Integration in controlled airspace: definition and validation of link loss contingency procedures for RPAS in terminal manoeuvring areas

G. D'Angelo[1,a *], G. Pompei [2,b], A. Manzo[3,c], G. Riccardi[3,d], and U. Ciniglio[4,e]

[1]Leonardo, C.so Francia, 426 – Torino 10146, Italy

[2]Leonardo, Via Tiburtina km 12,400 – Roma 00131, Italy

[3]ENAV, Viale Fulco Ruffo. di Calabria – Napoli 80144, Italy

[4]CIRA, Via Maiorise – Capua 81043, Italy

[a]giuseppe.dangelo@leonardo.com, [b]gino.pompei@leonardo.com,
[c]alessandro.manzo.1@enav.it, [d]giovanni.riccardi.1@enav.it, [e]u.ciniglio@cira.it

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Abstract. Remotely Piloted Aircraft Systems (RPAS) are increasingly becoming a part of our day-to-day lives. The vast range of possible applications in both military and civil contexts (e.g. border surveillance, search and rescue, civil protection) is creating a new industry with a large economic potential that, consequently, is pushing the rulemaking and standardization authorities to define and publish the rules, standards and procedures the industry has to comply with in order to integrate its products with the Air Traffic Management System. From an operational perspective, the challenge lies in integrating the worlds of manned and unmanned aircraft in a safe and efficient way allowing both types of aircraft to share the same airspace. An aspect of this challenge consists in defining and validating operational procedures and technical capabilities that allow to manage safely the RPAS even when a (Command and Control and/or ATC radio) link loss occurs. This paper is aimed at describing the procedures for the management of link loss events that affect RPAS flying under Instrument Flight Rules (IFR) in a Terminal Manoeuvring Area (TMA). This paper also describes the distributed facility used to validate such procedures by means of real time simulations in an Italian operational scenario with pilots and Air Traffic Controller (ATCO) in the loop. Positive feedback was provided by both ATCO and Remote Pilots (RPs) on the overall acceptance of the proposed operational procedures which were considered satisfactory even in non-normal conditions (e.g.: degradation of the communication channel quality). The insertion of RPAS in TMA was considered feasible, even in case of single or multiple Command and Control Link Loss (C2LL) contingencies. The experiment described in this paper was part of the SESAR 2020 Programme, PJ13 ERICA project.

Background

In 2012, experts in the RPAS field were called upon by the European Commission to develop a European roadmap for the integration of civil RPAS. In 2013, in response to the 'Roadmap for the integration of civil RPAS into the European aviation system', the SESAR Joint Undertaking launched a set of projects within the SESAR1 framework, then continued in the frame of SESAR 2020 in 2019 [4]. Bringing partners together from across ATM and Europe, the projects aimed at validating emerging RPAS technologies and operational procedures in non-segregated airspace and supporting the update of the related avionic standards and flight rules ([2][3][6]). Overall, these projects perceived no significant difference between the behaviour of an RPAS and a general aviation aircraft of the same (small or medium) category, when operating in the Air Traffic Control (ATC) environment. However, the following threads needed to be addressed before integration could be considered:

- Updated and well-established civil regulation and certification system by the required certification authorities [7];
- Policies and procedures on how ATC should interact with RPAS to ensure efficient operations and to meet safety-level requirements [1];
- A detect & avoid (D&A) capability and compliance with European aircraft equipage requirements;
- A reliable Command & Control (C2) link as well as voice link together with contingency procedures in case of link failures.

Operational context and user needs

Accepting the integration of RPAS into the ATM system poses many challenges and the need to address operational, performance and safety concerns for each of the flight phases of the RPA and considered ATM scenarios. The operational context considered in this paper is the integration of civil RPAS in the 'certified' category flying under IFR in low/medium density non-segregated airspaces from class A to C. The considered ATM scenario was a TMA wherein RPAS and manned aircraft operate simultaneously (mixed traffic), flying Standard Initial Departure and Standard Arrival Route procedures (SID/STAR) and responding to ATCOs clearances and instructions (vectoring included).

In such context two main user needs can be identified:

- Ensure that the RPA are able to flow the same SIDs and STARs designed for manned aviation without penalizing the traffic operations (e.g. by introducing delays or degrading the overall flight safety) in the involved ATC sector[1];
- Ensure that a C2 link-loss or voice loss condition affecting an RPA, has an acceptable impact on RP and ATC in terms of workload and procedures.

Simulation objectives

This paper describes a specific Real Time Simulation (RTS) campaign executed in the frame of SESAR 2020 W2 PJ13 ERICA project, Solution 117 [5][8], aimed at defining and validating the long-term operational, procedural and technical capabilities required to allow the integration of certified MALE and Tactical RPAS into the Italian Area of the Brindisi Control Centre (Brindisi ACC), by using the BARI-PALESE (LIBD) as main airport and BRINDISI-CASALE (LIBR) as alternate one.

The validation experiment described in this paper is the last step of an extensive validation activity which comprised two other propaedeutic RTS campaigns. The final RTS campaign, based on a set of four defined validation scenarios, considered both nominal and link loss contingency situations [5][8]. The experiment aimed at proving the feasibility of mixed operations in nominal conditions, as well as at the acceptance by RPs and Traffic Controllers of the implemented Human System Interfaces and automatic C2LL contingency procedures. It was also used to define a specific ATC phraseology for handling such C2LL contingencies. The simulation framework as well as the functions and procedures used, the outcomes and the resulting recommendations, main scope of this paper, are reported in the next sections.

Distributed simulation framework

To get significative results against the validation objectives, several complex scenarios were built and executed by using the Capua-Roma-Torino Air Ground Operation (CARTAGO) simulation framework depicted in Figure 1.

[1] A defined airspace region for which the *associated* controller(s) has *ATC* responsibility.

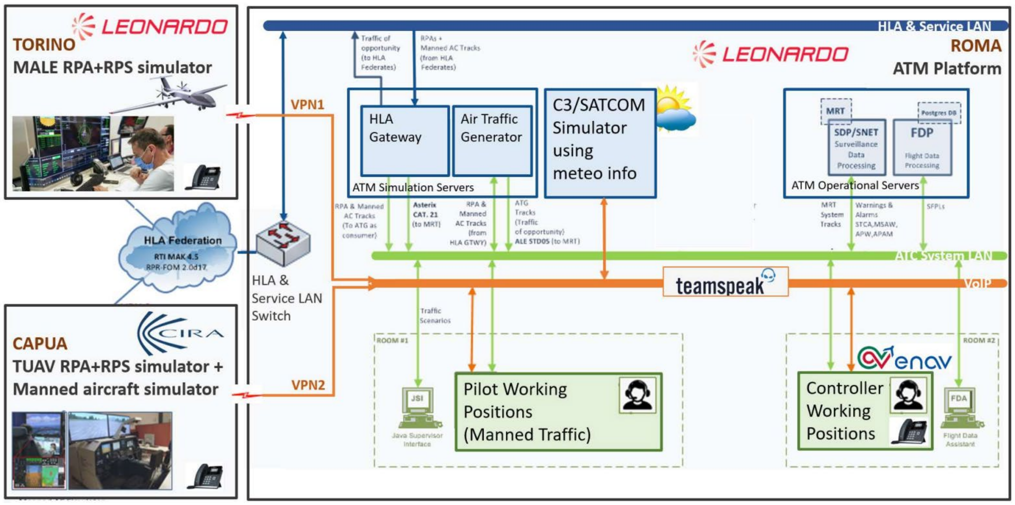

Figure 1 - The CARTAGO Real Time, geographically distributed, simulation facility

CARTAGO consisted of a Real Time geographically distributed simulation facility including:

- A Leonardo real ATC platform equipped with a Short-Term Conflict Alert (STCA) tool and upgraded to manage C2LL contingencies.
- A Leonardo MALE RPAS (10 tons of MTOW, 325 kt of maximum speed) full simulator hosting a Flight Management System model and a C2LL contingency function.
- A CIRA fixed wing Tactical RPAS (550 Kg of MTOW, 90 kt of maximum speed) simulator.
- A CIRA General Aviation manned aircraft simulator.
- A SATCOM model used by RPS to exchange both C2 messages with RPA and voice messages with ATCO. The model allowed to simulate the effects of different weather conditions on the link in terms of delay and degradation.

The geographically distributed simulation platforms were integrated by using the High Level Architecture (HLA) standard [9], specifically customized for ATM data run time exchange so as to keep under neglectable limits the related site-to-site transmission latency. In addition, as shown in Figure 1, the voice communication between RPs and ATCO was implemented by using the open-source TeamSpeak IP-based framework, adequately modified to emulate realistic disruptions over VHF radio link.

Technical functions, operational procedures and scenarios

An automatic C2LL contingency function was developed and tested together with a set of contingency procedures designed to allow the handling of a link loss condition in a wide range of possible situations.

Figure 2 shows the most complex operational scenario that was simulated where the MALE RPA lost the C2 link via SATCOM and the Tactical RPA lost the VHF radio. It can be noted the presence of a ground-ground voice link between the RPS and the ATC. Indeed, it is assumed that the integration of the RPAS into the ATM also requires a ground-ground voice link as essential enabler in order to ensure a back-up link in case of a VHF radio loss. It is still under discussion if this ground-ground link will be implemented by upgrading the existing telephone lines (quick solution) or by creating a dedicated ATM VoIP infrastructure (medium-term solution but with the advantage to avoid the communication latencies introduced by the SATCOM link).

Figure 2. Link loss continency - Complex scenario

Figure 3 shows one of the C2LL contingency procedures automatically executed by the RPA under the control of the on-board C2LL contingency function. The light blue arrow represents the direction from where the RPA could arrive. If the RPA loses the C2 Link (C2L) before the BAR Initial Approach Fix (IAF), it shall continue to fly in automatic way to BAR waypoint by maintaining the last authorized speed and Flight Level (FL). Once BAR IAF is reached, the RPA turns right (yellow path) direct to APFIB fix, then the RPA enters the holding pattern (red path) and holds it for 7 minutes. If the C2L is not recovered during the holding, the RPA shall go direct to BAR IAF (brown arrow) continuing to maintain speed and flight level. Once BAR IAF is reached, the RPA enters a second holding pattern to recover the IAF altitude if needed (green path). As soon as the IAF altitude is reached, the RPA flies to BD554 and starts an automatic RNP approach (purple path) and auto-landing procedure.

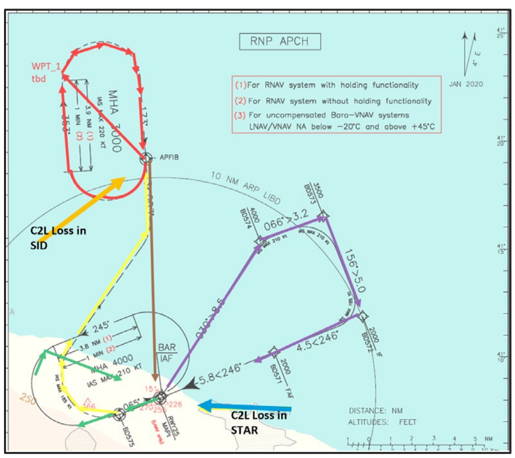

Figure 3. C2LL Procedure for SID and STAR, RWY25

The orange arrow represents, instead, the direction from where the RPA could come if the RPA lost the C2L before the Final SID Fix (FSF). In fact, if the C2L is lost during the departure phase, the C2LL contingency function will take the control of the RPA and, by maintaining the last authorized speed and FL, will complete the climb phase. Once the FSF is reached, the RPA flies automatically direct to APFIB (orange arrow) then enters the holding pattern (red path) and continue the procedure as already described above.

The C2LL contingency function is working properly even when the C2L is lost during the execution of a vectoring instruction. In that case, the C2LL contingency function maintains the last assigned instruction for two minutes then it commands the RPA to rejoin the original flight plan and reach the FSF or IAF as applicable, by maintaining the last authorized speed and FL. Once the FSF or IAF is reached, the RPA flies automatically direct to APFIB and continue the procedure as already described above.

Validation results and recommendations

Throughout the exercise, human performance and safety related aspects were investigated using a range of qualitative and quantitative assessment techniques including post run and post simulation questionnaires, debriefings sessions and operational expert observations annotated during the runs.

Operational acceptance. Positive feedback was provided by both ATCO and RPs on the overall acceptance of the concept and the procedures, even in case of single or multiple C2LL contingencies.

Human performance and perceived level of safety. Both ATCO and RPs stated that the overall workload was tolerable. Single and multiple C2LL contingencies generated a moderate workload but no concerns were raised about potential increase in human error linked to management of RPAS traffic. Positive feedback was provided by the ATCO in terms of impact on safety in both nominal and non-nominal conditions regarding the nominal and C2LL operational procedures, indeed the safety levels were not degraded.

Recommendation and future studies. As additional outcome of the exercise, the following set of recommendations was collected and reported by the ATCO and the RPs, suggested to be addressed in future studies and validations:

- in case a first C2LL procedure is already in place and another RPA is arriving at the same TMA, it was proposed that the ATCO (if needed) instructs this second RPA (with the C2 link still working) to update the pre-programmed C2LL trajectory in order to avoid potential overlapping on the same contingency path.
- to implement the automatic execution of the “open loop” clearances[2] with a flight level limit. In fact, only automatic execution of open loop clearances with time limit were validated, but the ATCO reported that this kind of clearance is rarely used, while flight level limit is more commonly used.
- to implement the automatic execution of “closed loop” clearances. In fact, despite the implementation of “open loop” clearance with limit was acceptable, ATCOs would prefer this implementation to allow them to specify the re-join waypoint together with a vectoring instruction.
- to implement an on-board emergency function to handle an FMS failure under a C2LL condition.

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[2] An ATC clearance that does not include a specified or implied point where the restriction on the trajectory ends.