# Workload of a collision avoidance system for remotely piloted aircraft

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**Abstract.** Active air traffic controllers and remotely piloted aircraft pilots were studied in a real time simulation providing results on actual and desired behaviour of the studied concept of a mid-air collision avoidance system in an air traffic control environment. The workload for the studied system seems to be acceptable at this state, and no major concerns regarding workload were found during the simulations. However, areas where the studied concept may be improved were identified concerning for instance suggested manoeuvre. A general conclusion from the simulations was that it is important that the D&A-system is correctly designed in regard to sensitivity.

**Keywords.** Workload, ATC, RPA, Collision avoidance

## 1. Introduction

As part of the European detect and avoid (D&A) project MIDCAS (Mid-air Collision Avoidance System) (Pellebergs, 2010; 2013), simulations have been performed with a remotely piloted aircraft system (RPAS) flying according to Instrument flight rules (IFR) in an Air Traffic Control (ATC) environment. The purpose of the project is to identify adequate technology, contribute to standardization and demonstrate a D&A system for RPAS able to fulfil the requirements for traffic separation and mid-air collision avoidance in non-segregated airspace. D&A is about determining the presence of potential mid-air collision threats and manoeuvring clear of them.

In a recent survey-study by Comstock, McAdaragh, Ghatas, Burdette, and Trujillo (2013) unmanned aircraft systems flying in the national airspace system have workload implications for the three groups, ATC, manned aircraft pilots and pilots of unmanned aircraft. In our study all three groups where represented in the simulations and assessment of workload was performed on remotely piloted aircraft (RPA) pilots and air traffic controllers (ATCO).

The performed simulations where carried out in two simulation campaigns carried out at Sturup, Sweden during one week in the spring and one week in autumn 2013, with some increased functionality, in the D&A system, in the second simulation campaign. The focus of the simulations performed was on evaluating interaction between the MIDCAS system, RPA pilot, ATC and surrounding Air traffic during mid-air collision incidents, including RPA pilot workload. The main subsystems were 1) Sense subsystem 2) Avoid subsystem (traffic avoidance and collision avoidance) and 3) Human Machine Interfaces. Figure 1, below, show a principal sketch of collision avoidance (CA) and traffic avoidance (TrA), whilst Figure 2 depicts an overview of the MIDCAS HMI, used in the simulations. CA being the last instance, high performance manoeuvre to be performed when collision is imminent and TrA being gentler, strategic manoeuvre to stay “well clear”.

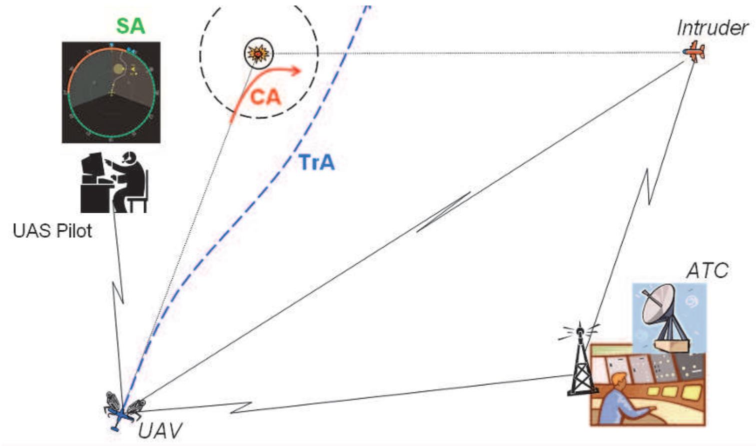


*Figure 1. Principal sketch of Collision Avoidance (CA) and Traffic Avoidance (TrA).*

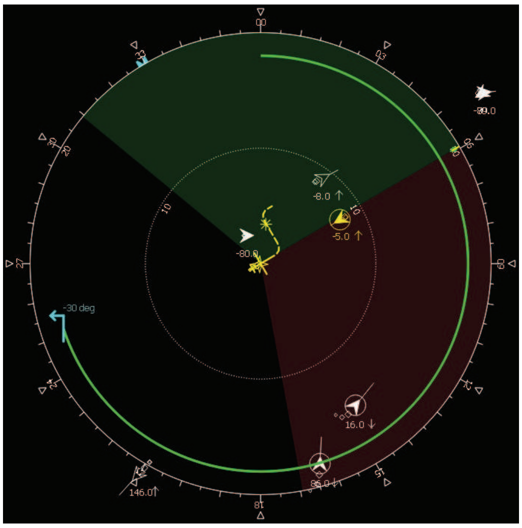

*Figure 2: Overview of MIDCAS HMI (Example from: Run 2 – Team 2, Conflict #3, Sim. 1)*

## *1.1 Workload*

Workload is a well-established concept, used for evaluation of human work in a wide area of applications, including air traffic control (Lee, Jeon, & Choi, 2012; Loft, Sanderson, Neal, & Mooij, 2007; Zhuoxi, Yangzhou, Zhenlong, Defu, & Hong, 2013). In this study, the concept of workload has been used as a frame of reference in the dialogue with participants as well as a concept for creating reliable and valid work constraints regarding scenario generation and simulation setup.

Workload is interesting to study by itself, but it is also interesting to study together with other concepts. Wickens (2002) describes the way the concepts of mental workload and situation awareness (SA) are linked. Mental workload and SA has also been shown to be systematically related to performance (Castor 2009; Svensson, Angelborg-Thanderz, & Sjöberg, 1993; Svensson, Angelborg-Thanderz, Sjöberg, & Olsson, 1997; Svensson & Wilson, 2002). Good SA is important for the ATCOs ability to handle unexpected aircraft behaviour (Endsley & Smolensky, 1998).

Controller workload is increasing with higher airspace complexity (Kopardekar, Schwartz, Magyarits, & Rhodes, 2009). However, in these simulations the airspace complexity was controlled through the design of traffic in the applied scenarios. The aim was to provide the participants with realistic workload, although the simulation environment was not identical with a real world setting in all relevant aspects.

## 2. Methods

The method used in this study is human-in-the-loop simulations. The two ATCOs participating in the simulations were both active ATCO in the real airspace that was simulated in the study, one with nine years of experience in that position, and the other with two years' experience in that position. The two RPA-pilots were both experienced pilots. One was a flight instructor and Saab 2000 pilot, and the other had 33 years of experience as military and civil pilot. The technical set-up of the simulation is illustrated in Figure 3, below.

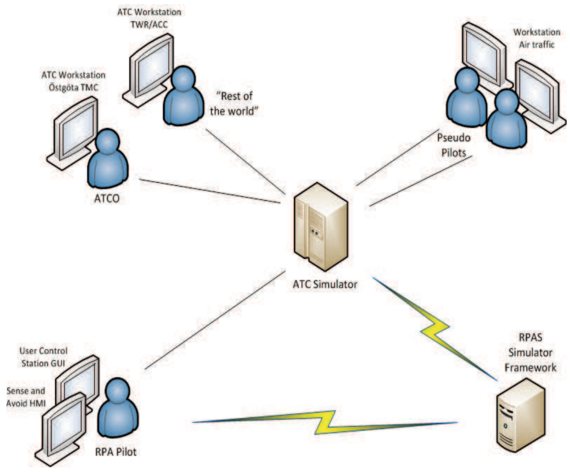


***Figure 3: Technical set-up***

There were two different teams participating in the simulations (change of both RPA Pilot and ATCO). The simulated airspace was the Ostgota TMA. Contextual information was carefully provided to the participants since potential misunderstandings of clearances might depend on certain flights or certain waypoints (Ternov, Tegenrot, & Akselsson, 2004). There were three active airports/CTRs, the Linköping/ Saab CTR, the Norrköping/Kungängen CTR, and the Stockholm/Skavsta CTR. Both airspace class C and E were simulated. Each team consisted of one ATCO, one RPA pilot and two Pseudo pilots (controlling all manned aircraft and responding to ATCO communication) along with an additional "Rest of the world"-position in order to make the exercise realistic. 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.

Data was collected for qualitative analysis including: Observer logs, questionnaires, and notes from debriefings/workshops. Debriefings were held after each run performed and notes were collected by observers. In addition notes were taken for the end of trial debriefings along with the workshop in the end of the week. Since the participants were instructed to act in different ways, except for ATCO who was given instruction to act "as at work", for each conflict event during the simulation they gained different experiences from the different runs.

Also, assessment of workload by instantaneous self-assessment (ISA) was performed every second minute. ISA is a subjective measure of workload. It was integrated into the work environment for the RPA Pilot and the ATCO, and showed up on screen every second minute. The RPA Pilot and ATCO were instructed to mark their peak mental workload since last update. The scale was 1-5 (very low – very high) and the numbers were defined as followed:

**1 - Very low**: none to very few situations to keep track of, workload significantly

below
usual quiet time in operations
**2 - Low:** workload comparable to low workload periods in daily operations
**3 - Average:** workload comparable to typical operations outside peak and night traffic
**4 - High:** workload comparable to peak traffic periods in daily operations
**5 - Very high:** too many situations to keep track of, workload significantly higher than real life peak periods, safety might be a concern.

The RPA Pilot and the ATCO were instructed to prioritize between their tasks in the following order:

- 1 Keep acting in your role
- Mark ISA score

In addition, the observers were instructed to knock on the shoulder of the RPA Pilot/ATCO in case they missed the ISA rating.

Although not reposted in this paper, simulation recordings were performed for technical analysis and assessment of situation awareness by the subjective SASHA questionnaires were also filed for complementing analyses not reported in this paper.

## 3. Results

The results from the qualitative analysis based on observer logs, questionnaires, and notes from debriefings/workshops include:

From an ATC perspective the big challenge in designing the Detect and Avoid-system was expressed by ATCO team 2: "*Make the system invisible. I should not notice there is a MIDCAS system.*"

An indication that a preference might be to only show manoeuvre suggestion upon request by the pilot, is the way the RPA pilot team 2 acted in run 6, when he was requested to act as he liked. Here, the RPA pilot used the MIDCAS HMI for situation awareness, but implemented all manoeuvres on his own using the Remote Control Panel (RCP). However, this might also be due to the undesired complexity of the TrA manoeuvres suggested by the system in its current implementation, as indicated by a comment in the questionnaire: "*I feel good when I decide in cooperation with ATC what to do. I feel good SA looking at the HMI display .I can make a simpler manoeuvre myself than the system propose, for example just a heading change instead of multiple turns ("S-curve")*"

In the response to the questionnaires and in the workshops the participants stated that only one simple manoeuvre with a specified end state should be used. Also, as few dimensions changes as possible (if you are in climb when a heading change is initiated the manoeuvre should be performed during sustained climb – do not level out initially) as well as a stable and consistent manoeuvre type, direction and if possible strength (same suggestion as long as manoeuvre is safe).

Regarding the communication the participants stated that it is important to give the pilot sufficient time to communicate a manoeuvre to ATCO for TrA manoeuvres, as new clearance needs to be given for these manoeuvres in controlled airspace. Whereas CA manoeuvre should be communicated to the ATCO after initialization, as pilot is responsible for preventing collision, similar to the TCAS for manned pilots.

The ISA ratings were generally not high, see Table 1, below. In total, ISA was asked for 1147 times, of which only 25 times the participants did not provide a response. For instance, the second simulation ISA-ratings were asked for 205 times for the RPA-pilot. Only at five times did the RPA-pilot not give a response. The mean value of the ratings (n=200) were 1.5. Not at any time did the RPA-pilot nor the ATCO provide the highest available rating (i.e. 5).

***Table 1. Mean values of ISA ratings of workload.***

| Mean values: ISA | RPA-pilot | ATCO |
|---|---|---|
| Simulation #1 | 1.84 (n=337) | 1.69 (n=361) |
| Simulation #2 | 1.50 (n=200) | 2.65 (n=224) |

The results of the ISA ratings are in line with data collected in questionnaires. For example for question "The system does not increase workload to a degree where primary mission objectives are comprised or additional flight crew members are needed" there are 13 agree-responses and only three disagree-responses from the RPA pilots.

One of the major discussions in the debriefings was whether the traffic avoidance functionality is desirable or not. For all participants it was quite obvious that the traffic avoidance functionality is a good tool in airspace classes D and E (and below). However, for airspace class C it is not obvious to the same extent, since ATC is responsible for separation against IFR as well as VFR traffic. The outcome of the discussion was that the RPA pilot always has to follow clearance or ask for new clearance regarding traffic avoidance in controlled airspace.

In workshops it was concluded that collision avoidance is very different from traffic avoidance in that the pilots are allowed to do anything to avoid a collision (even violate a clearance), which potentially affect technical system requirements of a mid-air collision avoidance system.

An ATC perspective is that ATCO does not want to treat the RPA differently than other traffic. For instance, the ATCO expressed that it is important that pilot is able to call contact by the information from the MIDCAS system in a similar manner as a pilot in a manned aircraft is able to call contact when he sees traffic visually. The clearance has to be in line with current communication in semantics and complexity. The clearance should only involve one manoeuvre with a specific end state, and thus primarily be to a new heading or altitude.

A general conclusion from the qualitative analysis was that it is important that the D&A-system is correctly designed in regard to sensitivity. A system that is too sensitive and provides unjustified warnings and changing manoeuvre suggestions will only be frustrating for the RPA Pilot and possibly also for the ATC.

## 4. Discussion and Conclusion

The workload for the studied system seems to be acceptable at this state, and no major concerns regarding workload were found during the simulations. However, areas where the studied concept may be improved were identified concerning for instance suggested manoeuvre. A general conclusion from the simulations was that it is important that the D&A-system is correctly designed in regard to sensitivity.

The RPA pilot workload, as assessed by ISA-ratings, was moderate in the performed simulations. This was quite consistent over time and over various conditions (between runs). The ratings obtained were not extreme in any way and the results support the idea to perform simulations with realistic level of workload to achieve simulation validity.

Still, the pilots have missed to rate the ISA at a few occasions. Why they missed is hard to tell. It might be due to such a high workload that he did not manage to also rate the ISA. But the reason might also be that the workload was so low that the pilot for example was talking to people around and because of that missed the ISA rating. A guess is that if ratings around the missed rating are high, the pilot probably missed the ISA because of high workload.

This simulations add to the findings from Comstock, McAdaragh, Ghatas, Burdette, and Trujillo (2013) that unmanned aircraft systems flying in the national airspace system have workload implications for the three groups, ATC, manned aircraft pilots and pilots of unmanned aircraft. However, our findings indicate that the workload could be manageable. Baring in mind that this study only is a simulation study, simulation studies of mental workload has been shown to be transferable to real world equivalents (Dahlström & Nählinder, 2009; Nählinder, 2009).

Also, keeping in mind that RPAs are new in this kind of setting and that there are state-of-the-art methods to enhance safety within the domain of air traffic control (Ternov, 2011; Ternov, Tegenrot, & Akselsson, 2004) when they will be in use and we all can learn from practice, the result from this simulations are hopeful.

Further research is needed to better understand this area. As part of that a third simulation campaign is planned, with enhanced functionality.

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