ICAS 2016
30th Congress of the International Council of the Aeronautical Sciences
DCC, Daejeon, Korea ; September 25-30, 2016

INVESTIGATIONS OF GROUND INFRASTRUCTURES FOR UAS FLIGHT MONITORING

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Keywords: *UAS, flight monitoring, ADS-B, ground infrastructures*

Abstract

This article deals with the investigation of on-ground infrastructures to be exploited to monitor Unmanned Aerial Systems during their operations. In particular, this work evaluates the usefulness of a radar technology to be installed in an airport facility. Simulation analyses have been carried out considering the installation of Primary Surveillance Radar, Secondary Surveillance Radar and ADS-B. Then, in order to ensure the economic viability of these infrastructures, the impact on civil aviation monitoring activities has been evaluated. Eventually, for the selected reference case, located in Northern part of Italy, the ADS-B is proposed, taking also into account the results and the future trend already suggested by several other European Research projects focused on airspace integration.

1 General Introduction

Nowadays, Remotely Piloted Aerial Systems (RPAS) are extensively used for different kinds of applications, both in civil and in military applications. Considering the current market outlook and the demand forecasts of the near future it is possible to notice that lack of regulations, procedures and infrastructure can be deleterious game stoppers for their application.

In order to overcome one of these problems, this paper investigates and suggests on ground infrastructures to improve RPAS (and more in general UAS, Unmanned Aerial Systems) flight monitoring.

In order to achieve this goal, an overview of airport approach procedures and a detailed description of possible on ground infrastructures are proposed in Sections 3. Then, six real monitoring scenarios have been simulated and the most meaningful results are reported in Section 4.

It is worth to notice that the proposed monitoring scenarios are real cases envisaged by a large group of Italian Stakeholders and the entire work has been carried out within the framework of SMAT-F2 (Sistema di Monitoraggio Avanzato del Territorio – Fase 2 , Advanced Territory Monitoring Systems – 2nd Phase) funded by Piedmont Region and FESR (European Fund for Regional Development). The aim of this research project, since its first phase, was the feasibility study of an integrated system exploiting a heterogeneous fleet of RPAS for civil monitoring purposes in both nominal and emergency conditions.

2 Main assumptions for Ground Infrastructure definition

2.1 Overview

As highlighted in Section 1, this work has been carried out within an Italian regional framework. Notwithstanding, the study and the definition of the major requirements for RPAS integration within the civil airspace should not be limited to some specific regional environment only, but the regulations and the guidelines for the on ground infrastructure development should have a general validity.

In order to enhance their field of application, different strategies for developing sustainable solutions for RPAS insertion in non-segregated areas are in continuous evolution, as well as the related enabling technologies [1] [2] [3]. Indeed, besides they are currently operated in segregated areas in order to maintain an acceptable level of risk, in a medium-long term, there will be a complete integration with civil air traffic according to the most promising research activities such as SESAR and other research activities all around the world.

In order to propose solutions for UAS flight monitoring, an overview of the currently used approach techniques for civil aviation has been carried out, considering the ICAO (International Civil Aviation Organization) definitions and rules.

2.2 Visual and Instrumental Approach

First of all it is necessary to make a distinction between Instrument Flight Rules (IFR) and Visual Flight Rules (VFR).

- IFR flight includes a series of rules and procedures for aircraft that are able to fly even in case the pilot is not able to recognize and avoid obstacles, terrain another airspace users. Among these rules, there is also the collection of information about the flight route to follow, directly communicated by the ATC.
- VFR flight is performed whether the pilot is able and responsible to see and avoid any kind of obstacles with the support of the air traffic control but without exploiting instrumentation to navigate and to control the aircraft.

2.2.1 Visual Approach

Considering these definitions, a visual approach is directly influenced by visibility, that ICAO defines as the greatest distance at which a black object of suitable dimensions, situated near the ground, can be seen and recognized when observed against a bright background; or as the greatest distance at which lights in the vicinity of 1 000 candelas can be seen and identified against an unlit background [4]. In this context, the definition of the Runway Visual Range plays a fundamental role and it is defined as the distance until which the pilot on an aircraft, positioned on the runway, can see the markings, runway edge lights or runway centreline.

In Section 4, in order to set up the simulations, Cuneo-Levaldigi Airport has been selected as reference case study. In this airport and its related proximity areas, the phenomenon that most often leads to visibility reduction is fog. Fog is a weather phenomenon that reduces the horizontal visibility below 1000 m and is caused by the presence of drops of water or ice crystals.

2.2.2 Instrumental Approach

The instrumental approach is considerably different from the visual approach. In particular, following the ICAO reference, an instrumental approach procedure consists of up to five different segments:

- Arrival Segment
- Initial Approach
- Intermediate Approach
- Final Approach
- Missed Approach

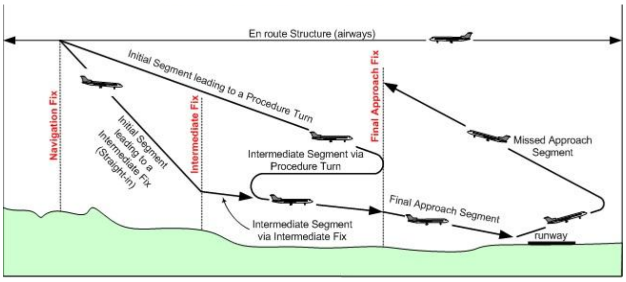


Fig. 1. Instrumental approach segments

Within the family of instrumental approach, both a precision and a non-precision approach are allowed. The Minimum Distance Altitude (MDA) is a fundamental parameter, indicating the lowest allowed altitude. Reached this altitude, the pilot will have to "level off" and maintain it until the MAP (Missed Approach Point Time), at which it will go-around only if the pilot haven't the runway in sight. MDA is determined by each company for each procedure and may not be below the OCA (Obstacle Clearance Altitude) published by the local national authorities in the instrument approach charts. On the other hand, a precision instrument approach consists of a number of prearranged maneuvers that allow the pilot to position the plane on a radio path (ILS), which provides the alignment with the axis of the runway and the correct angle of descent for the separation from underlying obstacles. The pilot reaches the DH (Decision Height) will begin the missed approach procedure only if a visual contact with the runway has not yet been established. Even the DH is decided by companies for each procedure and it cannot be lower than the values set by the local national authorities. Considering this type of procedure, the Instrumental Landing System (ILS) is the on-board radio guidance system able to provide precision lateral guidance, guaranteeing the alignment with the runway and vertical guidance, maintaining the plane on a slope ending on the surface of the runway. In order to measure the distance from the runway, the ILS system exploits two or three vertical beacons, called markers. The pilot understands that he passed the vertical line of a marker because he can hear the acknowledgment signal transmitted in Morse code, and he can see the appropriate indicator light flashing with the same sequence.

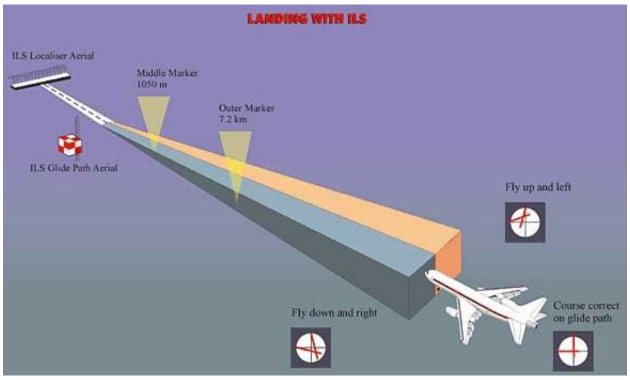


Fig. 2. ILS Landing

2.3 Procedural versus Radar Approach

In order to authorize an aircraft landing, the controller must be reasonably sure that when the aircraft will cross the runway threshold, the one, which came first, has:

- passed the end of the runway or has begun the turn of removal, if departing;
- liberated the runway, if incoming.

This concerns both the VFR and the IFR.
Table 1 provides a comparison between a procedural approach and a radar approach.

Tab. 1. Procedural vs Radar approach

Procedural Approach	**Radar Approach**
Procedural separations determine delays and altitude limitations	It reduces delays and altitude limitations
Procedural control does not allow vectoring and reduction of flight paths.	It allows the vectoring and therefore a reduction of flight paths
It does not allow an optimal sequence of arrivals	It allows the vectoring and then a sequence of optimal arrivals
In bad weather conditions it does not allow to safely deviate from the published routes to avoid areas with presence of dangerous clouds for the flight	It allows the vectoring in free cloud zones
It does not allow you to view traffic and therefore unintentional deviations from the nominal flight path	It allows you to view traffic in order to inform pilots in case of significant deviations from the nominal flight path over the whole trip under radar coverage
It does not allow the display of aircraft that affect the control area without radio contact and prior authorization	It allows you to view all aircraft inside the control area and inside the field of radar coverage even if the aircraft is not equipped with transponder

3 Technologies applicable to Ground Infrastructures for in-flight monitoring of Remotely Piloted Aircraft (RPAS) platforms

Primary Surveillance Radar (PSR) technologies as well as Secondary Surveillance Radar (SSR) technologies have so far been considered for ground infrastructures. The ADS-B (Automatic Dependent Surveillance-Broadcast) technology is also going to be considered in this work.

3.1 Primary Surveillance Radar

It is worth remembering that with primary surveillance radar high energy is directed via an antenna to illuminate the target, which in our case is a MALE platform. The energy is then reflected back from the aircraft's body to provide range and azimuth measurements.

Primary Surveillance Radar has its own disadvantages:

- The amount of energy being transmitted is very large if compared with the amount of energy reflected from the target;
- Small targets, or those with poor reflecting surfaces, could further reduce the reflected energy.

Main advantage of the Primary Surveillance Radar is that it does not require any specific equipment on board the aircraft. The PSR can also be used without other ground equipment, but is not able to obtain information from the aircraft found.

3.2 Secondary Surveillance Radar

Secondary Surveillance Radar overcomes the typical disadvantages of the Primary Surveillance Radar by transmitting a specific low energy signal (the so-called interrogation) to a known target. This signal is analyzed by a transponder on board the aircraft and a new signal, i.e. not a reflected signal, is sent back (the so-called reply) to the origin, i.e. the ground infrastructures. Main disadvantage of the Secondary Surveillance Radar is therefore that it requires specific equipment, the transponder, on board the aircraft. SSR cannot be used without a PSR for its necessity to "interrogate" a specific aircraft (i.e. cannot be used to find unknown aircrafts but only to obtain information from them).

3.3 Automatic Dependent Surveillance-Broadcast

Automatic dependent surveillance – broadcast (ADS–B) [5] is a new concept of cooperative surveillance technology, element of the US Next Generation Air Transportation System (NextGen) and the Single European Sky ATM Research (SESAR) [6] and is the radar that will be mandatory in Europe from 2017. In this kind of radar the Ground Station has to receive the transmission of an aircraft that communicate its position in broadcast and via satellite. The information, received by the ATC ground station, is able to replace PSR and SSR information, in the future ATM (Air Traffic Management) organization. The ADS–B is automatic and no pilot interface is needed, but it is dependent from the aircraft's navigation system.

4 Simulations and Results

4.1 Reference aircraft and scenarios

As it has been highlighted before, the aim of this work is to investigate, to evaluate and to propose ground infrastructures for UAS flight monitoring. In particular, in this paper, it has been assumed to deal with MALE UAS (Medium Altitude Long Endurance).

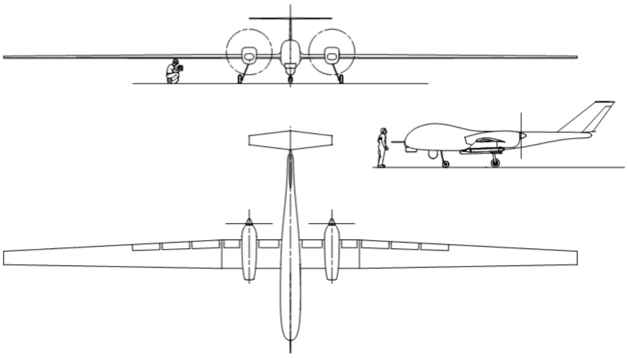


Fig. 3. MALE reference aircraft, belonging to SMAT-F2 fleet.

Tab. 2. MALE reference data

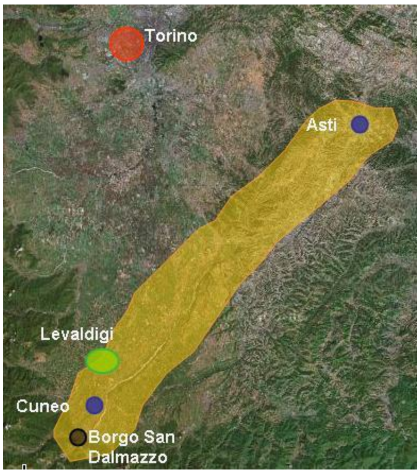
Characteristics	Value
Maximum take off weight	3500 kg
Wing span	16 m
Wing area	18 m2
Length	10,2 m
Engine type	Piston diesel engine
Engine power	450 hp
Payload weight	450 kg
Number of simultaneous payload	3
Maximum speed	330 km/h
Operational speed	260 km/h
Maximum endurance	30 h
Service ceiling	9500 m
Take off and landing requirements	Conventional take off and landing
Take off/landing run	500 m
Communication type	LOS/BLOS
Environmental conditions	STANAG 4370

Moreover, the following table contains a list of scenarios selected as reference.

Tab. 3. Reference Scenarios

Flood Scenario

This scenario deals with an emergency situation linked to the flooding of a large river, affecting large extent, creating difficulties for basic infrastructures and threatening the population



Costal weather pollution scenario

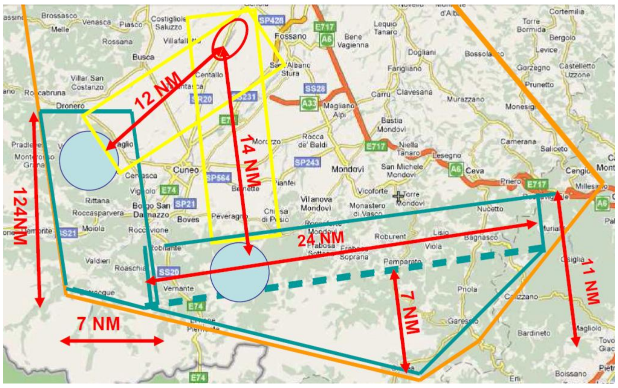
This emergency scenario deals with a critical situation generated by the pollution of a large water area with impact on a wide costal area.

Regional monitoring scenario

This is a routine monitoring activity aimed at collecting information about the over-flown territory at different purposes, such as, the verification of the compliance with certain procedures, or to provide population with timely informative services, etc…

Simple prototypal UAV test scenario

The aim of this scenario is to highlight the efficacy of ground radar not only sustaining fully developed UAV, but also helping prototypal vehicles during initial tests. The tests conducted during the initial phase of an UAV design, are usually simple routes, conducted over non-highly populated areas and planned to be similar to usual task of the fully designed vehicle. SMAT-F1 studies has been take into account into this scenario



Civil air traffic management

In order to analyze the features of ground surveillance radar in the common civil ATM two days of high traffic in Cuneo-Levaldigi airport has been considered. Usual flight and daily planning has been taken in consideration, adding some other uncommon eventualities (e.g. a flight redirected from Torino-Caselle airport due to bad weather conditions or a private business jet arrival). Three kinds of aircraft have been considered in this scenario: Boeing 737, ATR-42 and a Challenger 604.

Procedural and radar approach comparison scenarios

In order to fully analyze the benefits of ground surveillance radar some situations has been considered comparing the procedural approach and the radar approach. Some reference radar, one for each kind of radar, has been considered, together with the actual normative about the procedural approach.

Furthermore, the following table summarizes the radar and related technologies taken as reference. The right-hand column provides a legend of reference name used in the following subsections, for simplicity reasons only.

Tab. 4. On ground infrastructure designation

Primary Radar	
ATCR – 33 S	Radar Dome 1
ATCR – 44 S	Radar Dome 2
ALE 3x5 L	Radar Dome 3
ASR 9	Radar Dome 4
ASR 910	Radar Dome 5
ASR 12	Radar Dome 6
ASR 2000	Radar Dome 7
ASR E	Radar Dome 8
DASR	Radar Dome 9
Morova	Radar Dome 10
Secondary Radar	
SIR – S	Radar Dome 1 It consists of • Receiver 1 • Transmitter 1
RSM 970 S	Radar Dome 2 It consists of • Receiver 2 • Transmitter 2
ADS – B	
1090 MHZ ES	Radar Dome 1 It consists of • Receiver 1
Aircraft	
NGIFF – Transponder - M425	• Receiver A • Transmitter A

4.2 Input for simulations

In order to analyze these scenarios, a commercial software, widely used also in space context, has been selected. STK (Systems Tool Kit or Satellite Tool Kit) is a physics-based software developed since 1989 by AGI (Analytical Graphics, Inc.), software that allows the performing of complex analyses on ground, sea, air, and space assets.
The main considered constraints for all the first four scenarios listed are:

- Local terrain elevation, through a multi-regional map loaded in the STK scenario;
- Specific surveillance radar maximum range;
- Typical Default STK constraints as the geo-localization of target and observer or the roundness of the Earth.

In these scenarios some variables has been considered in order to have a more detailed vision of a radar utility in UAV missions. These variables have been considered together in order to have all the possible combinations of them. The first variable considered is the flight altitude of the UAV. This altitude has been varied between these inputs: 1000 m, 2000 m, 3000 m, 4000 m and 5000 m. The aim of this variable is to show the influence of the terrain altitude constraint over the radar capability to see the vehicle. Also the presence of clouds has been considered through pre-loaded STK model [7] [8] [9]. The data considered as inputs in this model has been considered in two ways:

- ITU-R P.840 standard,
- Incremented data in order to examine a worst condition.

The other variable considered in these scenarios is the weather condition: indeed, for each operating scenario both favorable and adverse weather conditions have been taken into account.
Adverse weather conditions considered are:

- Rain;
- Low clouds;
- High clouds.

The "Civil air traffic management scenario" uses the same assumptions and model features used in the previous described scenarios. The route modeled can be divided into four main groups:

- Planned flight: all the common flight for Cuneo-Levaldigi airport;
- Charter flight. all the possible charter that can take-off or land in Cuneo-Levaldigi airport;
- A private business jet landing and take-off between Cuneo and Verona;
- A flight redirected from Torino-Caselle airport due to bad weather conditions.

All these flights have been packaged in two days of planning both to examine the behavior of a surveillance radar in the worst ATM condition and to not increase the model calculation time. The results obtained in this scenario can be modified into different flight planning considering the validity of the superposition principle.

The active normative and the landing procedures for Cuneo-Levaldigi airport have been also considered in the route modeling in STK, taking into consideration also the single aircraft features.

4.3 Analyses and results of ground Infrastructures monitoring of MALE UAS

In order to accomplish the analysis of the capability of ground infrastructures to monitor MALE platforms, three different technologies for ground infrastructures have been selected as well as the different operative scenarios for the MALE platform. In each operating scenario, geographically situated in the north west of Italy (Piemonte/Liguria), the ground infrastructure is located at Levaldigi airport. In addition, both favorable and adverse weather conditions have been taken into account. A specific scenario software tool, AGI STK, has been used as tool to perform the analysis.

Results considered are the following:

- *Access by constrain* (i.e. the an access interval is the time period during which line-of-sight visibility between two objects is possible and allowed by all the object constraints). STK is able to calculate accesses between the ground radar and aircraft. This value can be considered the most important result because it highlights the influences of terrain elevation and other constraints on radar range. The constraints considered are: the radar range, the Line of Sight (i.e. if this option is checked, access to the object is limited to lines of sight not obstructed by the ground), the Azimuth Elevation Mask (here called AzElMask for simplicity, i.e. if this option is checked, the access to the object is constrained by azimuth-elevation masking., considering that the mask used come from the defined terrain mask or a custom Az-El mask as defined in the basic object properties), the Terrain Mask (i.e. if this option is checked, access to the object is constrained by any terrain data in the line of sight to which access is being calculated) and the Field of View (i.e. if this option is checked, access is denied if the associated object is not within the field of view as defined by the angle settings for the sensor type in question).
- *Antenna gain* (i.e. Antenna Gain provides Antenna Gain vs. Elevation Angle). Inputs required before the report is created include the range of elevation angles and the fixed value of azimuth angle that the user is interested in seeing. This value has been considered for each type of simulated radar.
- *Link budget* obtained considering the definition of detailed properties for each scenario object related to the communication system. In particular, STK incorporates detailed rain models, atmospheric losses, and RF interference sources in the analyses and generate detailed link budget reports and graphs. As already above mentioned, two models for the presence of clouds (the basic one and the one called the worst case scenario) and two models for the presence of rain, (i.e. Crane and ITU) have been considered.

In the following subsections, the most significant results are reported. As the reader will notice, in the following subsections, only the most meaningful subset of output is proposed.

4.3.1 *Simulation and results for flood scenario*

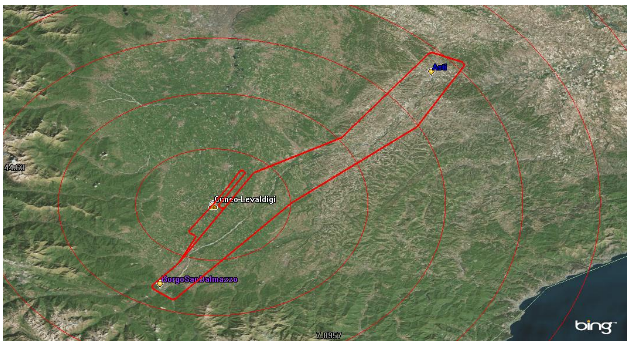


Fig.4. Flood scenario: flight route

Figure 4 represents a graphical view of the area interested by the UAVs monitoring activities while the red circles are the coverage limits of the considered radar. More detailed information about coverage and transmission could be seen in Figure 5 were the link budget between Receiver 1 and Transmitter A has been reported.

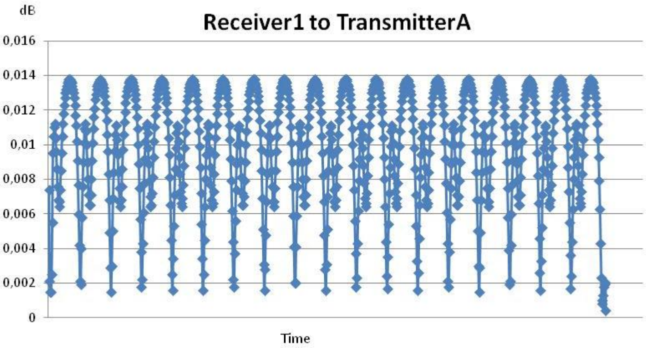


Fig.5. Flood scenario: Receiver1 – TransmitterA link budget

While the results for the accesses for SSR result to be similar to those referred to the PSR, the link budget analyses, which have been carried out, show that values change depending on the type of the chosen model for the clouds. In most cases the trend of the graphs remains the same but with the values of the worst case signal loss increases a little bit. However, these values are not so high as to affect the effectiveness of the radar. Results obtained exploiting ITU rain model seems to be more accurate.

4.3.2 Simulation and results for costal weather pollution scenario

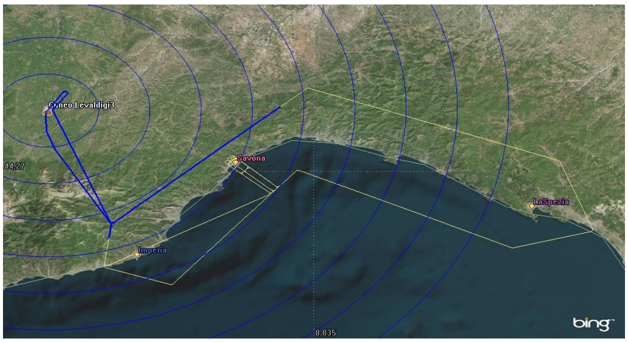


Fig.6. Costal weather pollution scenario: flight route

The results obtained through the simulation of this peculiar case study shows that the terrain has a deep impact on radar signal losses. This is mainly due to the morphology of the area selected for this peculiar application, located in the northern part of Italy. Indeed, the mountains of Piedmont and Liguria tend to stop the signal. Furthermore, some of the radar taken into accounts does not have a sufficient range to cover the overall trajectory.

Then, considering only one type of radar it was possible to investigate the impact of altitude flight on the coverage. In particular, the ATCR-33S Selex (the Radar Dome 1) has been selected for further investigations because, as previously stated, it is one of the most widely used in our country. Simulation results highlight that increasing the flight altitude the impact of terrain morphology decreases. If the aircraft flies higher there will be fewer problems with the signal from the radar. In order to analyze SSR, Radar Dome 1 has been chosen as reference, with the SIR-S by Selex. Again, similar results have been obtained.

As far as link budget is concerned, the results confirm that the main differences in the forecast depend on the rain model selected for the investigation.

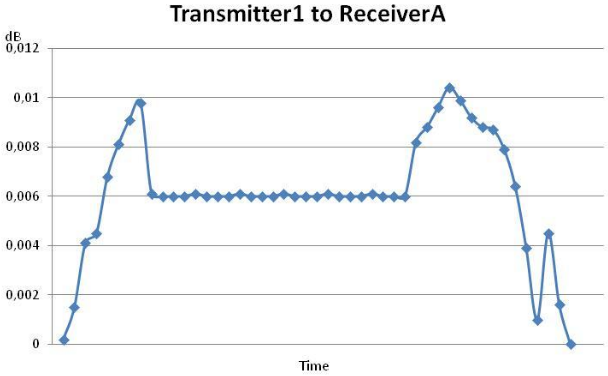


Fig.7. Receiver1 to TransmitterA RAIN CRANE model.

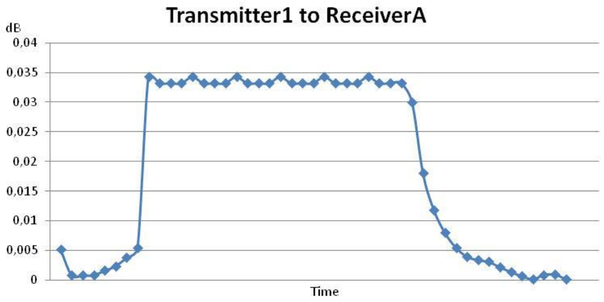


Fig.8. Receiver1 to TransmitterA RAIN ITU model.

4.3.3 Procedural and radar approach comparison

In this scenario, the difference between procedural and radar approach has been investigated, following the regulations currently prescribed at the airport of Cuneo Levaldigi. According to one of the most influencing rules, no more than one aircraft in IFR navigation at the same time within the airport ATZ is allowed. This rule does not concern VFR flights in the area.

Looking at the results gathered simulating the presence of a PSR, it is possible to notice that the radar is able to recognize the aircraft at a great distance from the airport. This allows the airport to control the airspace throughout the approaching aircraft. On the other hand, as far as SSR is concerned, the results show that the controlled area is still wider. However, it is necessary to remember that the installation of a secondary radar will always be accompanied by a primary radar.

In conclusion, for this scenario, the presence of three controllers in the control tower of Levaldigi has been simulated in STK. The number of controller used has been selected in order to allow the model to simulate all the aircraft of the scenario. The results highlight the period of time in which a controller (among the three considered) sees the considered aircraft. In this analysis, the most important parameter is the visibility. In particular, when the visibility decreases, the controller sees the aircraft for a very short period of time. Radar is able, as it is shown in the previous analysis, to see an aircraft for a larger period of time and for higher distances than the one constrained by the visibility. Exploiting these on-ground infrastructures to control the movements of the aircraft fleet during their flights, a higher level of safety could be reached, even in case these vehicles are too closed to the airport. In particular, the controller can only see a plane that is already close to the airport. Although the results are obtained varying the visibility up to 20 km, considering this distance as the optimal condition.

Furthermore, other parameters such as the antenna gain and the radar cross-section have been evaluated.

4.3 Overview of the results

Looking at the main results, it is clear that there is not a great difference between different kinds of aircraft, especially as far as antenna gain and cross-section is concerned. Moreover, it is crystal clear the need of a ground surveillance in all the analyzed scenarios. Comparing PSR and SSR, the PSR is preferable because it can also be exploited alone, while the SSR has to be used with a PSR, cause it is not able to find a target without knowing its position. It is also true that the SSR and ADS-B radar have a higher range than the PSR. Above all these considerations, there is the fact that, in future, the ADS-B technology will be widely used, as suggested in several research project like SESAR. This technology allows pilots and air traffic controllers to see aircraft and vehicles with the greatest possible precision, without increasing the ATM complexity. Unlike the other radar categories, that base their operations on the return of an echo due to the signal reflection on the considered target and that present relevant errors in the ground areas control, ADS-B works very well also at low altitude and in ground proximity. Moreover, the ADS-B can also be used to monitor traffic at the airport ground, and not only for the common air traffic management. It is also efficient in remote or rugged terrain where radars result inadequate. The ADS-B on ground receivers can provide the location of the target in real time, making viable and economically feasible the "radar-like" service, where this is not implementable. It has also to be considered that, right now, in order to have the chance to test ADS-B technology, Milano-Malpensa airport has to be used also for the Piedmont research projects. It would be a great opportunity for companies and industries of the Piedmont area, interested in the ADS-B project and in the SESAR program to have the chance to use Cuneo-Levaldigi airport to do their own testing activities.

Eventually, this technology has already been used on UAVs. Indeed, the 26th January 2014 at

Camp Roberts, California, a fixed wing drone (Arcturus T20) was used in a civil traffic area with a Cirrus SR22. The UAV were proved to be able to fly in the same airspace while controlling its position and the one of the other vehicle positions, attitude and altitude. The system that provided self-separation is the ADS-B. This experiment shown that using this technology, the flight of UAVS and traditional aircraft in the same areas is possible and it is simpler and more feasible from the economical point of view than expected.

5 Conclusions

The present document deals with the analysis of ground infrastructures for UAS in flight control. The most relevant ground technologies for in-flight monitoring were considered and real cases taken as reference. Four scenarios for UAV platform has been created one of which used for the simulation of UAV test. Two scenarios were created to simulate civil aircraft management around Cuneo Levaldigi airport. The analyses and the results of ground infrastructures for MALE platform monitoring suggested to built ADS-B infrastructures in order to contribute to the renewal of Cuneo Levaldigi airport, enabling this place to become a test base for UAS flight tests and integration in the existing airspace.

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