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# Preliminary Validation Results of a Novel Concept of Operations for RPAS Integration in TMA and at Airports

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**Abstract.** The paper describes the results of recent research activities carried out to investigate the safe integration of Remotely Piloted Aircraft System (RPAS) into ATC controlled airspace with a focus on Terminal Manoeuvring Areas (TMAs) and airports. The research activities presented in this paper started with the definition of RPAS-specific use cases and the development of a preliminary novel Concept of Operations. This was followed by the definition and the execution of a simulation test plan for the validation of this new operational concept. The validation campaign has been carried out involving aerospace research centres in the Netherlands (Royal NLR), Germany (DLR), and Italy (CIRA), respectively. Different aspects of RPAS integration in the TMA were considered, such as latency of command & control (C2) link and voice communication link, Automatic Take-off and Landing (ATOL) operations, contingency procedures, and handover of control between two different remote pilot stations. The validation exercises were conducted using real-time human-in-the-loop simulation facilities to assess the human performance of both air traffic controllers and remote pilots. The results showed that the proposed novel concept of operations is suitable for the integration of RPAS at TMAs and airports, with 80% of the objectives fully and 20% partially achieved, and acceptable to excellent results regarding acceptance/situational awareness (8.2/9.0 out of 10 points; higher is better) and workload (2.6 out of 10 points; lower is better).

## 1. Introduction

As of today, remotely piloted aircraft system (RPAS) missions require segregated airspace configurations, largely restricting their operational capabilities and economic viability. RPAS, in this context, are understood as unmanned aircraft which are piloted from a remote pilot station (RPS) and are expected to be integrated into the air traffic management system equally as manned aircraft, while real-time piloting control is provided by a licensed remote pilot (RPIL).

In consideration of the predicted market growth for RPAS, the relevant European air traffic transport masterplans target the full integration of RPAS (and other unmanned aircraft systems) by 2035 in both controlled and uncontrolled airspace [1]. However, in recent years European airspace has reached its capacity limits, especially in terminal manoeuvring areas (TMAs) and airports, making this resource the bottleneck of the industry. Consequently, the integration of RPAS in such kinds of



airspace becomes one of the most relevant issues to be dealt with to achieve the seamless full integration of RPAS in the civil air transport system.

In the course of state-of-the-art research, it becomes evident that there are several challenges associated with the RPAS integration. For example, different RPAS configurations lead to different approach speeds and wake turbulence susceptibility, especially when aircraft frames are considered that are much smaller and less heavy than regular traffic that is flying under instrument flight rules (IFR). Further, required additional links between the RPS and the remotely piloted aircraft (RPA) on the one hand and between the RPS and air traffic controllers (ATCO) on the other hand can be affected by latency, especially when a beyond radio line-of-sight (BRLOS) connection is used. Lastly, RPAS specific effects on current operations (e.g., reduced situational awareness due to lack of human senses on board the aircraft) or completely new operations (e.g., failure of automatic take-off and landing systems) require an adequate concept of operations.

The INVIRCAT project aimed at creating and validating such a concept of operations in a two-step approach, in which it is refined after the validation exercises at the aerospace research centres of Royal NLR in the Netherlands, CIRA in Italy, and DLR in Germany. The validation context, planning, execution and especially the results with major findings from the feedback and questionnaires obtained from the participating RPILs and ATCOs are presented in the following.

## 2. Validation Context

### 2.1. RPAS-specific Use Cases

To enable the creation of an adequate concept of operations and the consecutive validation exercises, the INVIRCAT project compiled and defined a set of RPAS representative nominal and non-nominal use cases for TMA operations, distinguishing between applicable flight phases in the TMA, if required. The nominal use cases included the use of an Automatic Take-off and Landing system (ATOL) and handover operations between RPSs. Non-nominal use cases considered were missed approaches/go-arounds (as consequence of an ATOL system failure), ATOL system contingency, Command and Control (C2) link failure, traffic conflicts, transponder failure and Radio-Telephony (R/T) communication failure. The use cases were described as a flow of activities per involved actor.

### 2.2. Novel Concept of Operations for RPAS in the TMA

The developed concept of operations of the INVIRCAT project aims to define systems, architectures and operations for the integration of IFR RPAS into the airport and TMA environment. Key assumptions for the RPA are based on the UAS traffic class VI as defined by EUROCONTROL [2]. These assumptions are complemented by elements necessary for the concept, e.g., the ability of the RPA to taxi on its own power to reduce the impact on runway capacity, or the requirement to have only one RPA under control by a licensed RPIL at all times in the TMA and airport environment.

The impact on current procedures and workflows, especially with regard to air traffic control (ATC), is aimed to be minimized. However, some additional tasks for RPILs were required to be formulated: monitor and configure remote pilot station; monitor and control status of links; transfer control; provide known high latency values to ATC. Additional tasks for ATCOs include the consideration of higher separation values, the clearing of termination areas in case of C2 link loss, and consideration of earlier landing clearances for RPAS. Whenever possible, current operations should also be applied in RPAS operations. However, some RPAS specific operations needed to be adapted or created, such as contingency procedures (e.g. ATOL or C2 link failure). Further, handover procedures and guidelines for a handover briefing are part of the concept.

Finally, a considerable impact to efficient and safe RPAS operations in comparison with manned air traffic can be the level of system latency, that is caused by the distinct RPAS architecture. The potential architecture solutions are radio line-of-sight (RLOS), BRLOS or ground connection/relay for C2 and R/T communication [3], where RLOS or ground connection/relay should be the preferred options in the TMA as they are considered to have the lowest impact. Literature review performed

within the project, using sources from EUROCAE, RTCA, ITU, ESA and TNO, yielded the following expected latency values [5] which then served as input to the simulation activities as described later:

- C2 link: 1000/2000/1500 ms in RLOS/BRLOS/ground relay conditions
- R/T: 290/700/150 ms in RLOS/BRLOS/ground connection conditions

### 3. Validation Planning

#### 3.1. Validation Objectives and Focus Areas

The project identified 18 validation objectives and the five key performance areas (KPA) Safety, Human Performance, Operational Efficiency, Capacity, and Equity to support the detailed design of validation exercises with ATCOs and RPILs. For each validation objective, qualitative or quantitative feedback from RPILs and ATCOs was required and assessed using questionnaires, debriefing sessions, and recorded simulation data. As the INVIRCAT project encompasses a novel concept, the impact on the human actors (i.e., ATCO and RPIL) is assessed through the Human Factors area and on the Efficiency of the aviation ecosystem through the Efficiency area.

Specific attention is given to the systems and factors that highly impact RPAS operations. The following focus areas have been under particular investigation for the validation results:

- ATOL system: investigate the criteria to design ATOL procedures acceptable for both ATCOs and RPILs.
- C2 link and R/T communication latency: measure the impact of representative latency values.
- Handover: procedures and phraseology required for a handover of an RPA between RPSs with varying involvement of ATC.
- Phraseology: to understand if the current phraseology is suitable or needs adaptation, also considering that, in case of R/T failure, RPILs and ATCOs will activate alternative voice communication means (e.g., landline phones).
- Contingencies: such as C2 link failure, transponder failure, R/T failure, ATOL failure, or conflict situations.

#### 3.2. Selection of Use Cases and Data Collection Methods

The use cases chosen for validation were selected based on the ability of the validation platforms of each partner to perform a realistic human-in-the-loop real-time simulation. For execution of the relevant use cases, simulation elements such as the RPAS, RPIL, ATCOs, controller working positions (CWP), pseudo-pilots and aircraft models (for manned traffic and additional unmanned traffic) were considered. The identified use cases were then divided among the three simulation sites. CIRA focused on use cases with ATOL operations, including ATOL contingencies, C2 link failure and latencies. At DLR, specific nominal and non-nominal use cases (e.g. transponder failure, C2 link failure and conflict situations) including varying latencies of the C2 link were validated. At NLR, nominal and non-nominal use cases for varying C2 link and R/T voice latencies were validated, including R/T failure conditions and specific traffic conflict scenarios. In addition, different RPA handover procedures were evaluated.

The data coming from these different facilities were aggregated by using the same data collection methods for all the simulations. The following methods were used: (i) data log for system performance measurements and quantitative evaluation of key performance indicators, (ii) audio recording used as additional data source to be analyzed in case of controversial or unclear results with reference to specific events, (iii) two questionnaires (one to be filled in at the end of each run and one after the execution of the entire simulation campaign) different for both the RPIL and the ATCO, (iv) debriefing sessions conducted by human factors experts executed after each run to collect data and thoughts of the involved actors. The questionnaires were designed to complement selected standard tools by adding ad-hoc questions targeting specific issues investigated by the use cases.

### 3.3. Validation Architecture

A common architectural design was utilized by all of the locally executed validation exercises to validate the objectives described above. For each validation architecture, this design foresees to include remote pilot stations, controller working positions, pseudo-pilot stations, and a traffic simulator.

For each of the experiments, the architecture was composed by integrating proprietary simulators of research centres Royal NLR, CIRA and DLR. The conceptual architecture is sketched in Figure 1.

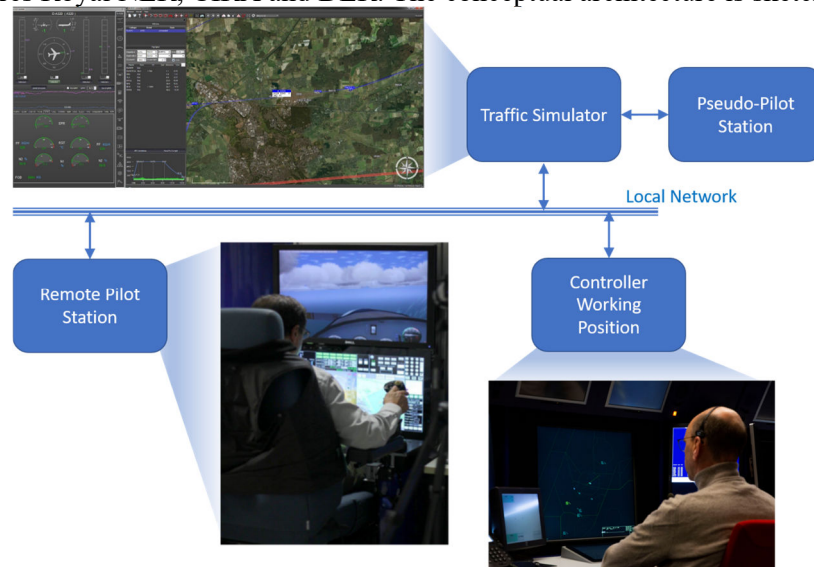


Figure 1: INVIRCAT General Simulation Architecture

## 4. Validation Execution

The validation campaign consisted of 73 scenarios in total, with the following thematical focuses.

### 4.1. Automatic Take-off and Landing focused Validation Exercises

The INVIRCAT project took EUROCAE ED 283 “ATOL MASPS” [7] as main reference for the ATOL related concept elements and use case definitions. ATOL is considered essential for integration of RPAS in the TMA to prevent manual operation, that would be affected by latency, and to tackle contingencies such as C2 link failure.

The ATOL exercises considered the operations during final approach and landing (until the RPA stops on the runway), and take-off and initial climb (starting from holding on the runway), focusing mainly on the automatic execution of Missed Approach/Go Around (MA/GA) and Rejected Take-Off (RTO) manoeuvres, considering the ATOL being capable of following the same procedure as a manned aircraft during nominal take-off or landing.

More specifically, 17 simulation scenarios were tested to assess the effect of the automatic execution of these operations on RPIL and ATCO in nominal and off-nominal conditions. ATOL operations were manually triggered by the RPIL in 11 scenarios, also allowing an evaluation of the effect of the C2 link latency, and they were autonomously initiated by the ATOL after failure detection in 6 scenarios. ATOL is considered (and required) to be fail-operational, meaning that a single failure does not prevent the ATOL system from operating.

### 4.2. R/T and C2 Link Latency focused Validation Exercises

The potential architecture solutions for C2 and R/T as presented in section 2.2. were used as input for the simulation scenarios and made a distinction between different values of signal latency for the three cases of RLOS, BRLOS and ground relay. The latter case implied that there was a dedicated ground communication line between RPS and ATC, and that the C2 link was accomplished via ground relay to a station in RLOS of the RPA.

The effect of R/T communication latency was evaluated at each simulation site by introducing a slight delay on the R/T communication channel of the validation platform. C2 link latency was simulated by adding a small amount of system input delay to the RPS simulation unit.

In some of the scenarios, a complete R/T failure was simulated, following an automatic contingency loitering procedure. A back-up communication method through an available phone line was made available to both ATCO and RPIL to initiate a backup call. After R/T has been restored, the communication method switched back to R/T communication.

#### 4.3. Contingency focused Validation Exercises

For the contingency focused validation exercises, the failure of C2 link in the approach phase has been selected as a severe incident requiring swift actions from ATCOs and RPILs. The failure has also been applied to up to three RPAS in the arrival phase, simulating a communication infrastructure breakdown and testing the workload limits of RPILs and ATCOs. The contingency scenarios have been complemented with a transponder failure on the downwind leg during the arrival phase, and a conflict situation with manned aircraft due to an unplanned turn of the RPA while in the trombone of the airport under investigation.

All scenarios have been modified with increased latency on the C2 link as sketched in section 2.2. Voice latency has been set to small latency values and was present at all times.

#### 4.4. Handover focused Validation Exercises

According to the INVIRCAT concept of operations, a handover between two RPSs can be beneficial in several cases, e.g. for minimizing latency (when switching from a remote RPS to a local RPS for the arrival and landing), or for shared workload. To investigate the defined handover procedures and requirements, a handover was simulated to be conducted after the departure of the RPAS between the penultimate and the final waypoint of a published SID.

Three different scenarios were investigated:

1. Handover during a dedicated loiter manoeuvre with active ATC involvement (sign-out/-in)
2. Handover on the last SID segment with active ATC involvement (sign-out/-in)
3. Handover on the last SID segment without ATC involvement (transparent to ATC)

During the simulation, the two RPILs (one per RPS) and the ATCO applied the proposed handover procedure including phraseology.

### 5. Validation Results

As described in section 3.1, INVIRCAT investigated the impact of 18 validation objectives on 5 different KPAs. Overall, the simulations produced positive results. 80% of the validation objectives were fully achieved, and 20% were partially achieved.

Further, the ATCO acceptance of the proposed concept was assessed once per ATCO after each exercise (consisting of multiple runs) using the Controller Acceptance Rating Scale (CARS) [6], with options from one (“too low”) to ten (“excellent”). The CARS evaluation result shows positive acceptance with an arithmetic mean of 8.2 (n = 10; min = 6; max = 10; median = 8.5).

The situational awareness of ATCOs and RPILs was measured once per ATCO/RPIL after each run using the China Lake Situational Awareness (CLSA) scale [6] with the same options as CARS. During most runs, the situational awareness was excellent/good and no particular issues were raised, yielding an arithmetic mean of 9.0 (n = 95; min = 6; max = 10; median = 9.0).

The assessment of perceived workload was performed once per ATCO/RPIL after each run using the Bedford Scale [6], with options ranging from ten (“unable to complete task”) to one (“workload low, insignificant”). The workload was maintained at satisfactory levels for the involved participants with an arithmetic mean of 2.6 (n = 95; min = 1; max = 6 (outlier); median = 3.0).

These results show that the proposed novel concept of operations is suitable for the integration of RPAS at TMAs and airports, with acceptable to excellent results regarding acceptance, situational awareness, and workload. A summary can be seen in standard box plots in 2.

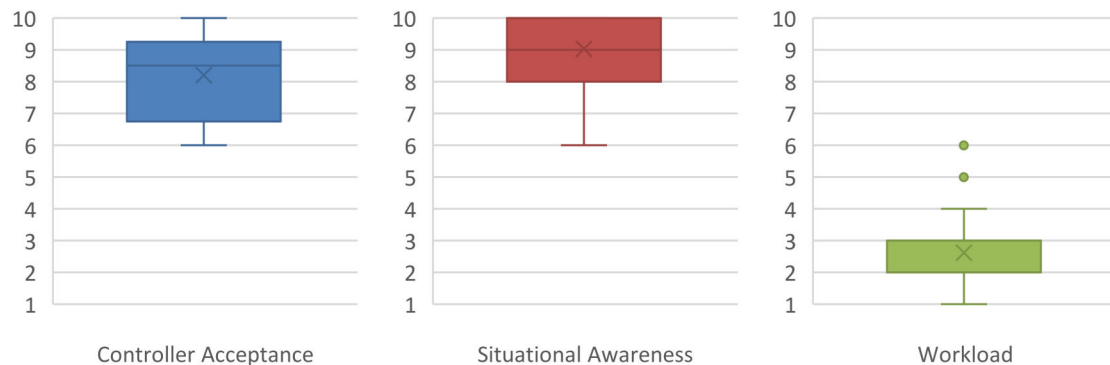


Figure 2: Results for Controller Acceptance, Situational Awareness and Workload

Furthermore, the results on the focus areas of the project as presented in section 3.1. have been further assessed through feedback and questionnaires. The main findings are presented in the following sections. It should be mentioned that the results on the focus areas may be combined results from the exercises described in section 4.

### 5.1. ATOL System Validation Results

The usage of an ATOL system was met with very positive feedback. The RPIL always felt comfortable during the execution of ATOL procedures and stated that it worked as expected. In general, also ATCOs felt safe managing traffic including RPAS that executed an ATOL procedure.

All involved actors agreed that the ATOL was a useful and reliable system. Moreover, during the debriefing sessions, the RPIL highlighted that the ATOL was a necessary system to safely perform critical operations such as the landing and take-off procedure. In their experience, even with a low C2 latency, the absence of a pilot-in-command might generate problems regarding the awareness and understanding of the surrounding environment. Overall, the presence of the ATOL system allowed to maintain an acceptable level of situational awareness of both ATCO and RPIL.

### 5.2. C2 link and R/T Communication Latency Validation Results

In general, the simulated C2 link and R/T latencies were hardly noticed by the actors [4][5]. Especially R/T latency was not considered to be an issue, given the fact that also in manned aviation responses are not always on time. It was mentioned, however, that a notable latency on the C2 link could be an issue in dense arrival scenarios at hub airports. However, during the validation exercises, no negative feedback was given. ATCOs and RPILs mentioned that it would be beneficial to have a latency indicator in their human-machine interface (HMI), if this value is known – especially if the value exceeds a certain tolerable threshold. As general conclusion regarding the latency, validation exercise participants noted that a BRLOS architecture should not be the first option in the TMA. This implies a preference towards RLOS, potentially by performing a handover to/from an RPS in vicinity of the airport.

### 5.3. Handover Validation Results

The handover scenarios did not result in an increase in controller workload. The phraseology for the communication between the controller and RPIL was sufficient. A general feedback was that the performance of a handover in the limited TMA airspace would result in more congested TMA airspace, especially if a handover loiter point would be introduced. In case no handover loiter waypoint is used during the handover and multiple handovers are taking place at the same time, an additional information in the aircraft label of the HMI that the RPIL is performing the handover procedure may be beneficial.

In case no notification is provided to ATC before the handover procedure is initiated, the Approach ATCO may be surprised by the delayed response from the RPIL. ATCO workload could be increased

in case multiple calls have to be made to the RPIL. Furthermore, if an R/T failure occurs during the handover procedure requiring the usage of the backup communication line, it may not be clear for the Approach ATCO which RPIL is in control.

#### 5.4. *Phraseology Validation Results*

The proposed phraseology was deemed suitable for the concept of operations under investigation. Only one singular negative feedback without a comment was collected in the assessment. However, it was mentioned by several exercise participants that additional standardised RPAS specific phraseology in contingencies should be developed. Further, it can be noted that, according to the participants, no special callsign (e.g., a preceding keyword “unmanned”) is required for the RPAS operations. The modifications of the HMI to highlight that the aircraft is an RPAS was deemed sufficient.

#### 5.5. *Contingencies Validation Results*

A C2 link failure represented the most critical contingency that can affect the RPAS. Indeed, in the ATOL focused validation exercises, the ATCOs stated that they only “sometimes” felt comfortable during this contingency as the RPIL would not receive any information regarding the status of the RPAS. In this situation, the ATCO was able to deliver instructions or clearances, but the RPIL cannot comply with them. The use of the backup communication method during an R/T failure received positive feedback from both ATCOs and RPIL. The use of the direct communication via the backup communication line resulted in the Approach ATCO managing the RPAS as if there was no R/T failure. The availability of the backup communication line between ATC and RPIL offers more possibilities and flexibility in operational solutions, although it is not as efficient as conventional R/T communication. Operational solutions vary depending on the situation, however, they do not necessarily require the use of a loiter waypoint in case of R/T failure. For R/T failures on arrival, ATCOs commented that there was an uncertainty when the failure will be resolved. In addition to the functional backup communication line and the additional effort to integrate the RPAS into the landing sequences once the failure had been resolved, the ATCOs preferred to proceed with normal operation with the use of the backup communication line rather than using the loiter waypoint. The RPIL also preferred to proceed with normal operation instead of operating towards the loiter area once an R/T failure occurred. Instead, the use of the backup communication line to receive instructions from ATC before deviating from the original flight plan was preferred. During one run of the contingency scenarios where the voice communication link was lost and the RPIL awaited the ATCO to initiate contact via a backup communication mean (i.e., conventional telephone line), the ATCO dialled the wrong telephone number. Thus, no contact was made with the RPIL and the ATCO was unaware regarding the RPAS status during the contingency until the RPIL contacted the ATCO. This situation resulted in a higher workload for the ATCO. ATCO and RPIL suggested to follow manned IFR, and recommended additional training on novel contingency procedures.

#### 5.6. *Additional Findings*

With regards to acceptability, further research and investigation on the HMI of the CWP was proposed, especially in contingencies when a backup communication line is used. The RPAS performances in the validation exercises have been selected to differ in comparison to conventional/manned IFR traffic. This resulted in slower traffic on SIDs and STARs, which was described as challenging by the ATCOs. However, the slower speeds were respected and the applied separation increased accordingly. The slower RPAS might have more impact at high capacity IFR airports. Special attention was given to the applicability of radar vectoring procedures for RPAS, especially in the Arrival flight phase. The ATCOs did not receive special instructions on how to handle the traffic, and the way of working differed across participants. It was noted, however, that the RPAS were not treated differently, including radar vectoring based operating principles. Thus, it can be stated that radar vectoring for RPAS is possible. Lastly, ATCOs stated that the introduction of IFR

RPAS into the TMA did not lead to different priority considerations (within applicable rules) among airspace users. IFR RPAS were treated in the same way as manned traffic, as apparent through observations and debriefing questions.

In essence, the current ATM system would permit the integration of IFR RPAS in the TMA and at airports using the proposed novel concept of operations.

## 6. Conclusions and Outlook

The proposed novel concept of operations for IFR RPAS in TMA and airport environments has been successfully validated according to the set validation objectives. In all simulations, the ATCOs stated that the RPAS was managed in the same manner as conventional/manned traffic. This fact did not represent an issue even in case where the approach speeds of RPAS traffic was slower than the manned traffic. Some parts of the concept were identified as requiring special attention, such as dedicated phraseology and training in contingency situations, or the usage of procedures from conventional/manned aviation wherever possible.

Valuable feedback was also collected regarding the simulation architecture and available modifications to the CWPs. Although these aspects have not been under investigation, some technical lessons were learned, such as missing or different tools for measuring distances and bearings, interactivity of aircraft/RPAS labels, or the display of radar tracks. Further, a stronger integration of the backup voice communication line in case of R/T failure has been suggested, and more visibility of squawk code changes in C2 link failure or R/T failure conditions was proposed. A display of latency values on the C2 and R/T link, when available, could be made visible to the ATCO and RPIL more prominently to aid in the decision making.

The collected feedback of the participants from the validation exercises and the gathered numerical data allowed for a detailed iteration of the concept of operations, building towards the final version of the documentation. In total, 94 elements of the initial concept of operations have been updated with additions, corrections and improvements.

Upcoming research activities could include the validation of a complete IFR RPAS flight with required interfaces between different simulation sites, the design and validation of a dedicated RPAS CWP based on the feedback collected, a more detailed handover process for additional use cases and including handover contingencies, and validation exercises at large hub-airports.

## 7. Acknowledgements

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