DERIVING SUPPORT FUNCTIONS FOR RADAR APPROACH CONTROLLERS CONFRONTED WITH MIXED MANNED AND UNMANNED AIR TRAFFIC

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Abstract

The introduction of remotely piloted aircraft is expected to revolutionize commercial air transport. This new technology promises an increase in efficiency and flexibility as well as cost benefits for aircraft operators. One use case which is likely to come up in the next years is unmanned air transport with remotely piloted wide-body freighter aircraft in analogy to present flights of cargo airlines, operating from large hub airports. For safety reasons, remotely piloted aircraft systems (RPAS) of this size will need to comply with the existing air traffic management standards and procedures when conducting such flights, including their arrival phase. A number of different concepts addressing the challenges that come along with the integration of RPAS into the air traffic have already been investigated in the past. However, it has not yet been decided by national, European or international authorities and organizations which concept will be applied in which case. Most of these concepts are very specific to the airspace environment, the RPAS category and the purpose of the flight. As a consequence, no detailed commonly applicable standards are currently available. In the frame of the DLR internal project "Unmanned Freight Operations", different support functions for air traffic control (ATC) were developed. This set of support functions shall ease the transition to a mixed manned and unmanned traffic independent from a distinct integration concept. One guiding principle was to use simple and versatile tools which can easily be implemented within the next years while keeping the impact on manned aviation at a minimum. One example is the direct download of information from the remotely piloted aircraft to air traffic control and visualization on the controller's radar screen, which shall make the manoeuvers and behavior of this aircraft predictable and plannable and which can serve as basis for RPAS specific monitoring functions. In order to verify this set of tools, several ATC simulations were conducted in autumn of 2017 using DLR's radar simulator ATMOS in Braunschweig. Simulation scenarios confronted the air traffic controllers with typical features of RPAS movements or constraints from different integration concepts. A comparison was made between a 'baseline' simulation using standard controller working position equipment and a 'solution' simulation using a modified controller working position including new supporting tools. Active air traffic controllers from the German Air Navigation Service Provider DFS as well as internal ATC experts attended the simulation campaign. The trials showed that the new tools decreased controller workload and significantly improved their situational awareness. In addition, positive qualitative feedback was collected showing that the approach taken is a logical step towards a first-and-easy integration of RPAS flights in a terminal control area of a hub airport. This paper gives basic information about developed support functions, describes the conducted trials, illustrates obtained results and provides a discussion and an outlook.

1. INTRODUCTION

Intense research activities and rapid technical progress in the recent years have paved the way for exploiting new possibilities in air transportation brought about by unmanned aircraft. Especially small systems with a weight of less than 25kg already found a broad application especially in surveillance, journalism and inspection work [1]. Unmanned aircraft are able to fly missions for which conventional manned airplanes are not maneuverable enough or which would simply impose a high risk to the pilot performing the flight. In a more commercial context, switching to remote flight control is a promising approach to maximize the usable payload of a cargo aircraft, to extend its endurance and to increase its flexibility while saving personnel costs at the same time.

1.1. Unmanned Aircraft as New Entrant

Since its beginnings, aviation was dominated by manned aircraft. Therefore, most existing regulations including the ICAO convention and its annexes have been designed with the assumption of the given presence of a pilot on board. As a consequence, they simply presuppose that [2]:

- every flight is able to use visual perception to locate other traffic, to avoid hazards and collisions with obstacles and as visual reference to the ground for navigation,
- every flight is always capable of human judgement to

react to unforeseen events or to situations which are not (sufficiently) covered by existing regulations,

- every flight is able to receive, understand and comply with air traffic control (ATC) clearances.

It is a well-known fact that a remotely piloted aircraft is not able to provide these capabilities without further effortful adjustments. The question how to integrate such a new kind of air traffic participant into an air traffic system which is designed as it is arises immediately.

1.2. Existing Integration Concepts

Intense research activities were performed in the last decades in order to integrate unmanned aircraft systems into the existing air traffic environment. TAB 1 shall give an overview on a selection of previous research projects related to remotely piloted aircraft systems (RPAS), regulations or RPAS flight operations. It also contains the core idea of the used integration concept(s).

It can be seen that the approaches followed by these activities are very diverse, covering different aircraft sizes and different aircraft configurations while using completely different integration concepts. However, only few activities are generic and not focused on a specific use case, but then they are in turn not mature enough for a broad commercial application with a significant number of flights. Until now no standard integration concept is available which is applicable to the entirety of unmanned flights and which is coequal to Visual or Instrument Flight Rules in manned aviation, allowing a safe, orderly and expeditious flow of air traffic in the same way.

1.3. Unmanned Freight Operations Project

From 2015 to 2017, the German Aerospace Center (DLR) conducted the project 'Unmanned Freight Operations Phase 1' (UFO Phase 1), which built upon previous

Project / Activity / Regulation	Year(s)	Kind of RPAS considered	Core Idea(s) of the Integration Concept	Reference(s)
Swiss Air Force RPAS Flights in Airspace Class E	1988-?	ADS-95 Ranger ca. 275kg	Manned chase aircraft following the RPA	[3]
IAI-MALAT Test Flights	ca. 1994	IAI RQ-5 Hunter, ca. 700kg	Segmented Segregated Airspace Corridors	[4]
WASLA-HALE	2000-2008	Dornier Do 228, ca. 4to - VFW-614, ca.15to	Guidance by ATC, sense-and-avoid-capability in non-cooperative environments, fully automatic recovery in case of a lost link between remote pilot and the aircraft	[5][6]
USICO	2002-2004	Fixed Wing MALE UAVs	'Equivalence' Principle: Unmanned aircraft systems (UAS) and their activities must show equivalence to manned aircraft as much as possible; No difference for ATC in handling unmanned aircraft; Guidance and procedures very similar to WASLA-HALE	[7]
Integration of certified RPAS according to German Military Regulations	2011-2013	Eurohawk ca. 15to	Full segregation in all airspace classes except when the certification of the UAS / RPAS allows participation in general air traffic	[8]
ICONUS	2012	all	Different strategies like new RPAS flight separation modes or integration of RPAS following the principles of 4D-trajectory negotiation with other traffic	[9]
AIRICA	2013-2015	Schiebel Camcopter S-100 ca. 200kg	Cooperative detect-and-avoid-capability based on transponder interrogation and ADS-B	[10]
INSuRE	2013-2015	SD-150 HERO <150kg	Guidance by ATC which is overruled by a detect-and-avoid-capability	[10]
NASA UTM	2014-2019	Multicopter <150kg	Height during flight <500ft above ground (below the majority of manned traffic) in uncontrolled airspace, onboard detect-and-avoid-systems, congestion management, geo-fencing and other measures	[11]
ICAO RPAS Manual	2015	all	Full application of instrument (IFR) or visual flight rules (VFR), RPAS must be able to comply with the air traffic management or must be able to interact with other airspace users, depending on the airspace class	[12]
EASA Technical Opinion for UAS Integration	2015	all	Risk-based classification of RPAS with own certification process and integration rules (RPAS classifications 'Open', 'Specific', 'Certified'; mainly focused on 'Open')	[13]
ALAADy	2016-2018	Fixed / Rotary Wing <2to	Height during flight <500ft above ground (below the majority of manned traffic), introduction of a new airspace class G+ with an obligation to all flights to broadcast the own position, calculated minimum noise routings	[14]
Eurocontrol RPAS ATM ConOps	2017	all	Distinction between very low level operations (below 500ft above ground), IFR/VFR operations and very high level operations (above flight level 600); further specifying classes of RPAS air traffic with different procedures, restrictions and required capabilities	[15]

TAB 2. Selected recent research activities or regulations related to RPAS integration

research activities and which continued to work on RPAS integration issues. The focus was on commercial air transportation by using conventional cargo airplanes that were converted to RPAS. Several approaches for a first-and-easy integration of unmanned aircraft of different configurations into the existing air traffic systems were further investigated. The impact on air traffic management including air traffic control, but also on airport management and logistical processes were examined. This project delivered several solutions how this impact can be handled, always with a view on the overall picture.

2. USE CASE AND INITIAL CONDITIONS

Within the UFO project, several use cases for a commercial application of unmanned aircraft systems (UAS) and RPAS were defined which were considered to be of special interest. These use cases are [16]:

- Use Case 1: Long-haul air transportation using hub airports,
- Use Case 2: Short-haul factory traffic using small uncontrolled airfields,
- Use Case 3: Relief flights including formation flights.

In this paper only Use Case 1 is of relevance. This use case aims at long-haul air transportation flights with RPAS in analogy to common cargo flights under Instrument Flight Rules (IFR). It is assumed that conducting such flights with a converted cargo aircraft, e.g. a fictional unmanned Boeing 777-200 Freighter, which is operating from large hub airports, is seen as a feasible and realistic scenario with a great potential. This is also confirmed by [1].

2.1. Problem Statement

Several questions are to be addressed when having a closer look at Use Case 1, i.e. how to integrate an unmanned aircraft into the airport surface traffic, into the airport Terminal Maneuvering Area (TMA) and into en-route ATC sectors with and without radar coverage.

The work presented in this paper in particular addresses the integration of RPAS cargo flights into a hub airport TMA within a time horizon of 5 to 10 years.

As demonstrated in chapter 1.2 there is no mature general integration concept available which is suited to enable a broad variety of commercial RPAS cargo flights inside of a TMA. In addition, no binding standards are already set for RPAS regarding minimum required equipment, minimum required capabilities and aircraft certification. If this is not going to be solved in the near future, the likely consequences for Use Case 1 are:

- different integration concepts may be used for different flight profiles, different unmanned aircraft types and different aircraft states due to the lack of standardization; e.g. for nominal and non-nominal conditions,
- in the same way, the integration concept may include different 'versions' of itself depending on aircraft capabilities and equipment; e.g. if in case of full segregation, the size of the segregated airspace may vary depending on the unmanned aircraft type using it,
- in case the economic and industrial pressure is growing further it cannot be assumed that the integration and certification issue will be completely solved before RPAS cargo flights are introduced widely. This means it is likely that some situations are not sufficiently covered by the applied integration concept.

Considering the envisaged time horizon of 5 to 10 years, it cannot be assumed that all RPAS flights will be integrated in the TMA in the same way with the same integration concept and the same parameters all the time. The used integration concept may be different from flight to flight and may even be changed depending on the flight status. This is especially a problem when radar approach controllers are confronted with more than one RPAS flight at the same time because then they have to deal with several RPAS integration solutions at once.

2.2. Assumptions

In order to follow a systematic approach and to clearly characterize the work presented in this paper against other RPAS research activities, the following assumptions were established based on the argumentation above:

1) All fictional unmanned aircraft considered in this work are converted conventional cargo airplanes, such as an unmanned Boeing 777-200 freighter, with the same aerodynamic performance than manned aircraft (rate of climb / descent, final speed etc.). That means possible deviations from usual flight performance characteristics of conventional aircraft do not play a role in this investigation.
2) The integration into en-route airspace as well as into ground traffic at the considered aerodrome is neglected.
3) There is a 1-to-1-relation between the remote pilot and the aircraft (one pilot is responsible for one aircraft for the whole flight portion inside the TMA).
4) The command-and-control-(C2)-link between the remote pilot station (RPS) and the remotely piloted aircraft (RPA) can be partially or completely lost, which partially or completely hampers the remote control of the aircraft but also the pilot-ATC communication via radio. It is assumed that the C2-link also drives the pilot-ATC radio communication.
5) The conducted flight operation of RPAS flights shall be equal to conventional IFR flights as far as possible. This means they are subject to ATC and there is an obligation to separate these flights from other RPAS or IFR flights.
6) The used integration concept can involve no, minor or major deviations from the handling procedures which

are usual for conventional manned IFR flights, depending on the concrete integration concept.

7) The concrete integration concept, related parameters and handling procedures may be aircraft type specific and/or specific to the situation due to a lack of standardization.

8) The concrete integration concept may not be mature enough to cover all situations that can arise in day-to-day air traffic. In detail, in such a situation a safety risk can nevertheless be present even when strictly following the requirements and procedures of the used integration concept.

9) All RPAS flights file a flight plan indicating the unmanned nature of the aircraft and a telephone connection to the remote pilot station for backup ground-ground pilot-ATC communication.

2.3. Approach

Considering these preconditions, the intention of the work presented in this paper is to develop controller assistance functions which are not specific to a concrete integration concept and which can provide versatile support. This seems to be appropriate as the majority of integration concepts including those written down in section 1.2 often use the same concept elements, such as:

a. fully automatic or autonomous maneuvers of the RPA without any ATC clearance and maybe without any pre-warning in a specific nominal or non-nominal situation,

b. detect-and-avoid capability of the RPA and ground-air or ground-ground controller-pilot-communication as essential pillars of the integration concept,

c. segregated airspaces in different forms (Corridors, level bands, areas; static or dynamic), which must stay clear of all other traffic,

d. predefined or negotiated 4D-trajectories for the RPAS flight or portions of it, which must be considered by all other aircraft.

Based on this list of bullet points a set of controller assistance functions can be defined. The overall goal here was to improve situational awareness of the controller and thus the predictability and plannability of the air traffic even in the situation sketched by the assumptions defined in 2.2.

3. ADDITIONAL SUPPORT TOOLS FOR CONTROLLER WORKING POSITIONS

As a response to the described challenges for an approach controller when handling RPAS flights, several support tools have been developed in addition to traditional functions of a controller working position (CWP).

3.1. Baseline

The baseline for the implementation was a human machine interface (HMI) which was developed to be similar in coloring and appearance to the "VAFORIT" system of German air navigation service provider (ANSP) "Deutsche Flugsicherung" (DFS).

The HMI in general consisted of a light colored radar data display, where aircraft symbols were indicated with speed vectors and classical label information like callsign, level, ground speed, wake turbulence category (WTC) if not "medium" (M) and aircraft type (see Figure 1). An arrow in the label additionally indicates the climb or descend behavior of the aircraft.

The users were able to control the zoom factor of the situation display via the mouse's scroll wheel; classical panning of the map via drag and drop was also possible.

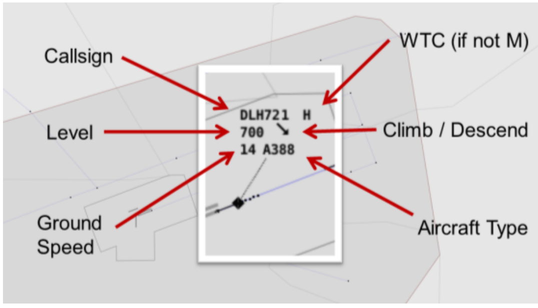

FIGURE 1: Used HMI design for aircraft labels

This HMI was used as a starting point for implementing additional assistance functions supporting the handling of a mixed manned and unmanned traffic constellation.

3.2. RPAS Status

As a first addition to the classical depiction, a change of the aircraft's head symbol was introduced for RPAS flights. As visible in Figure 2, the black square used for normal manned radar targets was rotated by 45 degrees for the unmanned targets. This subtle but recognizable hint was chosen, since in nominal conditions, the unmanned aircraft shall behave in the same manner as manned aircraft, so a salient visual difference between both was assessed unnecessary.

Class	Manned	Unmanned
Normal Target	◆	■
Emergency Target	◇	□

FIGURE 2: Aircraft symbols used to distinguish between manned and unmanned flights

In the case of an emergency, e.g. hydraulic, engine or electrical failures, fuel shortages or loss of the C2 link, the head symbol coloring changes from solid black to white with a red border for both manned and unmanned targets. The information whether an aircraft is manned or unmanned was assumed to be available in the filed flight plan or via transponder mode S responses / ADS-B.

To access more information on the RPAS status or an active emergency, controllers could open a context information menu via mouse click on the aircraft callsign. In addition to the button for assuming and handing over a flight from preceeding respectively to successive air traffic controllers, this menu offered the possibility to establish a direct ground-ground voice communication line to the corresponding remote pilot and to show the uploaded onboard trajectory if available (see more details in section 4.3.). Furthermore, as visible in Figure 3, the status of the C2 link was displayed by a pictogram reaching from the highest link quality with five "signal bars" as familiar from cellphone displays to a crossed-out antenna symbol when the link is lost completely.

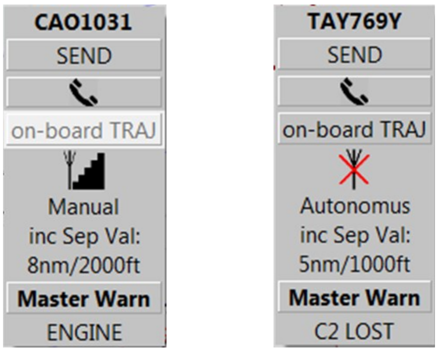

FIGURE 3: Context information menu with RPAS status download functions

Information regarding the flight mode of the RPAS was given in the context information menu by the label "Manual", "Automatic" or "Autonomous". If the flight mode is manual, the trajectory of the RPAS is controlled by the remote pilot directly via transmission of control instructions. Automatic flight control indicates that the RPAS proceeds on along a trajectory on control of autopilot and/or flight management functions, but it does not react to changed conditions, hazards or conflicts without the decision of the pilot, as it would be the case in fully autonomous conditions.

The menu also contained a so called "master warning" area that was shown below information about special handling procedures (see section 4.5). Master warnings were triggered as an additional warning sign for critical situations. For the following events, the aicraft label was framed with an intense red border (see e.g. Figure 4): hydraulic, electric and engine failures, fuel shortages, loss of the C2 link and loss of the RPAS' detect and avoid system. These events were indicated textually in the master warning section. The operator could then "acknowledge" the warning by clicking the "Master Warn"-button, resulting in the label frame to become a less saturated, darker red. In the case new information is received, the frame was colored in intense red again to indicate this change.

The data needed to display this information is assumed to be downloaded directly from the remotely piloted aircraft to ATC via transponder mode S responses or ADS-B / ADS-C.

3.3. RPAS Planned Trajectory Download

In order to inform the air traffic controller (ATCO) about any autonomous manoeuver performed by an RPAS under control (e.g. collision avoidance, contingency procedures), new information about autonomous manoeuvers shared via data exchange (e.g. via ADS-B or Transponder mode S) between the RPA and ATCO were indicated in the HMI.

The trajectory indication popped up as soon as a new trajectory was received, so that changes in the trajectory are easily noticed by the controller. At all times, provided a trajectory was available, the visual indication could be toggled with the button "on-board TRAJ" of the context menu or via click on the aircraft head symbol. Altitude information (A50, F60) was displayed at waypoints of the trajectory, as visible in Figure 5. If the trajectory changed, e.g. because of autonomous maneuvers, it was shown immediately. The trajectory was drawn in the color of the head symbol (normally black, red in case of emergency).

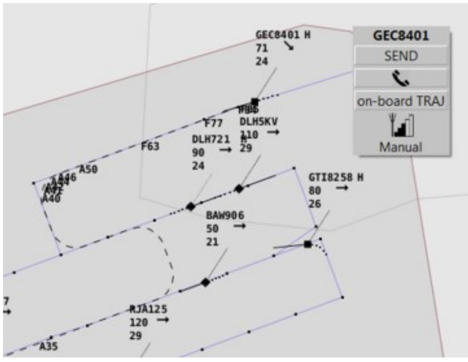

FIGURE 4: Display of RPAS planned onboard trajectory

The data needed to display this information is assumed to be downloaded directly from the remotely piloted aircraft to ATC via transponder mode S responses or ADS-B / ADS-C.

3.4. Segregated Airspace Handling

To fulfil the concept of segregated airspaces (see section 2.3), ATC must be able to request and / or coordinate and / or establish segregated areas in the air together with the person / unit responsible for airspace management in a very efficient and expeditious way. To this end, the controller was able to draw and transmit the desired area via mouse input on the radar screen. When segregated areas were entered or were received otherwise, they were displayed on the radar according to their activation times. Further information, such as name of the area, extend in altitude and validity times, were displayed in an additional information window or sidebar that could be toggled in the toolbar (see Figure 6).

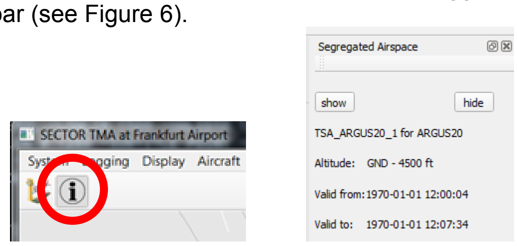

FIGURE 5: Segregated airspace toolbar toggle (red circle, left) and information sidebar (right)

On the radar screen, the segregated airspace was indicated by a dashed, orange line 10 minutes before the start of its validity and a continuous, red line when active. The depiction could also be changed by the controller by either pressing the “show”-button to produce a highlighted line (see Figure 7, left) or pressing the “hide”-button to disable the display of the segregated area.

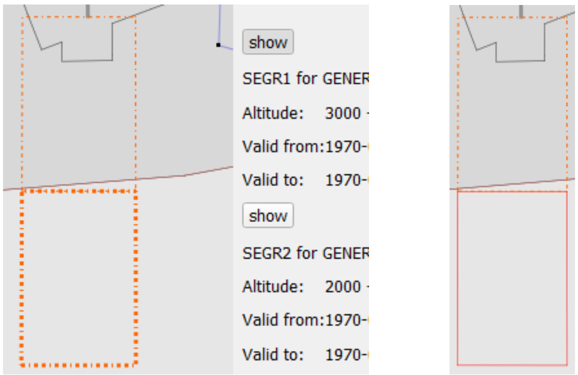

FIGURE 6: Segregated airspace depiction on the radar screen. Left: two not yet active segregated airspaces (south area is highlighted). Right: active (south) and inactive (north) segregated airspaces in comparison.

The data needed to display this information is assumed to be available via aeronautical networks, e.g. AFTN or the future SWIM.

3.5. RPAS Specific Non-Nominal Procedures

In the work presented in this paper, three RPAS-specific non-nominal procedures were implemented:

1) Lost C2-link indication.

2) Ground-Ground voice communication between the pilot and ATC in case of lost radio communication.

3) Situation- and type-specific increased lateral and/or vertical separation minima.

In the case of a lost C2 link, a corresponding symbol was also displayed in the aircraft label (Figure 4, left). In the same manner, if there is a “lost com”, i.e. the communication link to the remote pilot via radiotelephony is not available, the telephone symbol will appear in the label to indicate that ground-ground voice communication is the only option to contact the RPAS’ remote pilot (Figure 4, right).

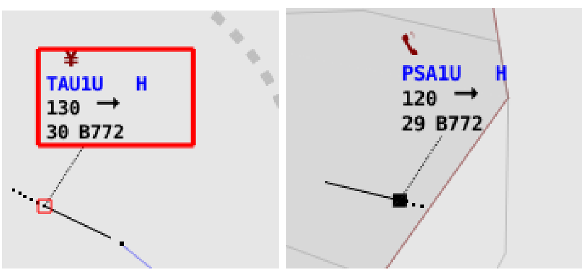

FIGURE 4: Used HMI design for aircraft labels

To assist the ATCO in applying increased separation minima, the HMI provided measures to ensure the awareness of such non-nominal separations. Therefore, in cases where increased separation according to defined procedures applied, a dashed circle around the aircraft symbol was shown. The circle radius represented the applicable lateral separation and the line strength indicated possible increased vertical separations (higher vertical separation = thicker line) for a quick impression of the separations dimensions. The quantitative details (radius in nautical miles, vertical separation in feet) are displayed in the context menu as explained in Section 4.2 (see Figure 8, left).

The data needed to display this information is assumed to be available via transponder mode S / ADS-B or ADS-C or from background databases containing all aircraft type specific handling procedures.

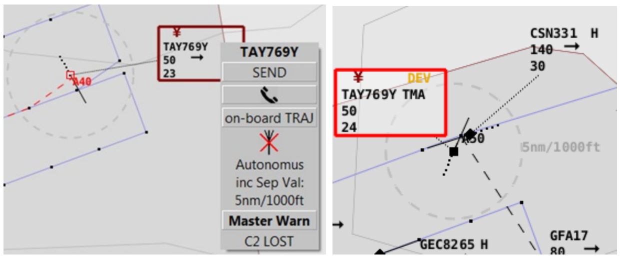

FIGURE 7: Display of increased separation minima due to RPAS contingency procedures

The HMI also uses conformance monitoring to compare the RPAS planned (on-board) trajectory with the actually flown radar data. Conformance monitoring is already a common functionality of modern ATC systems. As the HMI used here is based on VAFORIT, major lateral deviations greater than a defined threshold is displayed with an orange DEV in the first label line (see Figure 8, right). A vertical deviation greater than a defined threshold is indicated with a color change of the altitude value in the aircraft label.

4. VALIDATION TRIALS AND RESULTS

These additional RPAS specific CWP functions developed in the UFO project where validated in August 2017 in the frame of a simulation campaign, which took place at DLR's Institute of Flight Guidance in Braunschweig, Germany.

4.1. Trials Description and Scenarios

The trials were conducted as a set of human-in-the-loop simulations, using DLR's Air Traffic Management and Operations Simulator (ATMOS).

The simulation campaign consisted of four identical trial days, which all contained five simulation runs. Every trial day was completely passed by another test person. Two test persons were active radar approach controllers from the German Air Navigation Service Provider DFS; two more test persons were ATC experts from the German Aerospace Center (DLR).

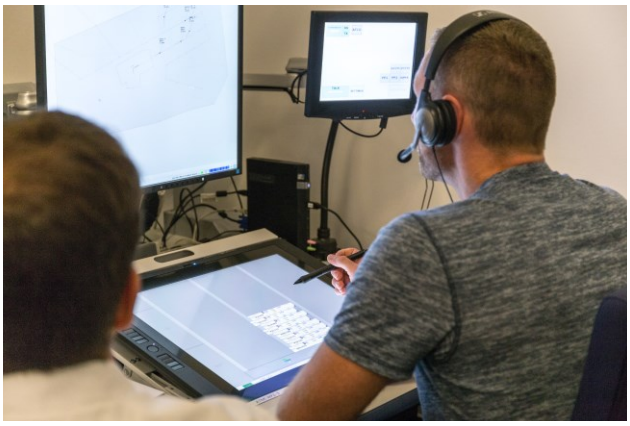

FIGURE 8: Test person performing a human-in-the-loop simulation during UFO validation trials

All simulations were based on the airspace and approach procedures of Frankfurt Airport as operational environment. However, for simplification there was no split between the pickup (FRANKFURT ARRIVAL) and feeder (FRANKFURT DIRECTOR) positions. The test person was tasked to guide arriving traffic until final approach no matter from which direction. All arrivals should use runway 25L for landing only. No departing traffic was simulated.

The traffic scenarios of all simulation runs contained conventional manned IFR arrivals with a moderate traffic load which could well be handled, considering the frame conditions described in the previous paragraph. In addition to that, several arrivals of wide-body unmanned cargo airplanes were contained in the scenarios, following different integration concept elements in accordance with the assumptions stated in 2.2:

- Some RPAS are fully treated like manned IFR flights and provide needed capabilities in nominal conditions ('equivalence principle', see also 1.2).
- Some RPAS perform portions of or the complete flight in fully automatic mode in nominal or non-nominal conditions.
- Some RPAS perform autonomous maneuvers in specific situations, such as a detect-and-avoid maneuver or an autonomous maneuver as part of a contingency procedure.
- Some RPAS use segregated airspaces / corridors for the approach.

On average, about 10-20% of all arrivals were RPAS flights. Apart from non-standardized integration concepts, also fictional non-standardized handling procedures in case of non-nominal conditions were introduced. Two or more of these flights often needed to be handled by the controller at the same time in addition to the conventional manned traffic. Simulated non-nominal conditions consisted of RPAS-specific situations, e.g. C2-link loss and switching to ground-ground controller-pilot-communication; as well as conventional emergency situations like hydraulic failure of RPAS or manned flights.

4.2. Objectives

The conducted validation campaign was designed to assess the benefit on controller workload and situational awareness of the developed toolset by means of a baseline-solution-comparison. The focus was on the situation when the controller is confronted with multiple RPAS flights and non-standardized integration concepts as well as non-standardized handling procedures.

As the quantitative measurement of every individual assistance function would significantly increase the effort needed to conduct the study, just qualitative feedback to every individual tool was collected.

4.3. Baseline Simulations

The reference (baseline) used for performing all measurements and assessments was defined as the situation described in 4.1, but handled by the test person without any RPAS specific controller assistance functions. This would reproduce the situation when remotely piloted cargo aircraft would be widely introduced into the air traffic system without any preparation on the ATC side. For the baseline runs, the test persons taking part in the trials got a comprehensive briefing about all relevant integration concepts and handling procedures and were allowed to always use paper sheets showing this information.

In total, two of five simulation runs per trial day were conducted in baseline configuration.

4.4. 'Solution' Simulations

Also two of five simulation runs per trial day were conducted in 'solution' configuration. This means during these simulations the test person got full support by the implemented assistance functions.

The traffic scenario, boundary conditions and procedures were identical to the baseline simulations in order to enable a direct comparison.

4.5. Benefit on Controller Workload

To measure the benefit on the controller workload the standardized NASA-Task Load Index (NASA-TLX) questionnaire [21] was used in all baseline and all solution simulations. The following table shows the results measured with this methodology. Measured NASA-TLX-scores are already averaged over both baseline runs as well as over both solution simulations per test person. A scale from 1 (= zero workload) to 20 (= extreme workload) was used here.

Test person ID	Mean NASA-TLX score for baseline runs (without assistance functions)	Mean NASA-TLX score for solution runs (with assistance functions)	Difference
C1 (DFS)	8.8	6.9	-1.9
C2 (DFS)	10.5	9.0	-1.5
C3 (DLR)	13.1	9.1	-4.0
C4 (DLR)	9.3	8.4	-0.9
Average	**10.4**	**8.4**	**-2.0**
Standard Deviation	1.9	1.0	1.3

TAB 2. NASA-TLX Results

It can be seen that the workload experienced by the test persons was never critically high during the simulations even without the developed controller assistance tools. This shows that the RPAS traffic as it was modelled and simulated seems to be still safely manageable even with conventional CWP equipment.

However, all four test persons show a decrease in workload between baseline and solution (by -2.0 on the average on a scale from 1 to 20). Apart from the safety aspect, this improvement has influence on the sector capacity as well as to the extent and quality of ATC service, as both are directly connected with controller workload. The toolset developed in the UFO project can therefore likely contribute to a safe, expeditious and orderly flow of mixed manned and unmanned air traffic.

4.6. Benefit on Controller Situation Awareness

To measure the benefit on the controller situation awareness the standardized Situation Awareness for Shape (SASHA) questionnaire [22] was used in all baseline and solution simulations. The following table shows the results measured with this methodology. Measured SASHA-scores are already averaged over both baseline runs or both solution simulations per test person. A scale from 0 (= "never") to 6 (= "always") was used here.

Test person ID	Mean SASHA score for baseline runs (without assistance functions)	Mean SASHA score for solution runs (with assistance functions)	Difference
C1 (DFS)	3.6	4.8	+1.2
C2 (DFS)	3.4	4.1	+0.7
C3 (DLR)	2.8	5.0	+2.2
C4 (DLR)	3.4	3.8	+0.4
Average	**3.3**	**4.4**	**+1.1**
Standard Deviation	0.3	0.6	0.8

TAB 3. SASHA Results

It can be seen that the average level of situation awareness was only moderate for the baseline runs. An average value of 3.3 clearly shows that test persons had difficulties to maintain the mental traffic picture in the baseline runs, which is a prerequisite for proper traffic preplanning. However, all four test persons show an increased situation awareness in the solution runs due to the availability of the developed toolset (by +1.1 on the average on a scale from 0 to 6).

4.7. Qualitative Feedback

Apart from quantitative measurements, comprehensive qualitative feedback was obtained from the test persons in the frame of de-briefings and post-trial interviews. These results are provided in this section.

1) General

Three of four test persons stated that the trials were realistic and the simulated situations, challenges and events are well imaginable. However, two of four test persons stated that the used concept elements for RPAS integration are still too futuristic, although they are quite simple and based on today's technology. A conclusion would be that the effort to find a simple and standardized RPAS integration concept and to develop versatile and simple tools to support it must be increased.

2) RPAS Status Download

All four test persons strongly appreciated the idea to extend ADS-B or Mode S functions to download information directly from the RPA. Although it is a simple approach which can easily be implemented, this function has the potential to significantly increase situation awareness when working with RPAS flights.

One test person stated that he just sees a risk of overloading the controller with too much details or when presenting information which can be better interpreted by the remote pilot.

More specifically, the following display features were seen as beneficial:

- RPAS head symbols: The presentation of this information needed some familiarization first and could also be more conspicuous. But especially in non-nominal situations this information is quite important as it has direct influence on the priority of service and selecting appropriate handling procedures.

- Technical failures of the RPAS: Provided that this information is not too detailed or too diverse this feature is helpful especially in case of a C2-link loss when the remote pilot has no awareness about the status of the flight.

The following display features were seen as dispensable:

- RPAS C2-Link Performance: this information was not used by any test person. Therefore, this information can be seen as not relevant for traffic guidance and preplanning.

- Display of RPAS Flight Control Mode: this information was not used by any test person. This was not expected, but the same information can indirectly also be drawn by the display function of the RPAS on-board trajectory. The indication of the RPAS on-board trajectory was in turn intensely used by all test persons.

- Display of messages of the detect-and-avoid-function: this information was not used by any test person. One active controller from the DFS strongly doubted the need for a detect-and-avoid-system for IFR flights of an RPAS, because ATC is fully responsible to prevent collisions.

3) RPAS Planned Trajectory Download

The feature of downloading and indicating the planned on-board trajectory of the RPAS flight management system was seen as most beneficial and very helpful as this information directly indicates how the RPAS will behave, which then can easily be considered by controllers. The on-board trajectory provides information about autonomous maneuvers and about the flown procedure even if it would not be standardized across unmanned aircraft types. In addition, it delivers essential information about the aircraft behavior in a C2-link loss situation, when also the remote pilot has no clear awareness about the current behavior of the RPA.

4) Segregated Airspace Handling

All four test persons confirmed that the display function of segregated airspaces was very beneficial and helpful. It provided all needed information to quickly recognize the status, to clear the airspace in time before its activation and to use the remaining airspace more efficiently. Compared to the baseline, it supported maintaining awareness about actual or near future activations and allowed appropriate preplanning to consider the segregated airspaces accurately.

However, all test persons were asked if they think an RPAS integration using segregated corridors is feasible. All four test persons stated that this integration solution is safe and realistic, but comes along with a huge loss in aerodrome capacity. In the simulation, segregated corridors produced a lot of delay and are enormously hampering for the other flights in the sector. As a consequence, RPAS flights which would be integrated like this would cause very high costs and increase controller workload in a working environment which typically is already a very busy one. As a conclusion, using segregated corridors in low traffic environments is absolutely feasible but this is not an option for large hub airports like Frankfurt.

5) RPAS Specific Non-Nominal Procedures

Regarding the implemented display of increased radar separation minima, very positive feedback was collected from all four test persons. This function very much supported the application of non-standardized handling procedures involving a change in required minimum separation, because this can only partly be covered just with additional training of the air traffic controllers.

Also the function to support switching to ground-ground controller-pilot-communication whenever needed was rated as very helpful in related situations, especially when this was necessary for just one or two of several RPAS flights under control.

5. CONCLUSION AND OUTLOOK

It cannot be expected that the issue of how to integrate unmanned cargo aircraft in a TMA will be finally solved within the next decade due to its complexity and diversity. Looking at this perspective on one hand, but also on the results collected in this study on the other hand, the approach to derive and develop versatile controller assistance tools based on common elements of RPAS integration concepts seems to be straightforward.

This paper does not contain all obtained results and does not describe all assistance functions developed during the presented work. For this reason, a compendium will be published soon, containing all results, considerations and developments from the UFO project, which can be seen as a continuation and supplementation to this paper.

The toolset developed in the UFO project can be seen as some kind of a first aid kit, which has already proved its benefits even when RPAS-specific regulations remain unspecific or incomplete. As it is not excluded that economic and industrial pressure will somedays force an introduction of commercial RPAS flights even without a fully developed integration concept as it happened for small drones, this toolset might contribute to nevertheless maintain a safe, orderly and expeditious flow of air traffic.

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