MALE RPAS INTEGRATION INTO EUROPEAN AIRSPACE

Part 2: Real-Time Simulation Analysis of Operations with Remain Well Clear

Emmanuel Sunil[†], *Erik Theunissen*[§], *Timothy Bleakley*[‡], *Erik-Jan Hartlieb*[†], *Paul Kuiper*[†], *Marieke Suijkerbuijk*[†], *Tim Dufourmont*[†] *and Timothy Grebe*[‡]

[†]*Royal Netherlands Aerospace Centre (NLR), Amsterdam, The Netherlands*
[§]*Information Systems Delft (ISD), Leiderdorp, The Netherlands*
[‡]*General Atomics Aeronautical Systems Inc. (GA-ASI), San Diego, United States of America*

Abstract

At present, Medium Altitude Long Endurance (MALE) Remotely Piloted Aircraft Systems (RPAS) are only permitted to fly in segregated airspace in Europe. Because such restrictions limit the efficiency of MALE RPAS operations, several European projects are working on the procedures needed to allow routine MALE RPAS flights in unsegregated European airspace. To contribute to these efforts, the Royal Netherlands Aerospace Center (NLR) has partnered with General Atomics Aeronautical Systems Inc. (GA-ASI) and Information System Delft (ISD) to gather the data needed to develop MALE RPAS airspace integration procedures through a series of Real-Time Simulation (RTS) experiments. This paper summarizes the results of the second RTS campaign performed in November 2020 under this collaboration, which focused on the procedures needed for the Remain Well Clear (RWC) component of Detect and Avoid (DAA). RWC systems provide RPAS pilots with cues that reduce the chance of a Collision Avoidance (CA) situation from occurring. In this work, the GA-ASI Conflict Prediction and Display System (CPDS), a DAA alerting, guidance and display system that meets the requirements set in RTCA DO-365B, was used. In addition to an active Royal Netherlands Airforce RPAS pilot, the RTS also involved a number of experienced Air Traffic Controllers (ATCOs) and airline pilots. The experiment considered several challenging RWC scenarios in both controlled and uncontrolled airspace classes, in both en-route and Terminal Maneuvering Area (TMA) settings. This included RWC encounters during the final approach phase to analyze the procedures needed for the new DAA Terminal Alerting (DTA) logic described in RTCA DO-365B. The results indicated that both ATCOs and RPAS pilots can become accustomed to operations with RWC/DAA with relatively little additional training. The results also suggest that RPAS pilots should avoid excessive RWC-related radio communications as this could have a negative effect on ATCO workload. To this end, RPAS pilots are recommended to integrate the information provided on the DAA display with information in radio communications to determine if the ATCO is already aware of, and is in the process of resolving a conflict, before reporting it. At the same time, the procedures should provide RPAS pilots with more flexibility than described in the current standards to resolve conflicts. In TMAs, this approach is likely to reduce the number of unnecessary go-arounds needed to resolve conflicts during final approach when DTA alerts are issued.

1 Introduction

In addition to supporting defense operations, Medium Altitude Long Endurance (MALE) Remotely Piloted Aircraft Systems (RPAS) have numerous civilian applications ranging from infrastructure inspection to search and rescue. However, the current regulatory environment in Europe inhibits such applications as they only permit MALE RPAS operations in segregated airspace, i.e., “airspace of specified dimensions allocated for exclusive use to a specific user” [1]. Furthermore, each MALE RPAS flight requires numerous permissions from national aviation authorities, and this process can be very time consuming. As a result of these restrictions, the frequency and the operational efficiency of MALE RPAS flights in Europe are presently limited.

Recognizing the need for a common European approach to address this challenge, several SESAR and EDA projects are currently working towards a comprehensive set of procedures, more formally known as a Concept of Operations (CONOPS), to enable MALE RPAS operations in unsegregated European airspace [2] [3] [4] [5] [6] [7]. Similar studies have also been performed in the United States [8] [9] [10]. In general, these studies focus on ensuring that the main difference between RPAS and conventional aircraft - the fact that the RPAS pilot is physically separated from his/her aircraft - does not adversely affect existing airspace users. Moreover for Europe, SESAR advocates for a phased approach to MALE RPAS integration, with an “accommodation” phase in the short-term (by 2025) with minimal changes to existing ATC systems, and a “full integration” phase in the longer-term (by 2030) that will require the introduction of new technologies such as Detect and Avoid (DAA).

To complement the aforementioned initiatives for integrating MALE RPAS into European airspace, the Royal Netherlands Aerospace Center (NLR) has partnered with General Atomics Aeronautical Systems Inc. (GA-ASI) and Information Systems Delft (ISD). The main objective of this collaboration is to gather the empirical data needed for developing a MALE RPAS airspace integration CONOPS through a series of Real-Time Simulation (RTS) experiments. The aim is to take into account both nominal and off-nominal scenarios, as well as operations in airspaces classes A-G, i.e., for operations in both controlled and uncontrolled airspace classes. It is expected that the results of these RTS experiments can be used as an additional source of data to aid policy makers, regulators and stakeholders, such as Air Traffic Controllers (ATCOs) and (RPAS) pilots, with their decision-making process in order to accelerate the integration of MALE RPAS into European airspace.

This paper presents the design and results of the second RTS campaign performed under this collaboration in November 2020. The main goal of this RTS was to consider the procedures needed to operate with the Remain Well Clear (RWC) component of Detect and Avoid (DAA) systems. RWC is the one of the two main functions of DAA. It aims to provide RPAS pilots with the alerts and guidance needed to maintain a safe distance from other traffic, and thereby decrease the need for Collision Avoidance (CA, the second function of DAA) maneuvers as much as possible. As such, RWC is often considered to be the unmanned equivalent of present day ‘see-and-avoid’ rule. But in contrast to see-and-avoid, for which the definition of ‘well clear’ is subjective, RWC systems make use of quantitative data from cooperative (e.g., ADS-B) and non-cooperative sensors (e.g., air-to-air radar), as well as a mathematically well-defined criteria for determining conflicts.

For the purposes of this study, the GA-ASI Conflict Prediction and Display System (CPDS) was integrated into NLR simulators, to provide RPAS pilots with RWC cues during the RTS. CPDS was designed to meet the latest RTCA standards for DAA equipment, namely RTCA DO-365B [11]. In addition to an active Royal Netherlands Airforce RPAS pilot, the RTS also involved a number of experienced Air Traffic Controllers (ATCOs) and airline pilots. The experiment considered several challenging RWC encounters in both controlled and uncontrolled airspace classes, in both en-route and Terminal Maneuvering Area (TMA) settings. This included RWC encounters during the final approach phase to analyze the procedures needed for the new DAA Terminal Alerting (DTA) logic described in RTCA DO-365B. As such, the participants were instructed to use the RWC procedures described in RTCA DO-365B in order to evaluate and recommend improvements to these procedures, particularly when considering operations in European airspace. The RTS also considered scenarios with Command and Control (C2) lost link and Radio Telephony (R/T) failure in order to validate the procedures developed for these contingencies during the first study in 2019 [12] .

This paper is structured as follows: Section 2 provides the reader with background information about RWC. The design of the experiment is described in Section 3. The results of the five most interesting experiment scenarios are presented and analyzed in Section 4. Section 5 summarizes the main conclusions of the present study, and describes topics that are planned for future research.

2 Background

2.1 Layers of Safety in ATM

In contemporary Air Traffic Management (ATM), there are four concentric layers of safety that aim to prevent mid-air collisions; see Figure 1. The outer-most safety layer aims to avoid conflicts on a strategic timescale, i.e., before take-off. Airspace design is an example of this layer. However, not all conflicts can be solved on a strategic timescale because uncertainties can cause variations between the planned and the actual routes flown by aircraft, e.g., diversions due to weather. The second layer of safety, known as separation provision service, aims to deal with such uncertainties. This service is primarily performed by ATCOs in controlled airspace and they are supported by radar, active surveillance and automation to provide this service.

Figure 1: Layers of safety in ATM

The third safety layer, known as self-separation, requires pilots to visually steer their aircraft away from neighboring traffic using a technique known as “see-and-avoid”. Although self-separation layer is applicable for all airspace classes, in practice it is primarily used in uncontrolled airspace classes. The fourth and final layer of safety focuses on last-resort Collision Avoidance (CA). The Traffic Alert and Collision and Avoidance System II (TCAS II) is an example of a CA system. This onboard system interrogates the transponders of aircraft in the airspace around an aircraft, to identify potential collisions, and provides pilots with traffic alerts, and in closer range, (coordinated) conflict resolution advisories to avoid mid-air collisions.

As a result of these four safety layers, mid-air collisions are, thankfully, extremely rare events in today's ATM system. To ensure that RPAS operate in unsegregated airspace with same level of safety as manned traffic, RPAS must also be able to comply with all four layers of safety. Although MALE RPAS may carry the same Communications, Navigation and airspace Surveillance (CNS) equipment as their manned counterparts, there is one critical difference: the pilot is not on-board. Consequently, the pilot cannot 'see and avoid' other aircraft by looking out of the flight deck. Instead, he/she needs a technological means to perform both the self-separation and CA tasks. The technological means to perform both these functions are often referred to as Detect and Avoid (DAA).

It should be noted that the self-separation layer of DAA is called Remain Well Clear (RWC). This paper focuses on the procedures needed for RWC.

2.2 RTCA Remain Well Clear Definition and Alerting

In May 2017 RTCA published DO-365, the Minimum Operational Performance Standards (MOPS) for UAS Detect and Avoid Systems [13]. Four months later the Federal Aviation Administration (FAA) published Technical Standard Order (TSO) C-211 for Detect and Avoid (DAA) Systems [14] referencing [13]. for the required minimum performance standards. An important milestone achieved with the DAA MOPS was the quantitative definition of DAA Well Clear (DWC), a temporal and spatial boundary around the aircraft intended to be an electronic means of avoiding conflicting traffic. The definition of a horizontal DWC boundary comprises both a spatial and a temporal threshold that are combined in the so-called modified tau equation. The spatial threshold in this equation is referred to by DMOD, which for the en-route phase is set to 4000 ft and for the DAA Terminal Area (DTA) to 1500 ft. Outside the DTA, the temporal component of the modified tau equation is equal to 35 seconds. For DTA traffic, tau is set to 0.

Both DAA alerting and guidance requirements are specified in relation to a prediction of losing DWC. In a non-maneuvering encounter, the pilot will be provided with a Corrective Alert approximately 75 seconds before a predicted loss of DWC would occur. If the time until a predicted loss of DWC decreases below approximately 25 seconds, the Warning Alert is declared.

To provide the pilot with guidance to avoid a loss of DWC, the directions in which a DAA alert is predicted to occur are indicated, color-coded yellow for a Corrective Alert and red for a Warning Alert.

2.3 RTCA Procedures for Remain Well Clear Alerts

In the Operational Services and Environment Description (OSED) of [13]. the pilot action after a Corrective Alert is described as follows: '*The pilot uses training, judgment, and display of traffic to assess the threat and the need to maneuver. If the PIC can't maneuver in response to ATC Traffic Advisory, the PIC will inform ATC*'.

In [13]. the associated pilot action is specified as: '*The DAA warning alert is intended to inform the PIC that immediate action is required to maintain DWC. The warning alert necessitates immediate awareness of the PIC and a prompt ownship maneuver*'.

2.4 Conflict Prediction and Display System (CPDS)

CPDS is a modular system comprised of separate components for data parsing and processing, alerting and guidance computations, and display. The components are integrated using industry-standard Data Distribution Service (DDS) Middleware. The first version of the GA-ASI Conflict Prediction and Display System (CPDS) was realized in June 2011 [13]. After the quantification of the DWC volume by SC-228 in 2014, this was used as the basis for the specification and configuration of the alerting and guidance function in CPDS.

CPDS complies with the requirements for DAA alerting and guidance data presentation specified in DO-365. Yellow heading bands on the DAA traffic display indicate the directions in which the loss of DWC is predicted to occur within the Corrective Alert time and red heading bands mark the directions in which a Warning Alert is predicted.

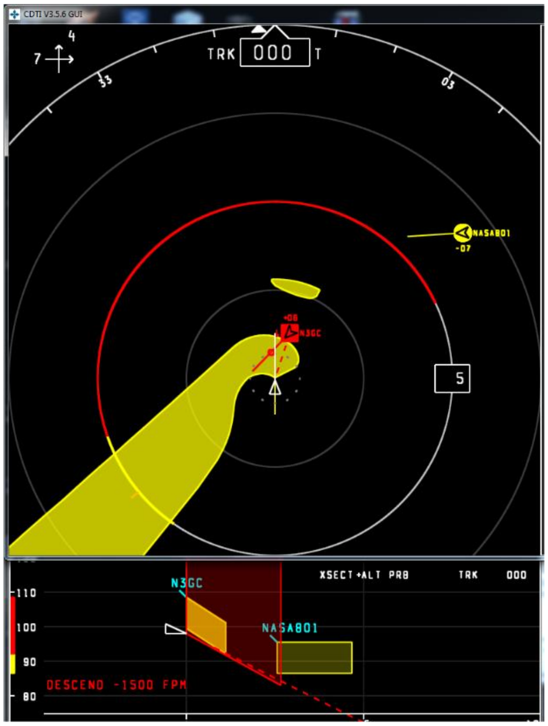


Figure 2. Example GA-ASI CPDS display during an RA

CPDS goes beyond the minimum requirements with the depiction of the conflict space on the Cockpit Display of Traffic Information (CDTI) and the addition of a vertical profile display that depicts the vertical cross-section of the conflict space.

3 Experiment Design

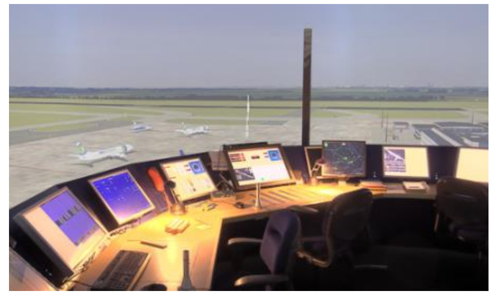
3.1 Apparatus

For this series of projects, NLR is using two of its simulators, namely the NLR ATM Research Simulator (NARSIM) and the Multi UAS Supervision Testbed (MUST). The combination of these two simulators is referred as the MALE RPAS Real-time simulation Facility (MRRF).

3.1.1 NLR ATM Research Simulator (NARSIM)

NARSIM was developed to evaluate new ATC procedures, automation tools and ATCO Human-Machine Interfaces (HMIs). To this end it simulates the most important aspects of a real ATC system, including realistic radar data and aircraft behavior. It also offers multiple ATCO and pseudo-pilot working positions. NARSIM development began in the late 1980s using commercial off-the-shelf hardware. But because its software is written entirely in-house at NLR, it can be easily adapted for a wide variety of ATC research studies and ATCO training courses.

a) The NARSIM Radar simulator



b) The NARSIM Tower simulator with Rotterdam airport scenery

Figure 3: The NLR ATC Research Simulator (NARSIM)

Two components of NARSIM were used in this study, namely NARSIM Radar for Approach (APP) and Area Control Center (ACC) simulation, and NARSIM Tower (TWR) for airport simulation; see Figure 3. During the simulations, the built-in Radio Telephony (R/T) system was used to emulate VHF voice communications between ATCOs, pseudo pilots and the RPAS pilot. The system was also used to emulate a fixed landline connection between the ATCOs and the RPAS pilot as a backup communication means during C2 Lost Link and R/T loss scenarios.

3.1.2 Multi UAS Supervision Testbed (MUST)

The Multi UAS Supervision Testbed, or MUST, was developed by NLR as a reconfigurable generic RPAS research simulation facility. MUST consists of two main components: the RPAS flight dynamics simulator and the RPAS Remote Pilot Station (RPS). The MUST RPS is shown in Figure 4. For the purposes of this study, the GA-ASI CPDS has been integrated into the MUST simulator to provide the RPAS pilot with RWC cues during the experiment.

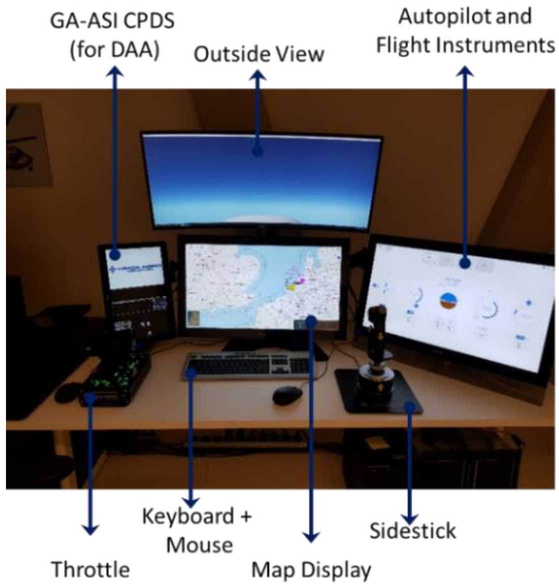


Figure 4: The NLR Multi UAS Supervision Testbed (MUST)

MUST has two control modes: Autopilot (AP) and Flight Management System (FMS) modes. In AP mode, RPAS heading, altitude, speed and vertical speed values can be adjusted and activated independently. Furthermore, AP mode allows pilots to initiate circular loiter patterns at the current position. In FMS mode, the RPAS autonomously flies waypoints along a predefined route. The pilot can select any waypoint in a route as the next active waypoint to fly directly to it. The pilot can provide control inputs via touchscreen / keyboard + mouse / Hands On Throttle and Stick (HOTAS).

In addition to the above control modes, MUST simulates the basic functionality of an Automatic Take-Off and Landing System (ATLS) whereby take-off and landing can be initiated by the RPAS pilot at the press of a button on the autopilot HMI. A range-and-bearing tool is available on the moving map display. This tool can be particularly useful for the pilot during contingency situations when it is necessary to deviate from the programmed route.

To enable RWC simulation, Automatic Dependent Surveillance-Broadcast (ADS-B) and air-to-air radar models were developed for MRRF. ADS-B data was used to track cooperative targets, and it was the primary source of data for DAA in this study. The ADS-B sensor had a maximum reception range of 100 NM and an update rate of 1 Hz. It was modelled as described in [12] and [14]. On the other hand, non-cooperative targets were tracked using the air-to-air radar. The radar was modelled according to the minimum specifications in [15] and had a max range of 6 NM, an azimuth of ±110°, an elevation of ±15° and an update rate of 1 Hz.

3.2 MALE RPAS and Related Assumptions

The GA-ASI MQ-9B SkyGuardian was used as the MALE RPAS platform in this study. A 3-D model of this aircraft was provided by GA-ASI and it was implemented in the MRRF; see Figure 5. Additionally, the kinematics model in the MUST simulator was adapted to match the performance of the SkyGuardian; see Table 1.

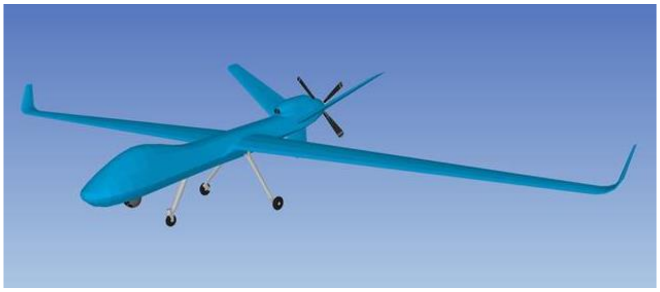


Figure 5: The General Atomics SkyGuardian RPAS

Table 1: Characteristics of the GA-ASI SkyGuardian

Characteristic	Value
Maximum Take-Off Weight	5,670 kg
Length	11.7 m
Wingspan	24 m
Ceiling	FL 400
Cruise speed	122 kts
Max speed	210 kts

Additionally, the simulation and the CONOPS were developed with the following MALE RPAS related assumptions:

- The RPAS has all the CNS equipment required for Instrument Flight Rules (IFR) flights.
- The RPAS has a single C2 link. The C2 link transmits pilot commands from the RPS to the RPAS, and transmits telemetry data from the RPAS to the RPS. The C2 link is also used for voice communications (R/T).
- The RPAS has an Automatic Take-Off and Landing System (ATLS). ATLS fully automates the take-off and landing phases of flight. The pilot can manually abort ATLS actions if required.
- The RPAS is flown with the pilot in the loop, except in the case of C2 lost link.
- The RPAS automatically changes its transponder code to 7400 after a predefined time interval during C2 lost link.
- The RPS has primary and secondary backup voice communication systems that can be used to contact

ATC. during C2 lost link and R/T voice communications failures.

- The RPAS is single engined.

3.3 Airport and Airspace

Rotterdam The Hague Airport (ICAO: EHRD) was used as the case-study airport in this study. EHRD is a busy single runway civilian airport with a mix of both IFR and VFR traffic. At EHRD, runway 24, with a length of 2,200 meters was used for all simulation runs; see Figure 6.

Figure 6: Layout of the Rotterdam airport [source: Google Maps]

To facilitate conflicts, the RPAS did not use standard Air Traffic Services (ATS) routes. Instead, a different route was designed for the RPAS for each scenario.

All background VFR and IFR traffic, i.e., non-RPAS traffic, used standard Air Traffic Services (ATS) routes as defined in the Netherlands Aviation Information Publication (AIP). To this end, all ATS routes within the following airspace regions were modelled for the experiment. Table 2 lists the airspace regions considered. Background traffic had different callsigns and routes in every scenario to avoid learning effects for the experiment participants.

Table 2: Airspace regions modelled in the RTS

Airspace Name	Airspace Type / Class	Altitudes
Rotterdam Control Traffic Region	CTR / Class C	GND – 3000 ft
Rotterdam Terminal Maneuvering Area 1	TMA / Class E	1500 ft – 5500 ft
Schiphol Terminal Maneuvering Area 1	TMA / Class A	1500 ft – 9500 ft
Amsterdam Sector South	En-route/ Class A	9500 ft – 19500 ft
Uncontrolled airspace outside Rotterdam CTR	Uncontrolled / Class G	GND – 1500 ft

3.4 Experiment Scenarios

A total of twelve scenarios were performed over a total of 3.5 days in November 2020. Of these, the first two runs considered nominal RPAS operations in TMA and en-route airspaces, respectively, without conflicts or contingencies and they were used as baseline scenarios for comparative purposes. The remaining ten scenarios considered conflict scenarios between the RPAS and background traffic. Additionally, three scenarios included RPAS contingencies after the conflicts were resolved. Each scenario had a total duration of one hour. A full overview of the experiment scenarios is available in Table 3.

Table 3: List of experiment scenarios

#	Scenario Name	Contingency	Total No. Movements
1	Baseline TMA	-	26
2	Baseline En-Route*	-	27
3	Crossing Encounter with Unknown VFR traffic	-	30
4	En-route Encounters I*	C2 Lost Link	40
5	En-route Encounters II	Transponder Failure	45
6	Blunder by RPAS on Approach	-	37
7	Overtaking on final by IFR Traffic	-	23
8	VFR Take-off without clearance	-	27
9	Blunder by VFR Traffic during final approach*	-	27
10	Blunder involving two VFR traffic on downwind*	-	28
11	Blunder by VFR Helicopter Crossing Runway*	R/T loss	29
12	Head-on encounter in TMA with unknown traffic*	-	30

It should be noted that the results section of this paper focuses on the five most interesting scenarios that led to the main conclusions of this study. These five scenarios are marked with an asterisk (*) in Table 3.

3.5 Experiment Participants

The main participants involved in the experiment are listed in Table 4. Note that the ACC ATCO only participated in the en-route scenarios of the experiment (see Table 3). It should be noted that the ATCOs and pseudo pilots received monetary compensation for their time.

Table 4: Main Experiment Participants

#	Role	Notes
1	MALE RPAS Pilot	Active RNLAF MQ9A pilot with 7 years of flight experience
2	TWR ATCO	Retired with 30+ years of experience
3	APP ATCO	Retired with 35+ years of experience
4	ACC ATCO	Retired with 35+ years of experience
5	Pseudo Pilot	Active 737 instructor, Ex F50 pilot
6	Pseudo Pilot	Active MD11F pilot
7	Pseudo Pilot	Active A320 pilot
8	Pseudo Pilot	Retired B777 pilot

3.6 Training

Prior to the experiment, all experiment participants were trained to use their respective part of the MRRF over a full day. The pseudo pilots and ATCOs that took part in the experiment were already familiar with NARSIM as they have all participated in previous NARSIM experiments. Nonetheless, the pseudo pilots and ATCOs were given a primer on the most important NARSIM functionalities, including the new features that were introduced for this experiment. Additionally, all experiment participants were briefed on DAA and specifically on RWC, as well as on their expected responses to different DAA alerts according to RTCA.

The training for the RPAS pilot consisted of two main parts: MUST familiarization and CPDS usage. A DAA expert who led the development of CPDS provided the RPAS pilot with a tutorial on how to use CPDS, including the appropriate responses for the different RWC alerts as specified in RTCA DO-365B; see section 2.3 for more details. This training was performed using a number of dedicated conflict scenarios that highlighted the features and correct utilization CPDS.

3.7 Experiment Procedure

The experiment was performed over three full days in November 2020. The participants were briefed prior to each scenario. This briefing consisted of two parts. In the first part, all participants were provided with the RPAS route and other basic details about the scenario. The second part of the pre-scenario briefing was provided only to the pilots. This included the exact details of the planned conflict between the RPAS and an intruder aircraft (call-signs, conflict times, intruder trajectories etc.). This part of the briefing also provided specific instructions to the pilots to increase the likelihood of conflicts, including the ‘blunders’ they were expected to make as part of each scenario. As such, the ATCOs did not have prior knowledge of the conflict(s) that would take place in each run, in order to obtain a more realistic response to each conflict.

Each scenario was followed by a debriefing session during which the experiment participants explained the timeline of events, and their decision-making process. These discussions led to specific recommendations towards improving the procedures for operations with RWC and for the contingency situations considered; see section 4.

3.8 Questionnaires

The ATCOs and the RPAS pilot were requested to fill in a questionnaire after each run. The questionnaires asked the participants to rate their perceived workload, Situational Awareness (SA), safety, and realism. The questionnaires differed between the RPAS pilot and the ATCOs. The results of the questionnaires for each scenario are presented in section 4.

3.9 Simulation Simplifications

3.9.1 RPAS Ground Simulation

The MUST simulator does not have a realistic RPAS taxi model. Therefore for TMA scenarios, the RPAS was spawned at the threshold of the active runway prior to take-off. Similarly, after landing, the RPAS vacated the runway by steering onto the grass next to the runway, and was then deleted from the simulation. Because of this simplification, this study does not consider RPAS ground operations.

3.9.2 Weather

All experiment runs were performed with ideal weather conditions, namely daylight lighting, unlimited visibility, calm winds (< 2kts and constant direction), and with a cloud ceiling of 3000 ft.

4 Results and Analysis

This section presents the results of the five most interesting scenarios of the RTS that lead to the main conclusions of this study. Note that the baseline scenarios, which considered nominal operations in en-route and TMA settings without conflicts, are not described below. Nonetheless, the questionnaire results of the baseline scenarios are used in the analysis that follows for comparative purposes.

4.1 En-Route Encounters I and C2 Lost Link

4.1.1 Summary of Events

During this run, the RPAS flew a zig-zag route in en-route airspace at FL115; see Figure 7.

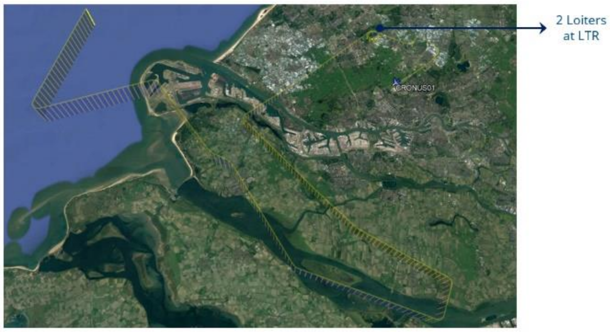


Figure 7: Route flown by the RPAS during the 'En-Route Encounters I + C2 Lost Link' run

The route and altitude profile of the RPAS for this run was designed in an effort to create conflicts with traffic on the Standard Arrival Routes (STARS) to Rotterdam and Schiphol airports. During the simulation, the ACC ATCO noticed several conflicts involving the RPAS and inbound aircraft. In *all* these cases, the ATCO issued radar vectors to the intruders (inbound traffic) to resolve these conflicts before the conflict escalated to an RWC alert on CPDS. In many cases, the RPAS pilot reported the intruders he saw on CPDS to the ATCO even though no alerts were issued. In one such encounter, the RPAS pilot steered his aircraft without clearance to resolve a future conflict with a descending aircraft before an RWC alert was issued on CPDS; see Figure 8. Note here the red range ring does not indicate an alert – only that an alert would occur in the future if the RPAS maintained its track, speed and altitude, and if traffic situation remained unchanged. Instead, RWC alerts are shown on CPDS by changing the shape and color of the intruder aircraft's symbol, and warning alerts the intruder's symbol turns red. The ACC ATCO indicated during the post experiment briefing that he was already aware of this intruder but did not consider it to be a problem, so the maneuver by the RPAS pilot was found to be surprising and unnecessary. This was indeed the case as the concerned intruder passed behind the RPAS with sufficient vertical margin and as such this encounter did not meet the criteria of a warning alert. The RPAS pilot commented during the debriefing that his pre-emptive action was aimed at preventing an anticipated dangerous situation from occurring in the future. It is assumed that RWC aural alerts, which were not turned ON during this experiment, will provide pilots with more clarity on when and when not to maneuver in response to alerts. This will be analyzed in future experiments.

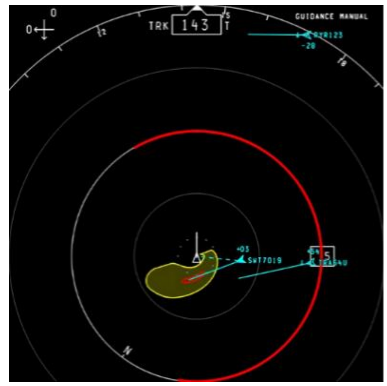
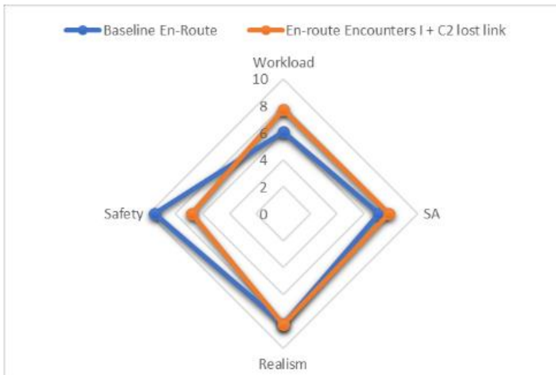


Figure 8: CPDS screenshot of the encounter with SWT7019

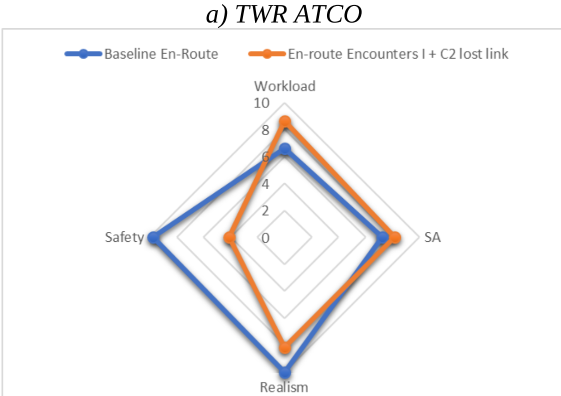
In the second part of this scenario, the RPAS descended to the Rotterdam TMA with intentions to land. However, during the approach, the RPAS experienced C2 lost link. Because C2 was not restored after a pre-determined time, the RPAS automatically changed its squawk code to 7400 and flew to its predefined C2 lost link loiter waypoint, LTR, which is located north of Rotterdam airport; see Figure 7. Because the APP and TWR ATCOs did not know the vertical profile of the RPAS during its flight to LTR, they delayed several outbounds out of concern that the RPAS could interfere with the Standard Instrument Departure (SID) routes of RWY24 at Rotterdam. During this time, the RPAS pilot and the TMA ATCO communicated with each other using the backup fixed line telephone since R/T is also unavailable during C2 lost link. This helped the ATCO to understand the intentions of the RPAS. This interaction was performed in Dutch as both parties treated the interaction as a regular phone call. After two orbits at LTR, C2 was restored as per the scenario scripting. The RPAS was cleared to land.

4.1.2 Questionnaire Results

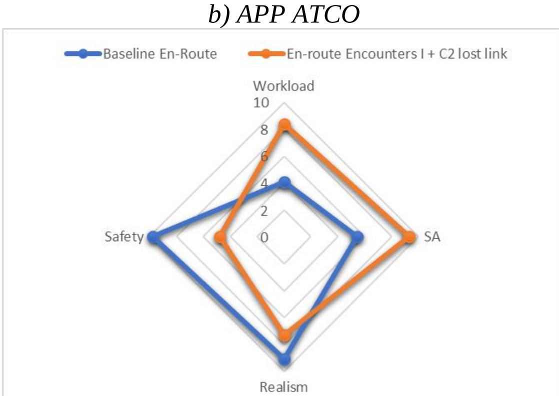
The questionnaire results for the experiment participants are given in Figure 9. Here, the blue line indicates the results from the baseline run for reference, while the orange lines are the results for this run. As expected, all participants experienced a higher workload and lower perceived safety than the baseline case as a result of the conflicts and the C2 lost link contingency that occurred in this scenario. Curiously, the ACC ATCO indicated he had a higher situational awareness during this run. He indicated during the debriefing that this was because this scenario required greater focus than the baseline simulation because of the numerous conflicts that needed to be resolved.



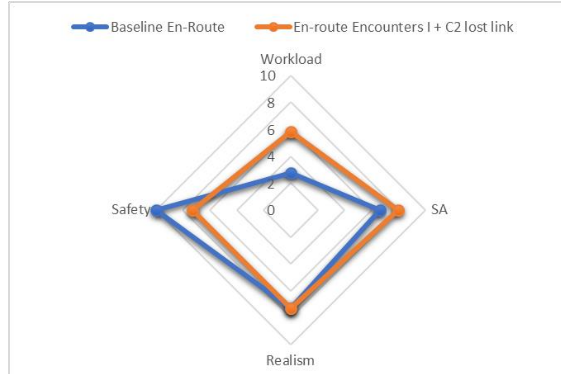
a) TWR ATCO



b) APP ATCO



c) ACC ATCO



d) RPAS Pilot

Figure 9: Questionnaire results for the 'En-Route Encounters I + C2 Lost Link' run

4.1.3 Analysis

The following learning points were obtained from this run:

- The RPAS pilot should not maneuver his/her aircraft without clearance, especially for an intruder in airspace class A-C that has not yet caused a DAA alert. Such maneuvers are detrimental to ATCO SA, and could, therefore, lead to less trust in the DAA system/procedures.
- RPAS pilots are recommended to integrate the information provided on the DAA display with information in radio communications to determine if the ATCO is already aware of, and is in the process of resolving a conflict, before reporting it. This approach may reduce the amount of DAA related R/T between the RPAS pilot and ATC, and could therefore be beneficial for ATCO workload.
- In addition to pre-defining the horizontal route towards contingency loiter waypoints in the RPAS flight plan, it is also necessary to pre-define the vertical profile towards such waypoints in order to increase the predictability for ATCOs during contingency situations such as C2 lost link. Such waypoints should be predefined for all phases of flight, and should be geographically separated from prevailing traffic flows to avoid conflicts during loitering.
- During R/T failure the backup fixed line telephone connection should be used to re-establish communications with ATC. Standard

R/T phraseology in the English language should be used on the backup telephone.

4.2 *Blunder by VFR Traffic During Final Approach*

4.2.1 Summary of Events

In this scenario, a conflict occurred between a VFR helicopter and the RPAS as the RPAS is on final approach. As the helicopter, callsign HELI, approached the field from the west, TWR instructed the helicopter to land behind the RPAS. However, the helicopter misunderstood TWR instructions and turned to base directly in front of the RPAS on final. Because the conflict occurred during final, a DTA warning alert was triggered on CPDS. On noticing the alert, the RPAS pilot immediately executed and declared a missed approach as per the procedure defined prior to the experiment for DTA warning alerts. The flown route of the RPAS for this scenario is displayed in Figure 10. Note that the simulation was stopped after the initiation of the missed approach. The CPDS screenshot of the conflict is shown in Figure 11.

Figure 10: Route flown by the RPAS during the 'Blunder by VFR traffic during final approach' run

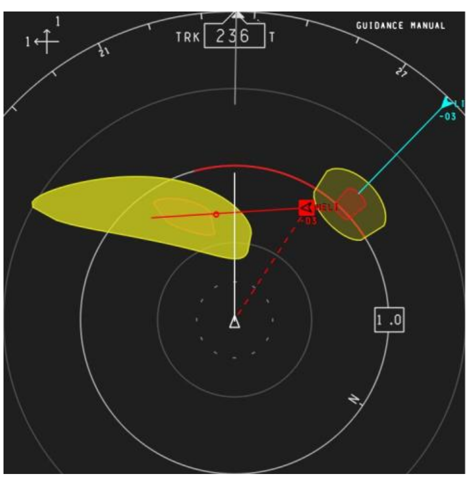
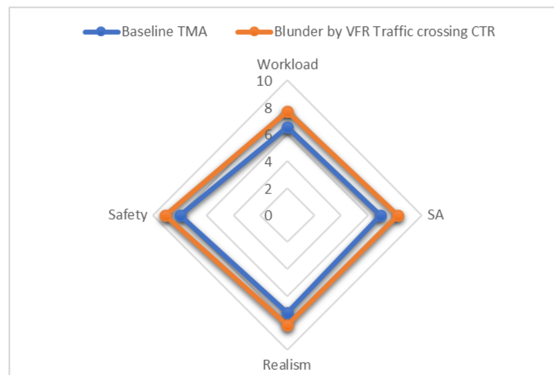


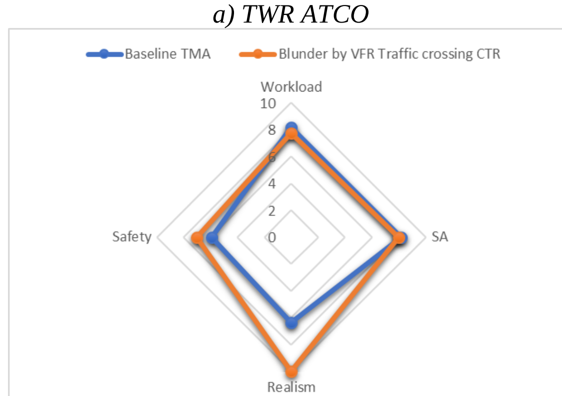
Figure 11: CPDS screenshot of the DTA warning alert conflict with HELI during RPAS final approach

4.2.2 Questionnaire Results

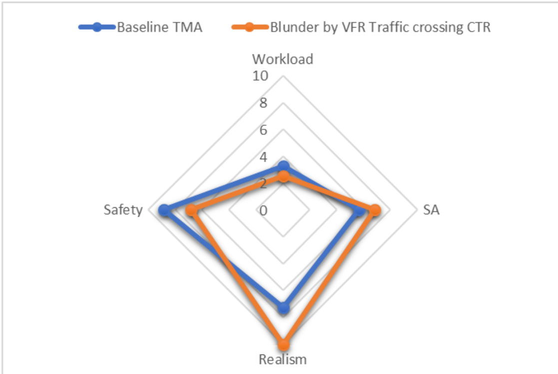
The questionnaire results for this run are shown in Figure 12. Here it can be seen that the TWR ATCO rated all metrics slightly higher than the baseline run. As a result of the conflict resolution action taken by the RPAS pilot, TWR did not consider the safety of operations to be negatively affected. The APP ATCO rated both workload and SA at comparable levels to the baseline scenario, while rating safety and realism to be better than the baseline. APP explained that the ease with which the RPAS fit into a natural opening in the approach sequence increased safety as he did not have to issue commands to the aircraft next in the sequence to ensure sufficient spacing. Although the conflict had a negative effect on the perceived safety level, the RPAS pilot considered the progression of the conflict in this scenario to be highly realistic to what he had personally experienced in real operations.



a) TWR ATCO



b) APP ATCO



d) RPAS Pilot

Figure 12: Questionnaire results for the 'Blunder by VFR traffic during final approach' run

4.2.3 Analysis

The conflict considered in this scenario occurred because the intruder blundered by turning to base too early - a classic blunder in DAA literature that is often used to explain the benefits of DAA. The RPAS pilot resolved the conflict by initiating a missed approach as required by the procedure described in RTCA DO-365B [15]. Because the intruder was in front and below the ownship, and because no other aircraft obstructed the RPAS, the go around led to a swift resolution of the conflict without negatively affecting safety. Therefore, it can be concluded that the go-around was the correct resolution for the conflict geometry that occurred during this run.

4.3 Blunder Involving Two VFR Traffic on Downwind

4.3.1 Summary of Events

In this run, two VFR aircraft trailed the RPAS. All three aircraft were on the same approach to the runway. When the RPAS turned to final, both VFRs blundered and turned base without clearance. This caused the RPAS to become 'sandwiched' between the two VFRs causing a DTA warning alert conflict with the VFR traffic in front of the RPAS. The RPAS pilot reacted by initiating a missed approach as recommended by DO-365 procedures. However, because the intruder was in front and above the RPAS, the conflict actually became more serious during the climb out - the time to Closest Point of Approach (CPA) decreased from 33 seconds to 12 seconds during the climb out. Because of the busy traffic situation, the APP controller instructed the RPAS to loiter at its TMA contingency loiter waypoint before an opening in the sequence made it possible for the RPAS to land. The route flown by the RPAS can be seen in Figure 13. The CPDS screenshot of the conflict is displayed in Figure 14.

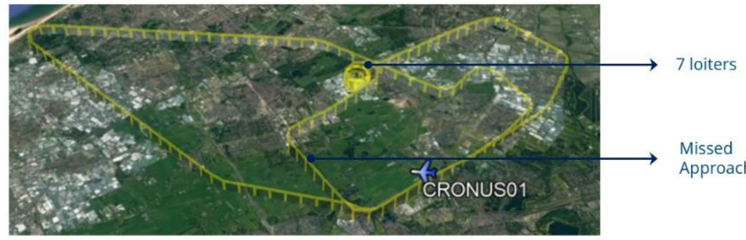


Figure 13: Route flown by the RPAS during the 'Blunder involving two VFR traffic on downwind' run

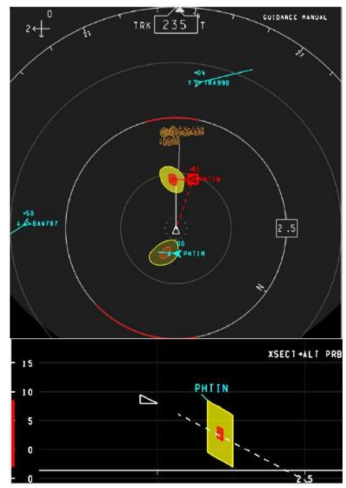
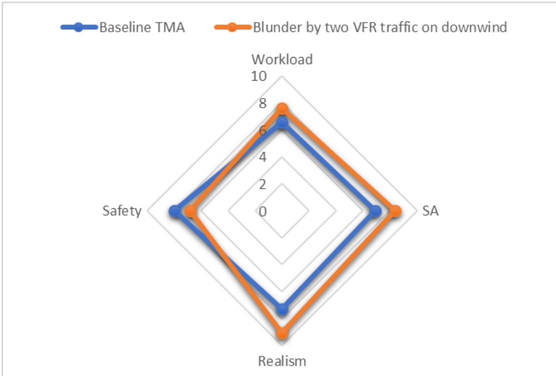


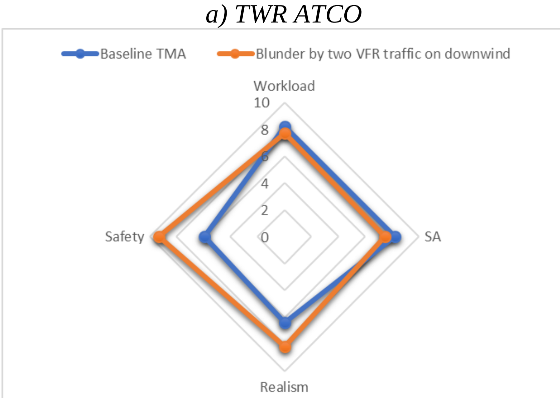
Figure 14:CPDS screenshot of the DTA warning alert conflict with PH-TIN during RPAS final approach

4.3.2 Questionnaire Results

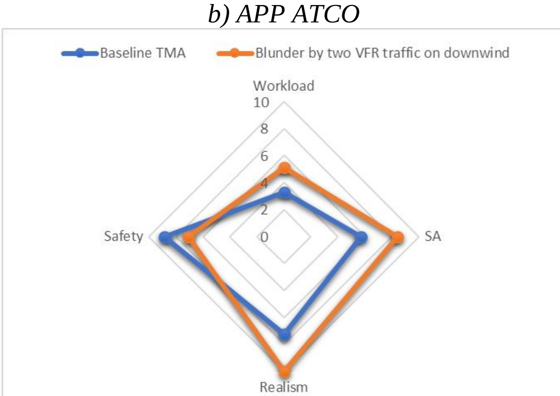
The questionnaire results for this run are shown in Figure 15. Because several go-arounds occurred during this run (in addition to the one used to resolve the conflict experienced by the RPAS), and because this increased the level of coordination required between TWR and APP, TWR rated this run with a higher level of workload than the baseline condition. However, despite the increased number of missed approaches, APP perceived safety to be substantially higher during this run than for the baseline condition. As expected, the conflict between the RPAS and the VFR traffic during final decreased the perceived safety, and increased the workload felt by the RPAS pilot.



a) TWR ATCO



b) APP ATCO



d) RPAS Pilot

Figure 15: Questionnaire results for the 'Blunder involving two VFR traffic on downwind' run

4.3.3 Analysis

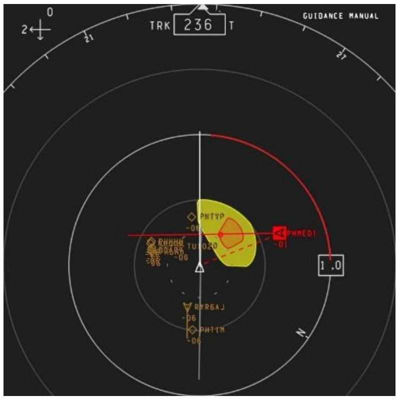
As for the previous scenario, the RPAS pilot followed the guidance in DO365B and executed a missed approach. However, during the debriefing of this run, the RPAS pilot suggested that a horizontal maneuver would have been a better resolution option in this scenario. This was because the RPAS was sandwiched between two intruders on base that were initially above the RPAS when the warning alert was declared. Therefore, in addition to initiating a missed approach, it was also necessary for the pilot to select a high vertical speed that resolved the conflict and waiting for the RPAS to achieve the desired vertical speed delayed the resolution of this conflict. The data shown on CPDS confirms this - the time to CPA decreased from 33 seconds when the warning was declared to 12 seconds when the RPAS had achieved sufficient vertical speed to clear the traffic. The pilot indicated, given the geometry of this conflict, a right turn would have resolved the conflict faster and therefore would have been a safer maneuver than the missed approach. This scenario suggests that missed approaches are not suitable for all conflict geometries on final, especially for cases when the intruder is in front and above the ownship.

4.4 Blunder by VFR Helicopter Crossing Runway and R/T Failure

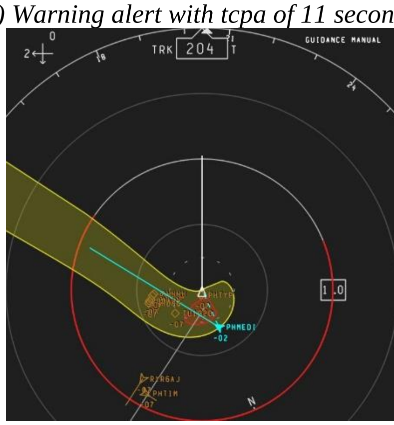
4.4.1 Summary of Events

During this scenario, the RPAS experienced a conflict with a medivac helicopter during its initial climb out from Rotterdam runway 24. The helicopter was en route to Erasmus Medical Center, and was instructed by the TWR ATCO to cross the field at the final end of runway 24, i.e., the landing side of the runway, to prevent a conflict with the departing RPAS. However, the helicopter pilot misunderstood TWR instructions and crosses the field directly in front of the RPAS, as the RPAS was climbing through 600ft. Because of the sudden nature of the blunder made by the helicopter pilot, the conflict had an initial TCPA of only 11 seconds thereby triggering an immediate warning alert on CPDS. The RPAS pilot steered his aircraft 32 degrees to the left to resolve the conflict based on the CPDS heading guidance bands to resolve the conflict. Nonetheless, due to the last second blunder made by the helicopter the RPAS momentarily lost well clear during the resolution. After the conflict was resolved, the RPAS pilot notified TWR on the resolution and requested clearance to resume the planned route of the RPAS.

The CPDS screenshot of the initial conflict and its resolution are displayed in Figure 16.



a) Warning alert with tcpa of 11 seconds



b) Resolution 15 degrees to the left. Momentary loss of well clear.

Figure 16: CPDS screenshots of the conflict with PH-MEDI, a medivac helicopter en route to Erasmus Medical Center

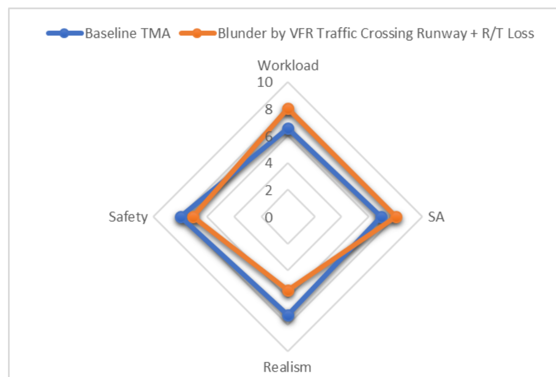
Once the RPAS was in approach airspace it experienced a R/T failure. Because attempts to cycle the radios were not successful, the RPAS pilot changed the squawk code to 7600 and called the APP ATCO using the backup telephone. In contrast to the en-route scenario described previously in section 4.1, this time both the controller and the pilot used English and regular R/T phraseology on the backup telephone. APP provided the RPAS pilot with vectors to intercept the RP24B approach to runway 24 at Rotterdam. Because of the busy traffic situation, APP requested the RPAS to hang up and call again when he neared the IAF of RP24B. The RPAS pilot provided APP with his phone number before hanging up. At the IAF, the RPAS pilot called APP again using the backup telephone. APP provided the RPAS clearance to start the RP24B approach. During final, CPDS issued a DTA warning alert with a VFR aircraft that had crossed the field and was instructed by TWR to loiter east of the field. Although the procedure for a DTA warning alert is to perform a missed approach as per DO-365B [11], the RPAS pilot decided that it would be easier to resolve by steering 5 degrees to the left. This resolved the conflict and the pilot decided to continue the landing.

The route flown by the RPAS during this run is shown in Figure 17.

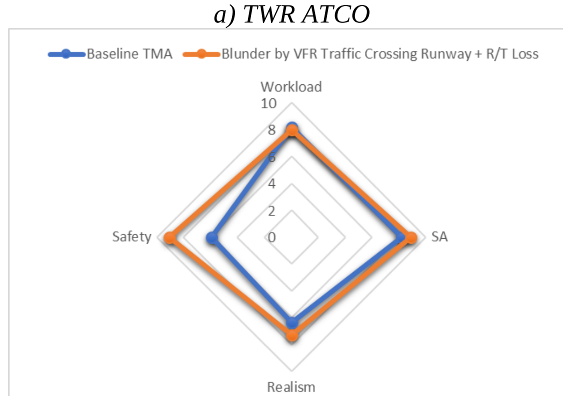
Figure 17: Route flown by the RPAS during the 'Blunder by VFR Helicopter crossing runway and R/T failure' run

4.4.2 Questionnaire Results

The questionnaire results for this run are displayed in Figure 4.40.



a) TWR ATCO



b) APP ATCO

d) RPAS Pilot

Figure 18: Questionnaire results for the 'Blunder by VFR Helicopter crossing runway and R/T failure' run

Here, APP rated workload and SA similarly to the baseline condition. This suggests that the procedure for using the backup telephone during R/T failure does not have a negative impact on operations. Despite initially not noticing the RPAS-helicopter conflict, TWR considered his SA to be better than the baseline scenario. One potential explanation for this strange result is that TWR became more and more used to expecting the unexpected as every experiment scenario had either an RPAS related contingency or conflict(s). During scenario debriefing, the TWR ATCO was highly appreciative that the RWC alert provided to the RPAS pilot that made it possible for the pilot to resolve a conflict that he noticed very late. As for most previous conflicts, the RPAS pilot rated his workload to be higher, and his perceived safety level to be lower, relative to the baseline situation. In spite of this, the RPAS pilot stated during the debriefing that CPDS provided him with the information he needed to quickly resolve the conflict with the helicopter by steering left - this explains the higher pilot SA rating than for the baseline TMA simulation.

4.4.3 Analysis

A very serious last-second conflict occurred between the RPAS and the medivac helicopter at the start of this run. Nonetheless, the RPAS pilot was able to make a quick conflict resolution decision based on the information provided in CPDS. As this conflict occurred with an initial time to CPA of just 11 seconds, it is understandable that the RPAS lost DWC during the resolution of this conflict even though the RPAS pilot steered an incredible 32° to the left. But, because TWR did not notice this conflict, the alerts and guidance provided by CPDS, as well as the immediate action taken by the pilot, were crucial to preventing a potential mid-air collision.

In contrast to DO-365B procedures, the RPAS pilot decided not to use a missed approach for the DTA warning alert caused by a loitering aircraft on final. Instead, the pilot resolved this conflict using a minor horizontal maneuver, and then successfully landed the RPAS. During the debriefing, the pilot stated that the red heading band for this intruder only overlapped with ownship track by two degrees, and therefore it was far easier and safer to resolve by steering the RPAS 5° to the left than executing a missed approach. The TWR controller agreed with the RPAS pilot and added that a missed approach should only be used when there is a serious safety risk as it has a large effect on ATCO workload. This scenario, therefore, provides additional evidence that it is not necessary to resolve all warning alerts on final with missed approaches. In fact, in some cases, a missed approach can reduce safety (as was the case in the previous scenario; see section 4.3). It should be noted that CPDS only issues red heading bands for the range of headings that lead to a warning alert. Although this is in contrast to the requirements in DO-365B which state that all headings should be blocked for DTA warning alerts (to indicate that no horizontal maneuver may be used), this design choice made it possible for the RPAS pilot avoid an unnecessary missed approach using CPDS.

Several lessons can be learnt from the R/T failure scenario that occurred in this run. Because of the traffic situation, the APP ATCO disconnected the call. However, given that the R/T equipment has already failed, it would be better to not disconnect the back-up telephone connection as well (in case it is difficult to reestablish communications later). In the rare cases where it would be operationally necessary to disconnect the back-up telephone connection, it is highly recommended to agree on a lost communications procedure before disconnecting. Furthermore, it recommended that the RPAS pilot should always initiate the voice communications via the backup telephone since he/she is more likely to notice the R/T failure before the ATCO, even this means that pilot will have to first speak to an ATC supervisor before being connected to the specific ATCO in question. Finally, the RPAS pilot is encouraged to directly contact APP if R/T failure occurs during take-off, and contact the next ATC center/sector in the path of the RPAS if R/T failure occurs during the hand-off from one center to the next.

4.5 Head-on Conflict with Non-Cooperative Traffic in Uncontrolled Airspace

4.5.1 Summary of Events

In this scenario, the RPAS track was head-on with a non-cooperative aircraft in class G airspace at the same altitude. Because the intruder was non-cooperative, it was detected by the onboard air-to-air radar. When distance between the two aircraft was less than 5.5 NM, a corrective RWC alert was issued on CPDS. Because the conflict occurred in uncontrolled airspace the RPAS pilot had to resolve the conflict without ATC assistance. The RPAS pilot observed the development of the conflict for about 30 seconds and then steered right to resolve. At that point, the conflict escalated to a warning alert. Therefore, the pilot increased to the turn rate to increase the speed of resolution, leading to a 32^{o} heading change. Because the intruder changed its track towards east, it fell outside the radar's field of view. When the RPAS pilot returned to his route towards the airport, the intruder re-appeared into the radar's FOV. In an attempt to keep the intruder in the radar's FOV, the RPAS flew a zig-zag pattern behind the intruder. Once the RPAS entered controlled airspace, the intruder flew away from the RPAS track. The RPAS landed without further incident. Due to the amount of traffic in this run, APP had to put several aircraft into holding. This was unrelated to the RPAS conflict. The route flown by the RPAS in this run, including the zig-zag track, can be seen in Figure 19. The CPDS screenshot of the conflict between the RPAS and the non-cooperative intruder can be seen in Figure 20.

Figure 19: Route flown by the RPAS for the 'Head-on conflict with non-cooperative traffic in uncontrolled airspace' run

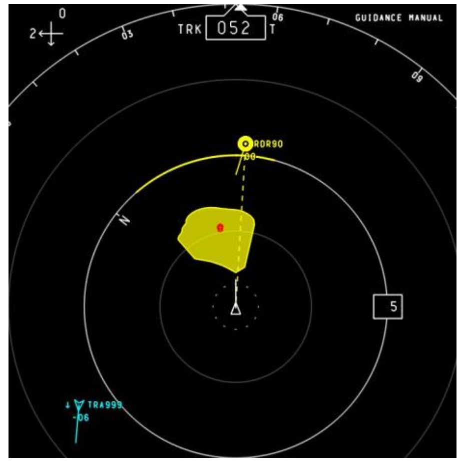
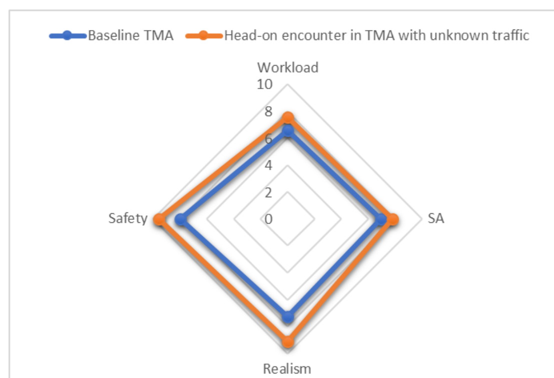


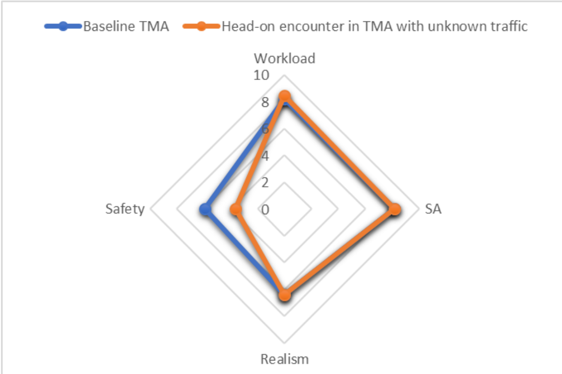
Figure 20: CPDS screenshot of the conflict with a non-cooperative intruder in class G uncontrolled airspace

4.5.2 Questionnaire Results

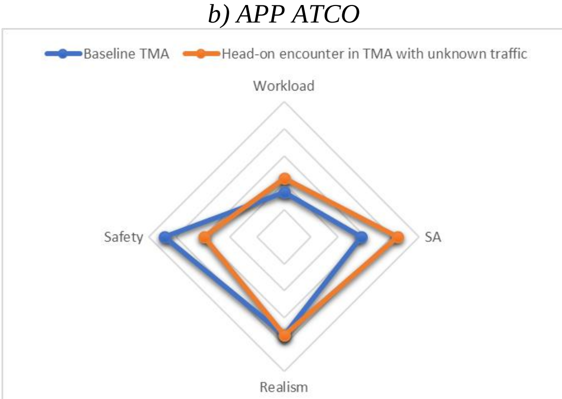
The questionnaire results for this scenario are shown in Figure 21. Here it can be seen that the TWR ATCO rated all metrics slightly higher in this scenario than for the baseline run. Although APP rated workload, SA and realism to be the same as for the baseline run, he rated safety to be lower in this run. This could be because many inbound aircraft had to be put into holdings in this scenario. As for most previous conflict scenarios, the RPAS pilot considered his workload and SA to be higher, while scoring safety lower than the baseline simulation.



a) TWR ATCO



b) APP ATCO



d) RPAS Pilot

Figure 21: Questionnaire results for the 'Head-on conflict with non-cooperative traffic in uncontrolled airspace' run

4.5.3 Analysis

There are two main learning points from this run:

- It is wise for pilots to observe conflicts for a few moments before initiating a resolution. This will make it possible to judge if an alert is a nuisance alert, especially after integrating the information in the R/T with the information on the DAA display. However, once an alert has been judged to be a legitimate conflict, immediate action should be taken to prevent the conflict situation from getting worse.
- Extra vigilance is required for radar-only intruders that cause conflicts because alerts are only provided for such intruders if they remain within the air-to-air radar's field of view.

5 Conclusions and Future Work

This paper is part of an ongoing, multi-year study that aims to support the development of the procedures needed for integrating Medium Altitude Long Endurance (MALE) Remotely Piloted Aircraft Systems (RPAS) into European airspace using Real-Time Simulation (RTS) experiments. The present paper focused on analyzing the procedures needed for the Remain Well Clear (RWC) component of Detect and Avoid (DAA). To this end, NLR performed a Real-Time Simulation (RTS) experiment involving experienced Air Traffic Controllers (ATCOs), RPAS pilot, and airline pilots. The experiment considered conflict scenarios in controlled and uncontrolled airspace classes, in both en-route and Terminal Maneuvering Area (TMA) settings. The experiment made use of the GA-ASI Conflict Prediction and Display System (CPDS), a RWC Human-Machine Interface (HMI) that is compliant with the latest RTCA technical standards for Detect and Avoid (DAA) systems, namely RTCA DO-365B.

The results of the RTS led to following RPAS integration procedures and human-factors related conclusions that were not identified in prior fast-time simulations:

- CPDS increased the Situational Awareness (SA) of the RPAS pilot during nominal operations and during conflicts. This was reflected in the questionnaire results of the RPAS pilot.
- In many cases, ATCOs detected and resolved conflicts at the same time as when an alert was declared on CPDS. This suggests that the alert timings used in CPDS match the internal conflict definitions used by ATCOs.
- Excessive conflict reports by pilots can have a negative effect on ATCO workload. To this end, RPAS pilots are recommended to integrate the information on the DAA display with communication exchanges on R/T to determine if ATC is already aware of, and is in the process of resolving, a conflict before reporting it to ATC. Furthermore, observing intruders causing alerts for a few moments can be used to filter out nuisance alerts that do not require further action (e.g. momentary alerts caused by maneuvering traffic). These aspects should be included in the training given to RPAS pilots to make operations with DAA fit within existing ATC norms as much as possible.

- In order to reduce the effect of DAA on ATCO workload pilots should:
    - Only report conflicts that have triggered corrective or warning alerts. Reports for preventive RWC alerts are not necessary. This complements the previous conclusion to reduce ATCO workload.
    - Only maneuver to resolve a corrective alert after ATC clearance as indicated in RTCA DO-365B.
- Pilots should be aware that non-cooperative intruders can disappear from the DAA HMI if the intruder flies outside the air-to-air radar's Field Of View (FOV). It is recommended to depict the radar's FOV as a toggleable feature on the DAA display for non-cooperative intruders.
- There was general consensus among the experiment participants that missed-approaches are not always the best resolution option for warning alerts on final approach as currently required by the new DAA Terminal maneuvering area Alert (DTA) function specified in RTCA DO-365B for three main reasons:
    - Firstly, missed approaches are not always the safest resolution option for all conflict geometries on final approach. This was found to be the case in experiment scenarios where the intruder was above the RPAS or was overtaking the RPAS, as a simultaneous missed approach by the intruder could potentially aggravate the conflict severity in such cases.
    - Secondly, some warning alerts on final can be resolved using minor horizontal resolutions after which the RPAS can safely continue its landing. This was demonstrated in some experiment scenarios.
    - Finally, the ATCOs considered warning alerts caused by VFR aircraft loitering near the runway to be nuisance alerts because such encounters would not cause a manned IFR aircraft on final to declare a missed approach. Preventing such differences between manned aircraft and RPAS, especially those that do not have a safety benefit, would be beneficial to improve efficiency and stakeholder acceptance of RPAS operations, and thus accelerate the integration of RPAS into the airspace.
- In addition to pre-defining the horizontal route towards contingency loiter waypoints in the RPAS flight plan, it is also necessary to pre-define the vertical profile towards such waypoints in order to increase the predictability for ATCOs during contingency situations such as C2 lost link. Such waypoints should be predefined for all phases of flight, and should be geographically separated from prevailing traffic flows to avoid conflicts during loitering.
- When communications are performed using the back-up telephone, both ATCOs and RPAS pilots should continue to use English and standard R/T phraseology – it should not be treated as a regular telephone call. Furthermore, a lost comms procedure should be agreed upon before disconnecting the telephone if it is necessary to disconnect the telephone for operational purposes. Because the RPAS pilot is more likely to notice the failure of R/T he/she should establish comms using the backup telephone. Contact should be made to the last ATC center the RPAS was in contact with except during take-off and during hand over from one sector to the next. In these cases, the pilot should contact APP and the next ATC center in the flight plan, respectively.

The next RTS planned in this series of projects will consider both the RWC and the Collision Avoidance (CA) safety layers of DAA systems. This will include scenarios to investigate how DAA can be used for increasing safety during aerial work missions, as well as scenarios that will trigger auto-CA during

C2 lost link situations. Additionally, the next experiment will consider the use of DAA equipment for facilitating CDTI Assisted Visual Separation (CAVS) to increase runway throughput for RPAS operations. Future studies will also quantify the impact of the differences between RTCA and EUROCAE standards for DAA on operations in European airspace. The results of these future studies will be made available to the ATM community and policy makers in an effort to accelerate the full integration MALE RPAS into unsegregated European airspace.

Acknowledgements

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