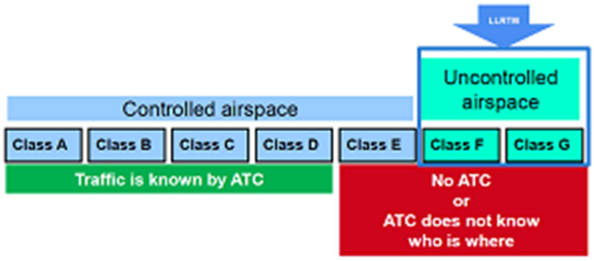

Figure 1: Airspace classes and ATC awareness of traffic

Some information services may be available in class F or G, but air traffic control (ATC) will not be able to provide traffic information. Aircraft are thus flying there freely, without having to fill neither a flight plan nor having to respond to ATC radars or to transmit any messages. The management of this part of the airspace is made by pilots themselves following the rules of the air thanks to a situation awareness built with their eyes, seeing other traffic, and ears, listening to radio messages.
Air traffic control is provided anywhere where flying fully freely cannot be performed safely due to the density of traffic and where commercial traffic has to fly, i.e. above a given flight level (FL) en-route but also at low altitude, in terminal areas, close to airfields and airports.
Class F and G airspace, uncontrolled airspace, is then found at low altitude out of terminal areas, from the surface up to an altitude depending on countries in Europe. Very Low Level (VLL) flights can thus be made either in controlled airspace, in terminal areas, or in uncontrolled airspace anywhere outside terminal areas: in all countries, a layer of uncontrolled airspace lies between the surface and 3000 feet.

RPAS operations will thus take place in the low level airspace volume which is mostly uncontrolled, but also in controlled dense traffic areas that are close to large towns having an airport and an associated Controlled Traffic Region (CTR). This implies two issues: 1) possible conflicts of RPAS with manned aircraft in uncontrolled airspace, where ATC provides neither separation nor traffic information, and 2) transition from the uncontrolled to the controlled airspaces. We’ll focus on the first issue, as in conformance with the current regulations, small RPAS operations may be limited to the uncontrolled airspace.

2.1.2 Detect and avoid and RPAS conspicuity

In uncontrolled airspace, pilots have to rely primarily on their eyes to detect other traffic and secondarily on their ears to listen to messages that are spontaneously transmitted by pilots. This transposes for the remote pilot of an

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RPAS to be able to ‘detect and void’ (D&A) the traffic, which is especially challenging without being on board, and deemed impossible without the technical support of a D&A system when operating beyond visual line of sight (BVLOS). Consistently with the safety barriers insuring conflict management, the D&A function can be split into two sub-functions, “separation provision” and “collision avoidance”. In uncontrolled airspace, both functions are under the pilot’s responsibility.
Moreover, the D&A is further complicated in the case of a small RPA by the fact that it may not be detected by manned aircraft’s pilots that, consequently, may not be able to maneuver in time to avoid collision. Due to this conspicuity issue making the situation of RPAS and manned aircraft asymmetrical, the current trend is to consider that, at low level, RPA would always have to give way to any manned aircraft, whatever would be the conventional right of way rule priority. The FAA for instance specifies among its operating rules that unmanned aircraft must yield right of way to manned aircraft.

The possible in flight collision of RPAS between each other is another concern for RPAS operations in the future, where higher density of RPAS traffic will occur. Simultaneous flights of thousands unmanned aircraft are indeed planned in the coming decades. These collisions constitute an issue for flight safety, although the risk may be rather on the ground for the people or infrastructures overflown, following the fall of the drones or debris.

2.1.3 Flights rules, minimal flight altitudes and meteorological conditions

Below 3000 feet above surface, aircraft can fly at any altitude, in any direction. The importance of the D&A concept is thus very clear in this layer of the airspace as there is no specific structure to avoid a head-on encounter. This particular layer of the airspace is the one where a number of small drone operations are expected to fly.
Manned aircraft generally have to fly at a minimum altitude of 500 feet above ground level (AGL) and at least 150 m from obstacles. They have also to overfly cities at higher minimal altitudes, depending on the town size. However, depending on national states derogations, some specific flights can be performed below 500 feet AGL. Even if they remain infrequent (aerial work, emergency recovery, etc.) or located in particular areas (gliders when soaring over a ridge), possible conflicts of RPAS with manned aircraft at these very low level cannot be excluded, especially when considering the attraction that constitute specific events for media or leisure remote pilots, and this risk will most probably increase with the number of RPAS in operations.

Visual meteorological conditions are also important to consider as they provide essential clues about the locations of potential traffic flying at low altitude and facilitate their visual acquisition. The appreciation of meteorological conditions and its exploitation by the remote pilot is however challenging, especially if flying BVLOS.

2.1.4 Reference altitude

As explained above, most of current manned aircraft operations during their cruise phase are made at a safe altitude, clear of terrain and obstacles (above 500 feet AGL and 150 m from obstacles). Flights can thus be performed with reference to a barometric altitude or flight level. The take-off and landing phases lower than 500 feet are flown near aerodromes, along designated flight paths and circuits, clear of obstacles and terrain. Nevertheless, aerial work is performed at low altitude by manned aircraft, their pilots are experts and they are specifically trained for this type of flight that requires to visually apprehending the clearance of the aircraft from ground and obstacles.
Flying a RPAS BVLOS at low altitude is more complex as pilot’s eyes cannot be used anymore to assess the altitude of flight relative to the ground. An altitude reference is therefore needed either to the bare ground earth's surface without any objects like trees and buildings, either to the surface including all objects on it.

2.2 Security issues

2.2.1 Threat to infrastructures and to people

Small RPAS can be real threats to populations and infrastructures, as the technologies enabling the automated flight of air vehicles are now very easily accessible. The security issues of small RPAS operations are highlighted by the increasing reports of unauthorized and unsafe use of small UAS, for instance close to nuclear power plants or during sport events. Also in violation of all regulations and possibly jeopardizing flight safety, reports of RPAS sights by manned aircraft pilots occurred at altitudes up to 10,000 feet and at distances less than 1 kilometer from airports [8]. Most of the time, these vehicles are flown by people that have no real awareness of the potential consequence of their lack of consciousness of the risk induced by their careless and unlawful behavior.

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Moreover, although the regulations do not permit the flight of large and heavy RPAs, such unmanned aircraft can be manufactured without any exceptional knowledge nor unattainable expertise. The possibility to use this type of RPAS voluntarily as destruction assets is also a threat that cannot be ignored.

2.2.1 Privacy concerns

Calls to the police are increasing by people complaining about the flight of a drone considered to threaten their privacy. Although this type of issue is not as concerning as the ones mentioned above, ways to avoid the violation of the citizen privacy have to be found.

3. Regulatory solutions

Flight safety issues may be mitigated by the adoption of appropriate regulations, addressing airworthiness, operations and crew qualification. RPAS operations are so diverse and specific that operational rules in particular will most likely have to be adapted to their peculiarities. Operating rules are also to be elaborated by the responsible authorities to address the security issues.

3.1 Definition of RPAS separation minima

Being initially intended for use by the pilots of manned aircraft, the ’well clear’ volume is intentionally not explicitly defined in the regulation and thus it is left to the subjective risk acceptance by the pilots involved. Moreover, the key principle for the remote pilot of a small RPAS is to avoid scaring the pilot of manned aircraft. The safest conservative measure may then be applied, which is to avoid the intruder laterally as soon as a possible conflict is detected in order to keep well clear and then to make a collision avoidance maneuver in case the lateral maneuver does not solve the conflict.
Further research is however required to investigate whether the well clear volume and time threshold should be standardized by fixed values for small RPAS applications or if they should be determined for each encounter case, possibly depending on characteristics (e.g. weight, size, aircraft category and performance) of both the RPA and the intruder.

3.2 Standardization

RPAS manufacturers are already proposing systems with advanced features (e.g. geofencing, failsafe, collision avoidance, control modes and innovative interaction devices including augmented reality). They will continue to put on the market new functionalities which make the use of RPAS easier and more efficient, at a pace which regulation can hardly follow. An example of such technological advances is the rapid development of first person view (FPV) technologies for racing hobbyists, which may open new perspectives for professional applications.
Nevertheless, at least for RPAS with a significant MTOM there is a need to guide these new developments by defining standards. The objective is to determine the minimum expected performances of the new features and the means to demonstrate that they are fulfilled, without hindering technical innovation. This is especially acute for the implementation of critical functions, such as automated guidance modes and the D&A function.

3.3 Mandatory registration

Several states have already mandated the registration of RPAS. The FAA for instance has mandated since December 21, 2015 the registration of all RPAS with mass between 0.55 pounds (250 grams) and 55 pounds, including model aircraft. Owners may register through a web-based service. As a consequence of this small RPAS registration rule, 500,000 owners actually registered in the first year. EASA proposed a registration rule for all UA in the open and specific categories except if the MTOM, including payload, is less than 900 grams [9].

3.4 Remote identification and tracking

Manned aircraft have to register and are attributed a unique identifier (aircraft registration number) and this identification information may be broadcast by the aircraft transponder.

In October 2016, the French parliament decided to mandate an online registration process and the carriage of an electronic identification device for drones having a MTOW above 800 grams. The FAA Extension, Safety, and Security Act of 2016 also called for “the development of consensus standards for remotely identifying operators and owners of unmanned aircraft systems and associated unmanned aircraft”.

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These new rules make any drone operator feel more responsible for the behavior or their flying vehicles as any deliberate violation of the established rules may be punished, in France, by imprisonment and heavy fines.

4. Concept of operation

Considering the issues raised by the low level operations of RPAS, a concept of operations for low level RPAS traffic identification and management (LLRTIM) has been established. This concept is consistent with the classical model of safety layers and barriers, providing mitigation of the issues at both strategic and tactical levels, and a last minute safety net (collision avoidance when addressing conflicting traffic).

A strong consideration is that the mitigation measures below may serve both safety and security objectives, providing that the regulatory requirements defined for each objective –and likely by different institutions- are made consistent. This would help limiting the cost imposed to the RPAS manufacturers, to their users and to the service providers, thus providing benefits to the market.

4.1 Assumptions

The LLRTIM concept of operation is built upon the following assumptions:
AS#1: Small RPAS operating at very low level (below 500 feet AGL), either VLOS or BVLOS.
AS#2: Mandatory equipment of RPAS with a cooperative identification and localization device.
AS#3: Uncontrolled airspace (class F-G): conflict management is under the remote pilot responsibility
AS#4: RPAS must yield right of way to manned aircraft.
AS#5: Make use of existing cooperative devices of manned aircraft.

4.2 Strategic mitigation

As discussed previously, the limitation of operations of manned aircraft above 500 feet / 150 meters AGL leaves some room to operate RPAS below this altitude, consequently providing some kind of natural "pre-strategic de-confliction" of RPAS with manned traffic that uses the lower layer of the airspace only for specific flights such as emergency recovery, aerial work or ridge soaring.

Another protection layer may be offered by promoting the sharing of flight information and intent before flight. Web-based flight preparation services could encourage the airspace users to share information. In return, the pilots of manned aircraft would get knowledge of possible RPAS operations close to their flight path and the remote pilots may also get an up-to-date view of the flight constraints in their area of operations.
Note that some states have already developed such a flight preparation and declaration service, which is indeed an efficient way to collect actual flight intents and to get an objective view of the planned RPAS operations. These services can also be used to implicitly deliver a flight authorization, or to reject it if some conditions are not required.

When higher RPAS traffic density is to be considered, solutions have to be found to mitigate the risk of RPAS vs RPAS collision. A solution within the LLRTIM concept of operation [7] is inspired by the semi-circular flight rule actually in force to vertically separate manned flights above the transition altitude. A way to avoid "head-on" encounters between RPAS is indeed to structure the very low level airspace into five layers, an eastbound (EB) RPAS flying zone and a westbound (WB) RPAS flying zone separated by a 50 feet thick buffer zone (Figure 1).

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Figure 1: Semi-circular rule for RPAS VLL operations and perspective view of the RPAS traffic.

The two RPAS flight zones are thus separated from manned traffic and from ground by two 50 feet thick buffer zones. Consequently, two drones flying in opposite directions should be vertically separated by a distance of at least 50 feet (buffer zone between the EB and the WB zones) as its equipment and its vertical agility should allow it to remain inside its assigned flight zone.

This structure for the airspace may be too rigid for RPAS applications which require flying without restriction between ground and the 500 feet AGL altitude limit. In that case, a portion of the airspace called a RPAS working volume (RWV) could be dedicated to a particular RPA, in-between the manned aircraft safety buffer zone and the terrain safety buffer zone. This volume may be static in case the aerial work requires stationary phases of flight, or dynamic –moving as required for the operation.

Some challenges raised by this concept are already identified, among which the altitude reference, the need for appropriate terrain and obstacles databases, the navigation robustness against wind and turbulence and the limitations for flying above steep terrain or obstacles.

In order to complement the airspace structuration and basic navigation principles, it is anticipated that all RPAS traffic will have to be cooperative and that RPAS operators will have to declare their flight intentions and ask for a strategic deconfliction before they can take off. A centralized flight management service would then be required, similar to the one envisaged in SESAR for the management of commercial aircraft business trajectories.

4.3 Tactical mitigation

Although manned aircraft encounters with RPAS should be uncommon under 500 feet, such an encounter will likely not be improbable enough to reach an acceptable level of safety: a tactical way to separate manned aircraft and RPAS still has to be found for this layer of the airspace.
An assumption of the LLRTIM concept of operations is that RPAS shall remain well clear from manned aircraft. Means should therefore be provided to the remote pilot to be aware of possible incoming traffic, such as the LLRTIM demonstration system which is described later in this paper.

All RPAS being cooperative, this concept of operations also permits the tactical separation between RPAS. Assuming that a potential conflict is detected, despite the structuration of the airspace, navigation principles and organization of the traffic depicted previously, then the remote pilot will be alerted and maneuver its RPA to solve the conflict.

The LLRTIM concept of operation also foresees the role of an RPAS traffic manager (RTM). This new role is thought as especially relevant for the operation of an RPAS fleet. It would be fulfilled by an employee of an organization operating several RPAS and would have to coordinate the simultaneous operation of the fleet, in link with the remote pilots. More precisely, the role of the RTM would be to manage the RPAS traffic, ie: 1) to watch the global traffic 2) to alert the remote pilots of incoming manned traffic and 3) to coordinate multiple-RPAS operations

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4.4 Collision avoidance

Collision avoidance is the last layer of conflict management. As far as safety is concerned, this layer brings an additional barrier that will be useful if the other mitigations means and the overall environment are not enough to reach the target level of safety (TLS).
The collision avoidance function would indeed be required only if the previously mentioned strategic and tactical mitigation layers fail to avoid the conflict. A priority objective is thus to insure and to demonstrate the robustness of these layers.
In case a collision avoidance function is deemed necessary, the LLRTIM assumption that the RPAS are cooperative and compatible with existing cooperative devices of manned aircraft makes it possible to envisage an automatic collision feature by connecting the cooperative traffic localization device to the RPAS flight control system.

5. System description

5.1 Overview and working principles

An RPAS traffic identification and management system (RTIMS) has been developed for the purpose of research and demonstration. It implements the technical functions of the LLRTIM concept of operation, providing namely:

1) RPAS identification and tracking,
2) Traffic awareness,
3) Detection of possible conflicts,
4) Support to the separation and task.
5) Provision for automated collision avoidance.

More precisely, the RTIMS allows remote electronic identification and tracking of the RPAS. It also provides manned and RPAS traffic information to the RPAS remote pilot and to a RPAS traffic manager (RTM), when available, by means of human-machine interfaces (HMIs) dedicated to these two roles. The RTIMS also provides conflict detection alerts when required in order to help the remote pilot staying well clear of manned traffic and avoiding other RPAS when relevant. The RTIMS operational concept is illustrated on Figure 2.

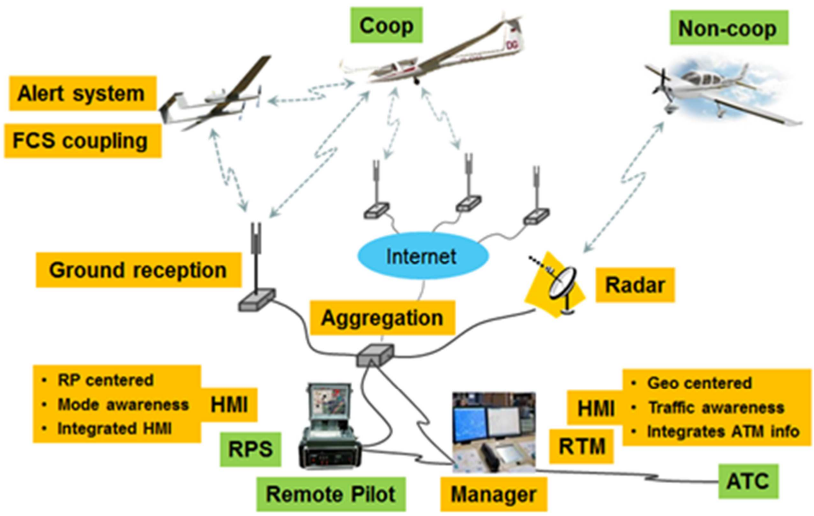

Figure 2: LLRTIM operational concept

The RTIMS is expected to cover a given zone of RPAS operation and to detect the low level traffic which may interfere with the RPAS operation, including the non-cooperative manned aircraft. It makes uses of existing components and is especially fitted for small RPAS for which onboard detect and avoid is not an option.
The RTIMS coverage may also be extended by connection through the Internet to existing networks of ground receivers and associated web sites.

5.2 System components

The LLRTIM system comprises the following components, which are further described below:

- Onboard cooperative identification and localization devices, equipping each RPA within the RTIMS;
- A ground receiver compatible with the onboard cooperative devices;

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- A ground radar for detection of non-cooperative intruders;
- A processing unit, aggregating the ground receiver and radar data and connected to the Internet;
- Graphical user interfaces (HMI) dedicated to the remote pilot and to the RPAS traffic manager.

5.2.1 Airborne cooperative devices

An essential assumption of the LLRTIM concept of operation is to mandate the equipment of RPAS with a cooperative device, serving the purposes of identification and tracking for the sake of both flight safety and security. A number of technologies are already available to fit this requirement, including mode C, S and ADS-B transponders, LPAT, GPS trackers and Flight Alarm (FLARM) devices.

In particular, FLARM devices have been initially designed for use by gliders pilots, and more recently adapted for use by general aviation and helicopter pilots (PowerFLARM variant, offering an extended range and receiving ADS-B and transponders mode C/S signals). These devices are based on a concept patented by ONERA in 1998 [10] and are currently built by various companies in the world under commercial agreement with FLARM Technology GmbH.
More than 30,000 FLARM devices have been distributed up to now (including over 1500 PowerFLARM units in operation in the US) and thus the community of FLARM equipped aircraft is already large, making it an especially interesting solution to satisfy both safety and security requirements.
The basic working principle of these devices is to broadcast the aircraft identification and its localization (GPS fix) at regular time intervals under a proprietary coded radio protocol. They operate on the 868 MHz frequency band (in Europe), thus avoiding the use of the 1090 MHz frequency already used by ADS-B. Although not certified, these devices are developed according to the standards of the electronic industry and they are widely recognized as beneficial for flight safety.
Although FLARM devices include a specific conflict detection and alerting logic and are primarily intended for use by glider pilots as an aid to visually acquire a conflicting traffic, they are readily available as transceivers (and receivers) for remote identification and localization source for RPAS traffic management.
The first version of the RTIMS makes use of the FLARM technology in order to benefit from the already large number of aircraft equipped. In particular a specific effort aims at developing a miniaturized FLARM for RPAS (FLARM4RPAS).

5.2.2 Ground components

The ground segment includes a radio receiver able to decode the signals of the cooperative devices and to share them under a generic format. The processing unit then aggregates all these data together with the radar data.
Once formed, the traffic tracks are further exploited by a conflict assessment function, which identifies and classifies the possible conflicts with the surrounding traffic and then computes the time to conflict.

The conflict assessment is based on the definition of a look-ahead time and of a conflict volume which dimensions still have to be validated. Current assumptions based on published documents (e.g. [11]) and values used in other projects concerned with detect and avoid is to define the conflict volume as a cylinder of 500 feet horizontal radius and 200 feet vertical height (+/- 100 feet), whereas a minimal look-ahead time of 30 seconds is deemed necessary. The conflict volume can be used in order to compute a potential collision risk. The choice between a first or second order interpolation of the trajectories is currently being investigated, with the aim to better take into account the undergoing manoeuvres of the aircraft. Anyhow it has to be noted that the pilots would most probably choose to pass at a larger distance from each other.

Moreover, a community of gliders pilots and associations has developed a network of more than 700 ground receivers that collect FLARM signals, decode them and display the flight tracks via internet open-access web sites. These sites are readily used for instance in glider competitions to simultaneously monitor up to one hundred flights in small areas.
A main benefit is that these networks provide a global view of the cooperative traffic, and thus considerably increase the range covered by the RTIMS, although the update rate of the downloaded information may be larger than for the information received locally. In particular the LLRTIM concept of operation considers that these networks would provide an efficient means for the RPAS traffic manager to anticipate the incoming traffic before the remote pilot may have to be alerted. Sharing of information with these services (uploading) may also be possible depending on the privacy policy of the RPAS operator.

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Eventually, the traffic information issued by the processing unit is displayed to the LLRITM users –remote pilots, RPAS traffic manager, or security officers- in an appropriate format through dedicated HMIs (Figure 3).

a) b)

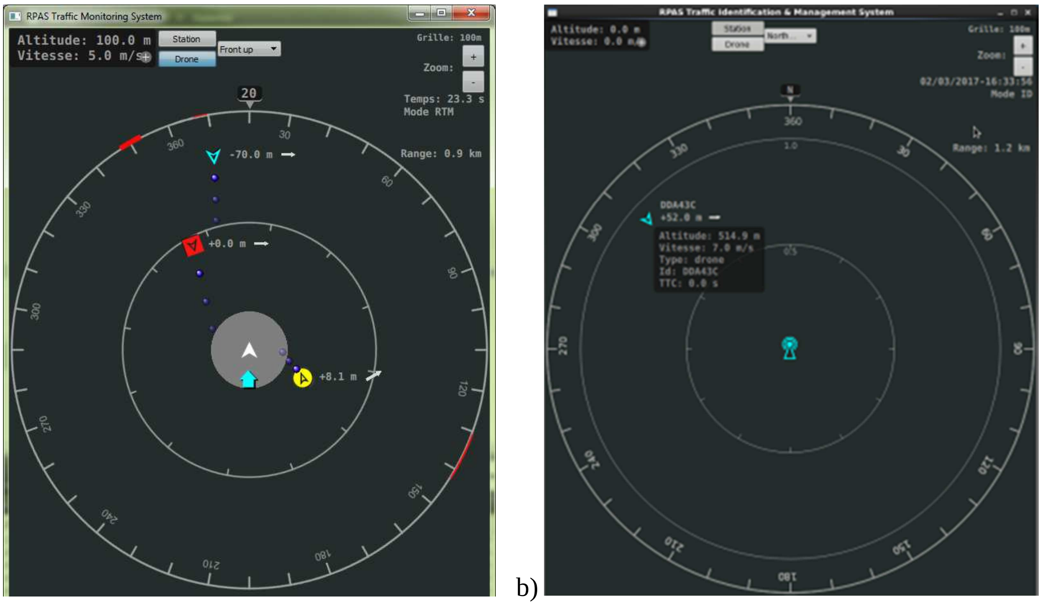

Figure 3: Example displays for a) remote pilots and b) security officers.

6. Simulation trials and preliminary flights tests

6.1 Simulation

Real-time simulation is widely used to verify and to evaluate the behavior of the RTIMS at the different stages of research and development. Software modules have thus been adapted from existing software of the ONERA Simulation Lab or especially developed in order to allow the simulation of the RPA flight with traffic encounters. Their outputs are then used to stimulate the RTIMS components, including the sense function and the HMIs.

Two modes of real-time simulation are in fact used, either full virtual simulation or hybrid simulation, using the actual ground receiver and traffic, while the RPA flight is simulated in both modes.
The simulation tests allowed to compare and to validate different possible solutions regarding the conflict assessment algorithms and the preliminary design of the HMIs.

The research perspective associated to the LLRTIM project include controlled human-in-the-loop experiments to further investigate the possible design alternatives regarding human involvement and interactions with the demonstrator in realistic but controlled settings.

6.2 Flight tests

Preliminary flight tests are performed since July 2016 in order to evaluate the potential of the LLRTIM concept.

In a first step, these tests involved the LLRTIM ground segment, a multirotor RPA equipped with a FLARM device, and a very light aircraft (VLA) playing the role of an intruder (Figure 17).

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Figure 4: Illustration of first flight tests, showing the flown intruder trajectories, a conflict situation between the RPA and the intruder, and the LLRTIM ground segment with the display intended for use by the remote pilot.

These preliminary tests focused on signal acquisition and detection range. In particular the detection range was shown to be as expected with several nautical miles coverage, although sensitive to terrain masking and antenna quality.
The results were promising, although several directions of improvements were identified. HMI design assumptions regarding the preferred frame of reference and the need for attention getters were also validated.

The flight tests planned for the next iterations will involve traffic of different nature (other RPAS and helicopter) and will focus on the remote pilot role and on the alerting features. Different options for the HMI will also be evaluated.

An in-flight demonstration using a dedicated variant of the HMI and involving the simultaneous flight of several drones was also conducted in March.
Identification and tracking of three drones at distances up to one kilometer were demonstrated.
On this occasion the following improvements were demonstrated:

- Onboard integration of the miniaturized cooperative device,
- Extended range by use of an high gain passive antenna (Figure 5),
- Dedicated HMI for use by security officers.

Figure 5: The ground LLRTIM station with the high gain antenna used in the demonstration of RPAS remote identification.

The potential benefits of the LLRTIM system for RPAS remote identification were thus demonstrated, as a possible answer to the recent legal requirements for security.

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7. Conclusion

Whereas the operations of small RPAS at low level raise several issues, an analysis of these issues shows that regulatory solutions together with an appropriate concept of operations can mitigate the issues both for flight safety and security.
The study reported in this paper shows that, in addition to a wisely defined concept of operation for RPAS flying at low altitude, a system consisting of light and low cost elements installed onboard RPAs and of ground elements located along RPAs flight paths could be an adequate solution to allow a safe and secure development of RPAS low level applications in the short term.
However, a consensus has to be reached to define common rules and to develop compatible and interoperable on-ground and onboard systems as it has been the case in manned aviation.
Although RPA are unmanned, the role of humans to manage the operations of the air vehicles and to make their flight safe and socially acceptable is still preeminent. The human situational awareness is thus an important factor as any violation of the rules may have safety, security and legal consequences.
Research and development are underway to demonstrate the feasibility of the LLRTIM concept and to assess its associated assumptions, the technical choices and the appropriate involvement of its human users.

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