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

DETECT AND AVOID FOR REMOTELY PILOTED AIRCRAFT IN AIR TRAFFIC CONTROL SIMULATIONS

Jens Alfredson*+, Petra Hagström****
***Linköping University, **Saab Aeronautics**
Jens.Alfredson@Saabgroup.com

Keywords: *Detect and Avoid, Future Air Systems, Interaction, Mid-Air Collision, RPAS*

Abstract

The operational perspective and the interaction with air traffic control is essential for a detect and avoid system for remotely piloted aircraft. We report on performed human in the loop simulations and related workshops that studied this in three simulation campaigns, focusing on mid-air collision. Results and conclusions include technical recommendations as well as lessons learned. Contributions include recommendations for design and validation of the MIDCAS concept as well as domain specific results concerning detect and avoid for remotely piloted aircraft as an example of adaptive interaction for future air systems, with relevance to the integration of remotely piloted aircraft into civil airspace.

1 Introduction

This study is about detect and avoid for remotely piloted aircraft in air traffic control simulations, focusing on mid-air collision. This includes operational perspectives that are best studied in real life. However, since the studied setting is not yet operational and since situations involving conflicts is included in the study, simulations had to be performed. The operational perspective and the interaction with air traffic control is essential for the seamless integration of a detect and avoid system for remotely piloted aircraft. To ensure that the operational perspective would be regarded, human in the loop simulations were performed with expert users interacting with a state of the art simulated detect and avoid system in a simulation context including Air Traffic Control (ATC) as well as remote pilot, focusing on mid-air collision.

As part of the European Detect and Avoid (D&A) project MIDCAS (Mid-air Collision Avoidance System) [1,2], three human-in-the-loop simulation campaigns of one week each have been successfully performed with a remotely piloted aircraft system (RPAS) equipped with a D&A system flying according to Instrument Flight Rules (IFR) in an ATC environment, focusing on mid-air collision. The simulations were conducted together with several partners within the project as well as with stakeholders outside the project.

The overall purpose of the MIDCAS project was to identify adequate technology, contribute to standardization and demonstrate a D&A system for RPAS able to fulfil the requirements for traffic avoidance and mid-air collision avoidance in non-segregated airspace. Successful evaluations were performed using simulations as well as flight tests with a RPAS equipped with a D&A system. In the project three types of simulations were used including, montecarlo, relatime and ATC simulations. The montecarlo were focused on performance assessment and included simplified pilot behaviour models and the realtime simulations focused on functional requirements and early feedback from the remote pilot on the HMI whereas the ATC simulations took the wider operational scope including full interaction with ATCO.

The main purpose of the ATC simulations reported here was to study the D&A system from an operational perspective and to evaluate the interaction with ATC, as a complement to the other project activities. Also, this adds empirical findings from simulations to questions

addressed in surveys [3], in other projects that has studied ATC, manned aircraft pilots and pilots of unmanned aircraft.
The objectives of the simulation included aspects related to:

- Traffic Avoidance (TrA)
- Collision Avoidance (CA)
- ATC Communication
- Pilot Situation Awareness
- Workload
- Failure Cases

In the studied system there are:

- Surveillance phase
- Traffic avoidance phase
- Collision avoidance phase

For an evolving situation the surveillance phase would come first in time potentially followed by traffic avoidance. Lastly, there might also be a collision avoidance phase, where an automatic collision avoidance maneuver could be performed.
The phases are clearly separated from each other and have different purposes and appearance. In the traffic avoidance phase a manoeuvre suggestion is presented but has to be manually activated by the remote pilot to be initiated. In the collision avoidance phase the manoeuvre will be activated, unless it is aborted by the remote pilot. This means that collision avoidance is also available even if the data link should be malfunctioning. This is not the case for traffic avoidance that includes remote pilot interaction to be executed. The remote pilot also has the possibility to make an early activation of the collision avoidance manoeuvre. The main difference between traffic avoidance and collision avoidance, as implemented in the concept used in this simulations, is that the purpose of the traffic avoidance is to not scare others whilst collision avoidance is created to avoid physical contact between aircraft in a conflict situation. Hence, traffic avoidance is used in routine situations but collision avoidance is using all or most of the RPA performance in extreme situations that would be very infrequent in real life but rather frequent in the performed simulations. After the performed simulations it was clear that traffic avoidance should be performed in accordance with clearance in controlled airspace, but collision avoidance is performed without such regards, since it is regarded as an emergency manoeuvre. However, after an activated collision avoidance manoeuvre ATC if informed as well as after deactivation at which clear of conflict has been reached. Traffic avoidance is using either altitude change, speed change, or heading change which makes these manoeuvres correspond to semantics used in current clearances resulting in a predictability to the ATCO. The implemented collision avoidance is performing a combined manoeuvre which may result in change to two or all of them simultaneously to avoid conflict in the best way possible.

2 Method

The main method used in this study was human in the loop simulations.
The simulations included valid scenarios performed by ATC experts and tested during a series of pilot studies, including technical verification and validation as well as scenario verification and validation.
The simulations were performed in three simulation campaigns carried out in Sweden during one week each.
The focus of the simulations performed was on evaluating interaction between the D&A system, remote pilot, ATC and surrounding air traffic during mid-air collision incidents. The main subsystems included in the simulation were:

- Sense subsystem
- Avoid subsystem (traffic avoidance and collision avoidance), and
- Human Machine Interfaces

The sense subsystem detect and track cooperative and non-cooperative intruders. Information from different sensors is fused before providing them to the avoid- and HMI subsystems.

The avoid subsystem estimates collision risk and calculate priorities within threats, conflicts and intruders, as well as calculates avoidance manoeuvre taking into account ACAS compatibility, right of way rules and performance. Finally, warnings and solutions are provided to the HMI and the RPA control system.

The human machine interfaces provide the remote pilot with traffic information so that he can build situation awareness. This includes the traffic situation relevant for the RPA and how dangerous it is for potential conflicts. Also, the human machine interface includes support to the remote pilot regarding self-separation assistance with controls to activate and inhibit collision avoidance manoeuvre.

Fig. 1, shows an overview of the remote pilot work station, and Fig. 2 shows a part of the human machine interface used by the remote pilot.

In the performed simulations the RPAS simulation framework was integrated with the ATC simulation environment that included control centres, control tower and surrounding air traffic simulations, including intruder´s pilots. All communication between ATCOs and pilots during the simulations were performed using a party line to emulate normal VHF. Besides the detect and avoid HMI the remote pilot also had a user control station GUI of the RPA and a map with the positions and flight plan of the RPA. The ATCO used an ATC workstation with Östgöta TMC and “the rest of the world” position interacted with an ATC workstation with TWR/ACC. Pseudo pilots interacted with a workstation for air traffic. Together with the RPAS simulation framework they were all interacting with the ATC simulator.

The participants in the simulation had highly relevant background and training.

The pilots were very experienced pilots of which some had mostly military experience and some were currently working as commercial pilots. Also, one of the remote pilots had some experience from piloting a RPAS. Every remote pilot in the study had a HMI briefing before the simulations and at the same time the project and its scope was presented to them. In addition, every remote pilot got the opportunity to receive practical experience of the system and simulation set-up in pilot studies. They were also provided a separate HMI user’s guide ahead of the simulations.

The ATCOs were at the time of the simulations all working in the actual Östgöta TMA as air traffic controllers. However, the working environment in the simulations were a bit different from their ordinary work environment in some regards. For instance, the simulation context did not support the use of strips, coasting lists or Short Term Conflict Alert.

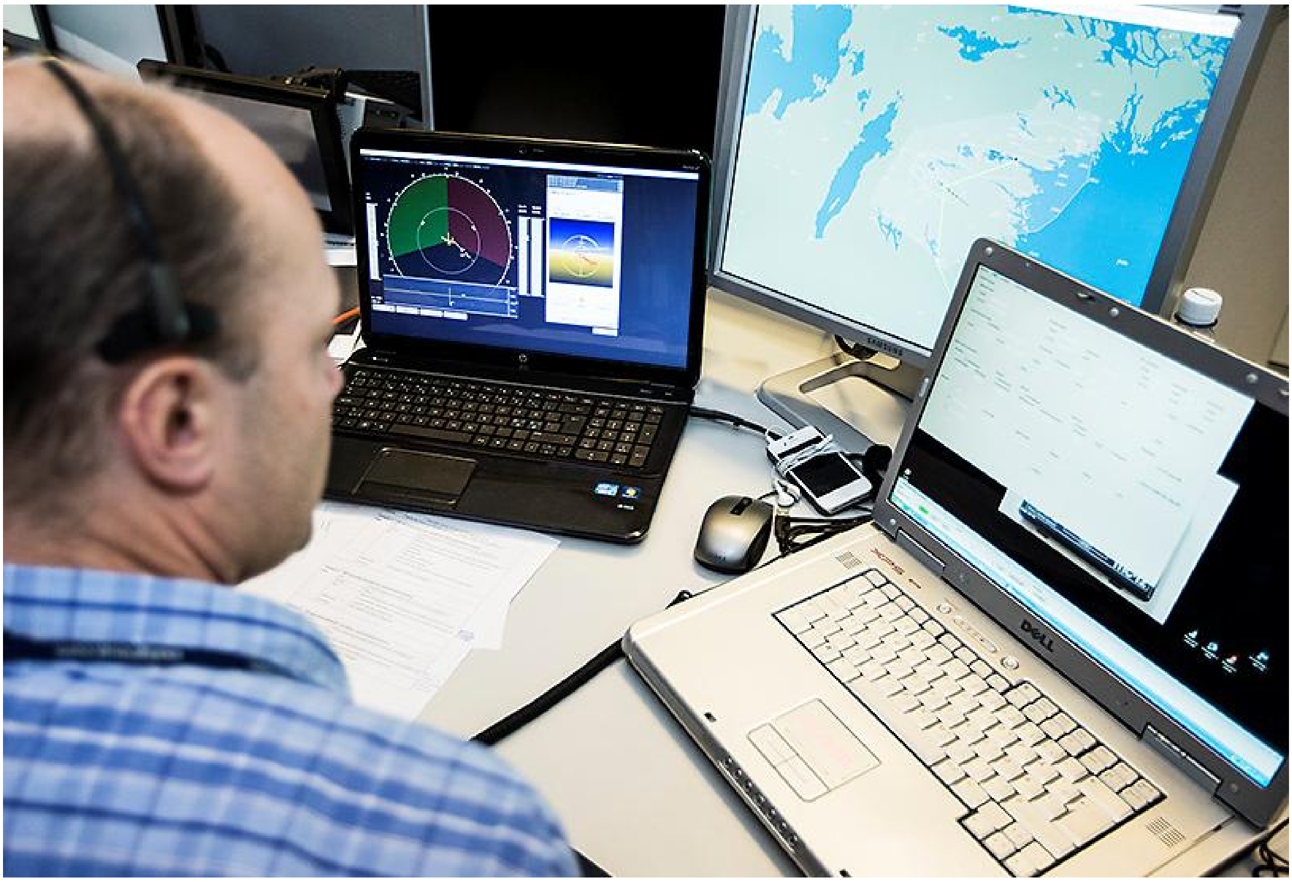

Fig. 1. An overview of the remote pilot work station.

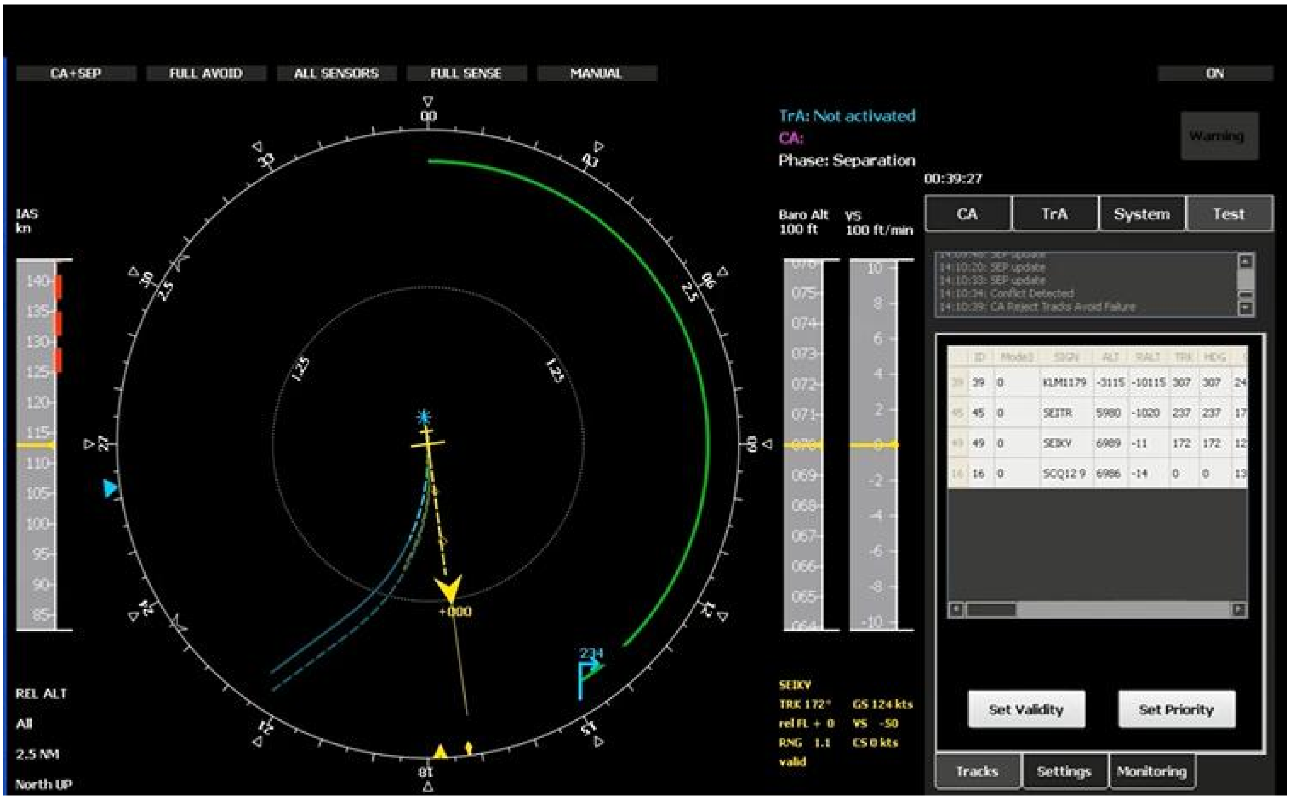

Fig. 2. A part of the human machine interface used by the remote pilot.

The simulation team consisted of one ATCO, one remote pilot and two intruder pilots (controlling all manned aircraft and responding to ATCO communication) along with an additional "Rest of the world"-position, controlling the CTRs and the other adjacent airspace around the TMA, in order to make the exercise realistic with regard to handover between controllers. The seating of the participants were decided after lessons learned in pilot studies and from earlier campaigns. For an overview of the seating, see Fig. 3 that show the seating for the third campaign.

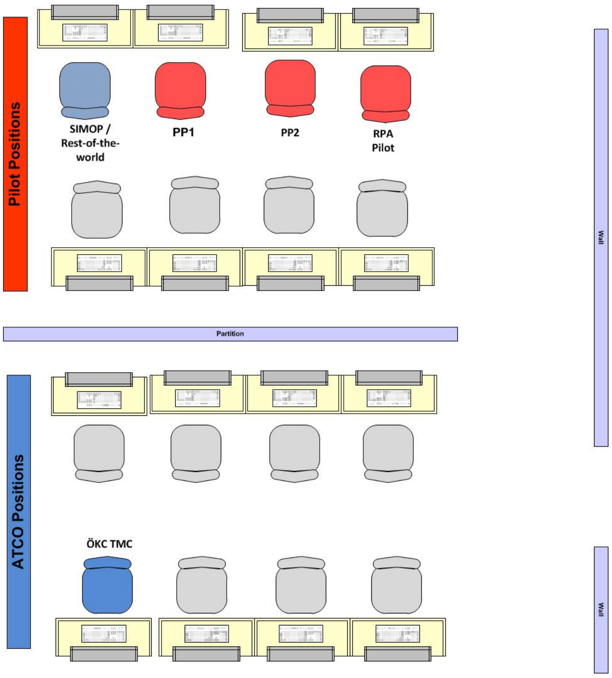

Fig. 3. Overview of the seating for the third campaign.

In the three campaigns five to seven one hour runs were performed with each team. There was also an initial reference run for each team with only manned aircraft, carried out for comparison.
The various runs were based on two basic scenarios, one where the RPA was flying southbound and the other northbound. The runs were conducted in order of priority. Before every run a short briefing was held to the participants including scenario context, The ATCO was only informed of the simulated airspace class and otherwise was told to act as if nominally "at work". The remote pilot got specific instruction on how to communicate and act during each encounter. After each run there was a debriefing in two parts. The first part included a joint debriefing for all the simulation participants with run and conflict discussions to enable all participants to form a common understanding of what happened and why.. The second part included a separate session for pilot and ATCO, including questionnaires.
It was challenging to plan runs so that conflict events were created without asking ATC to fail his job and at the same time remain realistic chains of events. The pseudo-pilots were asked to generate realistic events and were guided by a person involved in the scenario creation. The instructions to the pseudo-pilots were presented in a preplanned run description. Specific events were created such as level busts, transponder failure and emergency situations. Every run was planned to include three events. However, due to the set-up of the simulations each run was dynamically evolving and might turn out in various ways depending on decisions and performance of the participants of the simulation. In some runs there were opportunities to make more than three conflicts and for some runs the ATCO separated traffic in a way that lead to less than three conflicts.
Contextual information was carefully provided to the participants since potential misunderstandings of clearances might depend on certain flights or certain waypoints [4].
The simulated airspace under ATCO responsibility was Östgöta Terminal Maneuvering Area (TMA) in the south of Sweden. Fig. 4 show the Östgöta TMA with the RPA flightplan south to north. Also, the reversed flightplan, north to south, was used in the simulations to achieve more variance in conditions and for increased realism.

Fig. 4. Overview of the Östgöta TMA in the south of Sweden, and the RPA flightplan from south to north.

There were three active airports/CTRs under the TMA:

- The Linköping/Saab CTR
- The Norrköping/Kungsängen CTR
- The Stockholm/Skavsta CTR

Airspace classes C, D, and E were simulated, whereas the true class of the TMA is C.
Traffic density was also increased compared to current situation to enable assessment of a potentially more dense airspace in the future or on other parts of Europe.
Data was collected for qualitative analysis including:

- Observer logs by observers for ATCO and remote pilot
- Questionnaires
- Notes from debriefings/workshops

Aircraft positions and velocities as well as internal system parameters including the HMI were recorded to enable post time analysis as well as visualization of the scenario during the debriefing

Debriefings were held after each run performed and notes were collected by observers. The data were analyzed together with other obtained data.

4 Results and discussion

The main purpose of the ATC simulations was to support validation of the MIDCAS concept together with air traffic controllers and remote pilots. This has been done and a general conclusion is that the MIDCAS concept supported the work performed by ATCO and remote pilots. This was the overall impression in debriefings and workshops and is also supported by assessments in the questionnaires.
In the first campaign, the focus was to identify the structuring requirements on the system. The remote pilot was instructed to act in different ways to identify what is desired, acceptable and unacceptable in the interaction with ATCO.
In the second campaign the instructions for the remote pilot were therefore updated according to what was learned in the first campaign. For example the remote pilot was always instructed to ask for new clearance before implementing a traffic avoidance manoeuvre suggestion, as this was identified as required in the first campaign. In general, it seemed to be easier for the remote pilot to follow the instructions in the second and third campaign than in the first campaign. The instructions seemed to be more in line with the way the pilot would have acted without any instructions.
In the second campaign, the objectives were further refined. In the first campaign knowledge about what is acceptable and unacceptable were gained therefore focus in the second campaign could be on details on a lower level, such as phraseology and timing. Also, link loss was studied as a failure case.
In the third campaign, non-cooperative intruders, that is intruders that is not visible to ATC, were introduced, adding another dimension to the simulation.
During all the simulation campaigns there were no collisions between any traffic in any of the simulated runs, although there were lots of complex situations and active intruders instructed to generate conflict situations. The MIDCAS system solved all situations either

autonomously, or in cooperation with the remote pilot alone or in cooperation with the remote pilot that in turn cooperated with ATCO. Notable is that in some runs very complex situations with several intruders involved was created. Overall, the results were very positive regarding the MIDCAS concept.

For example, one of the ATCOs, who has participated in all three simulation campaigns, summarized his impressions in a debriefing (campaign 3, run 2, team 2): *I feel confident in the system. The RPA behaves pretty much as a manned aircraft. Turns can be a little bit different but are still reasonable. In the first ATC simulation campaign I felt I had to monitor the RPA more than other traffic. There were also some strange manoeuvres. It does not feel like that anymore. I can treat and monitor the RPA in the same way as other traffic.*

Analyzing the answers from one of the questionnaires that focused on key performance areas (KPA), it seems like the ATCOs experience the system as more mature than the remote pilot does. This probably implies that the remote pilots manage to handle the system in such a way that the experience from the ATCO perspective is that is does not differ greatly from manned flight. However, the system is not fully transparent towards the ATCO, and therefore the remote pilot may sort out some information. There were no indications from the KPA questionnaire that there would be any problem for the MIDCAS concept to be able to scale up, in large scale and in various operational contexts and geographical areas.

There were initial acceptance of the suggested communication, as reflected in one of the questionnaires that was answered in the end of trial for the second campaign by the ATCO, (ATCO #1) that answered the question "Assess the suitability of the proposed phraseology (safety, expediency). a) when manoeuveres are requested from the remote pilot b) in the recovery phase" by providing the following answer: a) *The used phraseology is good and understandable and conforms to older implemented phrases. "Request right turn heading xxx to avoid traffic" for example*, and b) *Clear of conflict after the collision avoidance is good and conforms with TCAS phraseology. No special phraseology is needed after the TrA. Ask for a new clearance.*

However, also one finding was that clear of conflict should not be the phraseology used in the communication with the ATCO. From the ATCO perspective there has probably not been a conflict situation at all if the situation is solved by using the traffic avoidance functionality. It was suggested that "Clear of traffic" would be a better terminology to use. But one of the ATCOs participating in the simulation thought that not even "Clear of traffic" is a necessity but that a request to return to flight plan is all that is needed.

Another suggestion that was an outcome of the simulations is to confirm contact with traffic by the phrase "sensor contact". In all ATC simulation campaigns it has been discussed whether and how the remote pilot should confirm contact with an intruder if traffic information is provided from ATC. It was concluded already in the first campaign that it is highly desirable from an ATCO perspective that the remote pilot is able to call contact in a similar manner as a pilot in a manned aircraft is able to call contact when he sees traffic visually. Besides being coherent with manned traffic, being able to call contact also gives the ATCO an indication whether he/she needs to continue helping with traffic information. In the second campaign, the appropriate phraseology when traffic is displayed on the MIDCAS CDTI was discussed, since "visual contact" could be misleading. One suggestion was "CDTI contact". However, in the third simulation campaign is was suggested that "sensor contact" would be the best phraseology to use to confirm contact with other traffic.

Designing a D&A-system is a fine balance between safety and operability. The results from the ATC simulations indicate that for the TrA function the operability is more important than safety in some regards. This has big impact on the design of the TrA functions in the sense that for the TrA manoeuvre it is much more important that the maneuver is stable (not switching in direction or type) than that the manoeuvre suggested is the optimal one. The value of a suggested traffic manoeuvre is significantly higher if it is static during the time the remote pilot is communicating it to ATCO as well as during its execution. This added value from a static suggestion is normally significantly higher than the value obtained from constantly updating a traffic avoidance suggestion to find an optimal suggestion. Also, from the remote pilot perspective there were two reasons expressed for why the manoeuvre direction should be kept stable. First, it does not seem logical and trustworthy that the manoeuvre is changing direction from left to right several times during a few seconds. Second, it makes it hard to communicate the manoeuvre to ATC if the direction is constantly changing.

Another outcome of the simulations is that situations where an intruder makes an unexpected and sudden maoneuvre close to the RPA is outside the scope of the TrA function.

The main purpose of the TrA function is to handle situations where separation for some reason is not maintained. From an remote pilot view the traffic avoidance functionality is desirable. In the simulation campaigns it was found that it is very important that the system warnings shall not come too early nor too late. The pilots expressed a desire to not get any Traffic Avoidance warnings unless an intruder is indicated to pass within +-1000 ft altitude (all airspace classes).

A comment from the remote pilot was that to increase the level of trust in the system, a warning should come along with a manoeuvre proposal. This discussion also touches the discussions about responsibility. When does the responsibility transfer from the ATCO to the remote pilot? In one of the workshops it was discussed that the MIDCAS system has to work the same way as TCAS in respect to that it has to be clear when the pilot takes the responsibility. To all participants, it seemed clear that the pilot takes the responsibility when activating a collision avoidance manoeuvre. One of the ATCO stated: *The pilot is expected to act within his clearance. But if he has to do a manoeuvre to stay safe he is allowed to manoeuvre. It is up to the pilot is he considers he has enough time to first ask for new clearance or if he has to act right away.*

Another question discussed was how fast the ATCO expected the pilot to implement a new heading/clearance. According to the ATCO he wants to see the traffic start turning within 10 seconds. It was also concluded that it is just to start turning that is important, initially the exact heading is of less importance.

It is very clear from the simulations that the traffic avoidance function should not be executed in controlled airspace if it is not according to clearance. The system should warn and direct the attention of the remote pilot as well as perhaps suggest manoeuvres to the remote pilot as a decision support and as an input for the remote pilot's communication with the ATCO. The value of this input increases if it aids the remote pilot in asking for clearance and helping the pilot to maintain clearance.

The results from the performed research can guide future development of detect and avoid systems for remotely piloted aircraft and how to interact with them. The interaction could be designed in different ways and a future model for adaptive interaction would help guide the design. The results from this study could contribute to such a model that could address what information should be used for interaction, how it should be transmitted and who should be interacted with and when.

The literature provides general design guidance for intelligent adaptive automation and interfaces [5], but there is also a need to make design considerations specific to an applied context and its constraints. Building on adaptive interaction criteria [6,7], the results of this study could contribute specifically to adaptive interaction for future air systems regarding detect and avoid systems for remotely piloted aircraft.

Reflecting on the results of this study it involves domain specific results and thereby contributes to a selective fidelity analysis for modeling and simulation of adaptive interaction concerning detect and avoid systems for remotely piloted aircraft. If results are transferrable to other domains is for future research to investigate. However it is clear that that study has provided some context specific knowledge although it has been simulator based, so there will still be open questions regarding the validity for a future

applied context. The simulated context was wide in the since that it included several humans in the loop, which is central for the study of several sociotechnical systems. Context specific knowledge is important for usability, coherency, transparency, level of fidelity, validity (external and internal) and performance aspects including function allocation, guidance of multimodal interaction, as well as applied decision support.
Potential future work could very well include further development of systems and functions for detect and avoid for remotely piloted aircraft. However, future work could also include focused studies of related aspects. In addition, results and lessons learned may be transferred to the domain of decision support for manned aircraft by future research efforts.

5 Conclusions

To conclude, the findings of this study support the validation of the MIDCAS concept, by ATC simulations, and related debriefings and workshops with air traffic controllers and remote pilots. The MIDCAS system supported the work of ATCO and remote pilots.
The study contributed to domain specific results concerning detect and avoid for remotely piloted aircraft as an example of adaptive interaction for future air systems, with relevance for remotely piloted aircraft integration into civil airspace.
Findings include insights on the balance between safety and operability for the traffic avoidance function under study.
It is important that the manoeuvre is stable. It is more important that the manoeuvre is not switching in direction or type than that the suggested maneuver is optimal.
Another conclusion is that situations where an intruder performs a sudden or unexpected manoeuvre close to the RPA is outside the scope of the traffic avoidance function. Also, the main purpose of the traffic avoidance function is to handle situations when, for any reason, separation is not maintained.
A conclusion from this study is that, from a remote pilot perspective, the traffic avoidance function is desirable.
The detect and avoid system should support the cooperation between remote pilot and ATCO, for instance supporting the remote pilot in asking for clearance.
Specific conclusions include that system warnings should not come too early, nor too late. Traffic avoidance warnings should not be presented unless an intruder is indicated to pass within +- 1000 ft altitude, for any airspace class.
By providing domain specific results the study also contributes to a selective fidelity analysis for modeling and simulation of adaptive interaction of detect and avoid systems for remotely piloted aircraft. Knowing what is relevant for a specific context is important for usability, coherency, transparency, fidelity, validity and performance aspects including function allocation, guidance of multimodal interaction, as well as decision support.
Future work could include further development of systems and functions for detect and avoid for remotely piloted aircraft, but also focused studies of aspects not yet scrutinized. Also, the potential of transferring results and lessons learned to the domain of decision support for manned aircraft could become a future area of research.

Acknowledgement

The authors would like to thank the financers and organization of the MIDCAS project. The MIDCAS project is funded by the European Defense Agency, supported by the Ministries of Defense from five European countries. In addition, this conference contribution is also financially supported by the Swedish Foundation for Strategic Research.

References

[1] Pellebergs J. The MIDCAS project. In *Proceedings of the 27th International Congress of the Aeronautical Sciences, ICAS,* Stockholm, pp 3241-3247, 2010.

[2] Pellebergs J. MIDCAS: The European detect and avoid project. In *Book of Abstracts of the 4th International Congress of the European Aerospace Societies,* Linköping Sweden, p 189, 2013.

[3] Comstock J R, McAdaragh R, Ghatas R W, Burdette D W and Trujillo A C. UAS in the NAS: Survey responses by ATC, manned aircraft pilots, and UAS

pilots. In *Proceedings of the 17th International Symposium on Aviation Psychology,* Dayton OH, pp 383-388, 2013.

[4] Ternov S, Tegenrot G, Akselsson R. Operator-centred local error management in air traffic control. *Safety Science,* Vol. 42, No. 10, pp 907-920, 2004.

[5] Banbury S, Gauthier M, Scipione A and Hou M. *Intelligent adaptive systems – Literature-Research of design guidance for intelligent adaptive automation and interfaces*. CR 2007-075, Defence Research and Development Canada, 2007.

[6] Alfredson J. Adaptive interaction criteria for future remotely piloted aircraft. In *Proceedings of the 7th International Conference on Applied Human Factors and Ergonomic,* Orlando FL, Accepted.

[7] Steinhauser N B, Pavlas D and Hancock P A. Design principles for adaptive automation and aiding. *Ergonomics in Design,* Vol. 17, No. 2, pp 6-10, 2009.

Copyright Statement