OPERATOR SUPPORT FOR TIME-CRITICAL SITUATIONS: DESIGN AND EVALUATION

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Abstract

The Ground Control Station (GCS) is a critical element in the control of Unmanned Aerial Vehicles (UAVs). Important issues in designing a GCS concern the automation, autonomy and authority of operator support functions. The research described in this paper focuses on the design and evaluation of both operator support functions that act in the time-critical domain and the Graphical User Interface of the GCS. The operator support functions are based on the current Airborne Collision Avoidance System and Terrain Awareness Warning System. Those algorithms have been extended to enable autonomous function execution. The evaluation has been done in two experiments. The objective of the first experiment was to explore the influence of the level of authority (LoA) assigned to the system on operator Situational Awareness (SA) and performance. The results of Experiment 1 showed no influence of LoA on operator SA and performance. Possibly, no differences between the LoAs were found, because user interventions occurred most often in the tactical time domain, whereas the autonomous functions operate in the time-critical domain. However, although participants had enough level 3 SA (projection of current state into the future) to timely detect conflicts, they often did not come up with a good solution for them. In these cases, the solution to one conflict directly caused a new conflict. It also occurred that participants misjudged a safe situation as an upcoming conflict, intervening when this was not necessary. In order to better support operator SA, the GCS displays were redesigned. A second experiment was conducted, investigating the effect of the modified displays and the influence of LoA on operator SA and performance. The results of this experiment showed no significant influence of LoA. With the modified displays, only one unnecessary intervention occurred, and not one solution to a conflict caused a new conflict. This led to the conclusion that the modified display design provided the participants with better terrain awareness (level 2 SA) and better level 3 SA in the vertical dimension.

Introduction

The Ground Control Station (GCS) is a critical element in the control of Unmanned Aerial Vehicles (UAVs). The information provided by the GCS and the way of presenting this information to the operator are important factors in the Situational Awareness (SA) that can be achieved by the operator. Important issues in designing a GCS concern the automation, autonomy and authority of operator support functions. Typically, humans are better able to adapt to a changing environment and to make appropriate decisions than a computer [1]. High-level automation of decision selection and action may be justified in highly time-critical situations in which there is insufficient time for a human operator to respond and take appropriate action [2]. This is also recognized in [3]: '*the primary mode of operation of a UAV (...) should entail oversight by the pilot-in-command, who should at all times be able to intervene in the management of its flight*'. A '*back-up mode of operation should enable the UAV to revert to autonomous flight that is designed to ensure the safety of other airspace users*'.

The discussion about autonomous systems aboard aircraft is not limited to unmanned vehicles. Recent developments show that there is an interest in automation of time-critical systems for manned aviation. For example, Airbus is exploring the possibilities of integrating both an auto pull-up option [4] and an autopilot traffic-alert and collision avoidance system [5] in their new aircraft.

Levels of Authority

A system of eight levels is developed in [6] to indicate the amount of automation that is incorporated in a function, its level of autonomy and whether the function execution authority is assigned to the system or to the operator. In this paper, the Sheridan levels are interpreted as levels of authority (LoAs). The Sheridan levels vary from level 1: ‘Computer offers no assistance, human does all’ to level 8: ‘Computer selects method, executes task and ignores human’. In table 1 below, the levels of authority as defined in [6] are given.

Table 1. Levels of Authority

Level	Computer task	Human task
1	No assistance	Does all
2	Suggests alternatives	Chooses
3	Selects way to do task	Schedules function
4	Selects and executes	Must approve
5	Executes unless vetoed	Has limited veto time
6	Executes immediately	Informed upon execution
7	Executes immediately	Informed if asked
8	Executes immediately	Ignored by computer

As indicated in the table, the levels of authority can be divided in three groups. In level 1 to 4 the operator has authority over function execution; in level 6 to 8 authority has moved to the system. In level 5 the authority is shared between the system and the operator. Figure 1 below shows the interaction between automation, autonomy and authority for a function that is part of a UAV system.

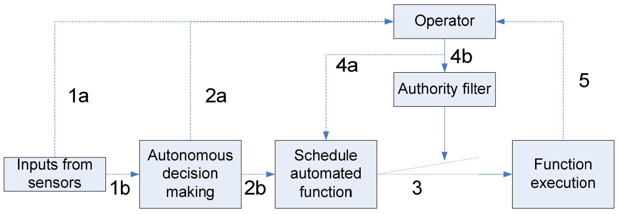

Figure 1. Interaction between Automation, Autonomy and Authority

Depending on the Sheridan level of the function, the raw sensor data is presented to the operator (arrow 1a) or used by the system part ‘Autonomous decision making’ to decide what action must be taken (1b), given these sensor inputs. Then, the system can suggest a particular function to the operator (2a), who then schedules the function execution (4a) or the system can select and schedule an automated function (2b). Whether the execution of the scheduled function must be acknowledged by the operator, depends on the LoA assigned to the function (4b). This is visualized by the ‘Authority filter’ and the switch below the filter that determines whether the scheduled function is executed (3). Depending on the setting of the ‘Authority filter’, the operator does or does not receive feedback upon function execution (5).

The interaction can be summarized as: Autonomy schedules automated functions, while authority allows or blocks function execution.

Human versus Computer Performance

When designing a system with flexible levels of authority, it is important to notice strengths and weaknesses in both human and computer performance.

Human operator strengths are clearly stated in [1]: *“Humans can respond perceptually to a changing environment and to relations in the environment. They can go beyond the information immediately given, respond to low-probability occurrences, and adopt alternative strategies and alternative modes of performance when necessary. In short, humans are flexible.*” On the other hand, having a human in the loop may also have disadvantages: “*Humans are also variable (they produce errors), and they may become creative in changing their responses when it is not optimal to do so.*” [1].

The potential contribution of the human operator’s flexibility to identify opportunities for appropriate solutions diminishes when the operator suffers from reduced SA or an out-of-the-loop experience. The human operator may also perform an inadequate action in a time-critical situation, when the operator does not have enough time to assess the situation and generate appropriate action. In those cases the autonomous system shows its strengths: A computer is able to determine an appropriate action, based on rule-based logic, much faster than a human operator.

As vehicle/system autonomy increases, the role of the operator changes from that of a manual controller to a supervisory controller. Successful coordination requires the operator to understand the tasks and goals of the automated system and to be able to predict how the system will respond to environmental perturbations as well as operator input [7]. In case of a UAV GCS, this depends highly on both the level of authority and the design of the interfaces.

Design

In the exploration of the influence of both the system LoA and the display design of the GCS on operator SA and overall performance, we used the research described above [1,2,6] as a framework. In the exploration, the level of authority functioned as the independent variable. Thus, functions were needed that are good candidates for being assigned a high LoA. According to [2], these are functions that act in the time-critical domain. Examples of this type of functions are functions that support the operator in the timely detection of potentially hazardous situations with respect to terrain and traffic separation. Therefore, functions have been developed and implemented that perform predictions on the likelihood of occurrence of these situations. For the development of these functions, the current Airborne Collision Avoidance System (ACAS) and Terrain Awareness Warning System (TAWS) algorithms have been used as a starting point. The traffic avoidance and terrain avoidance functions can be assigned different levels of authority, based on the system, summarized in Table 1.

Traffic Avoidance

In manned aircraft, pilots are instructed to always follow a Resolution Advisory (RA). Together with the remarks on autonomous action in [2] and [3], this led us to extend of the ACAS algorithm such, that it is able to autonomously follow a RA. This extended ACAS algorithm can be set to function at different levels of authority.

Traffic Avoidance at Different Levels of Authority

The baseline level is the level at which the system is currently used: the system gives a Traffic Advisory (TA) and if necessary an RA; the operator has to execute the manoeuvre. This corresponds to LoA 4.

The traffic avoidance function could also be assigned LoA 6. This level was integrated in the setup because now, the RA is executed autonomously, while the operator is still being informed upon function execution.

The third authority level used in the setup is LoA 8. This level is used to find out if, and if yes, how much operator SA will suffer due to the lack of information, and whether giving the system full authority will change performance.

Terrain Avoidance

The function that supports the operator in the timely detection of conflicts with respect to terrain separation is based on the current Terrain Awareness Warning System. The algorithm can be divided into three stages: conflict predicton, conflict assessment and resolution selection, as depicted in Figures 2, 3 and 4.

Conflict Prediction

The algorithm scans the terrain database between a predetermined distance to the left and right along the predicted track of the aircraft. The actual flight path angle is used to estimate the height at which each point will be cleared. In case this clearance height is below the specified minimum, the point is identified as a conflict location. Figure 2 shows an example of a forward scan and a scan into a turn. In this example, the forward scan covers and area of width w and length d_1. At distance d_3 the start of a conflict is detected.

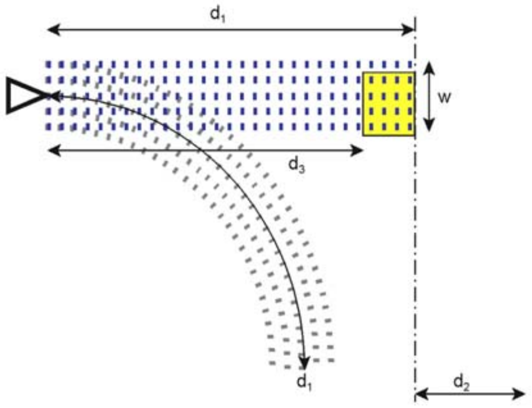

Figure 2. Conflict Prediction

Conflict Assessment

In case a conflict is detected, the algorithm increases its scanning distance to d_4 (see Figure 3) and starts to assess the conflict. Based on a predetermined setting of maximum flight path angle and maximum change in flight path angle, it is determined whether evasive options in the lateral domain need to be investigated. In the example shown in Figure 3, the red area represents an obstacle that requires a flight path angle that is above the specified threshold. In this case, the algorithm starts to search in the lateral domain. Figure 4 shows an example in which the algorithm searches over an angle α and identifies an area to the left of the obstacle that does not yield a terrain conflict. Depending on the situation, multiple solutions may be available. The most appropriate solution is determined by the resolution selection function.

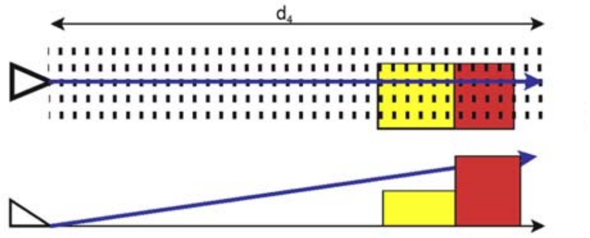

Figure 3. Conflict Assessment (I)

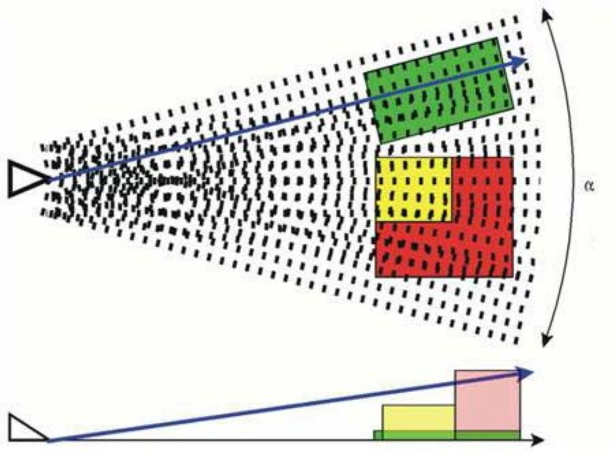

Figure 4. Conflict Assessment (II)

Resolution Selection

In case multiple solutions are available, the resolution selection function determines the lateral and vertical maneuver that will be used. The factors that are weighed are the required lateral deviation from the planned track and the increase in flight path angle that is required. For all options that are possible with a reduction in flight path angle, only the required track deviation is used in the cost function.

Terrain Avoidance at Different Levels of Authority

For the terrain avoidance function, the baseline level corresponds to the current Terrain Awareness Warning System; the system generates a warning when the aircraft will come below a predetermined minimum safe altitude above terrain when the current flight path vector is maintained. This corresponds to LoA 3.

The terrain avoidance function can also be assigned LoAs 6 and 8. When assigned LoA 6, the system will give the operator a warning and execute the manoeuvre, calculated as explained above, autonomously. At LoA 8, the manoeuvre will be executed autonomously without informing the operator.

Graphical User Interface

This section will discuss the display design of the GCS. The setup used in this exploration consists of two screens, located on the right side of the GCS concept demonstrator, shown in Figure 5.

Figure 5. GCS concept demonstrator

The upper display provides an ego-centric view of the situation, whereas the touchscreen shows a map-view and is referred to as 'planner screen'. The planner screen is also used for interaction with the (simulated) air vehicle. Figures 6 and 7 show the displays.

In Figure 6, the UAV and its altitude are shown in white, the UAV track in magenta and other traffic with altitude information in blue.

Furthermore, terrain above UAV flight level is colored red. This is also the case in the ego-view display, as depicted in Figure 7.

In the ego-view display, a real-time sensor image is integrated. These displays were used in Experiment 1.

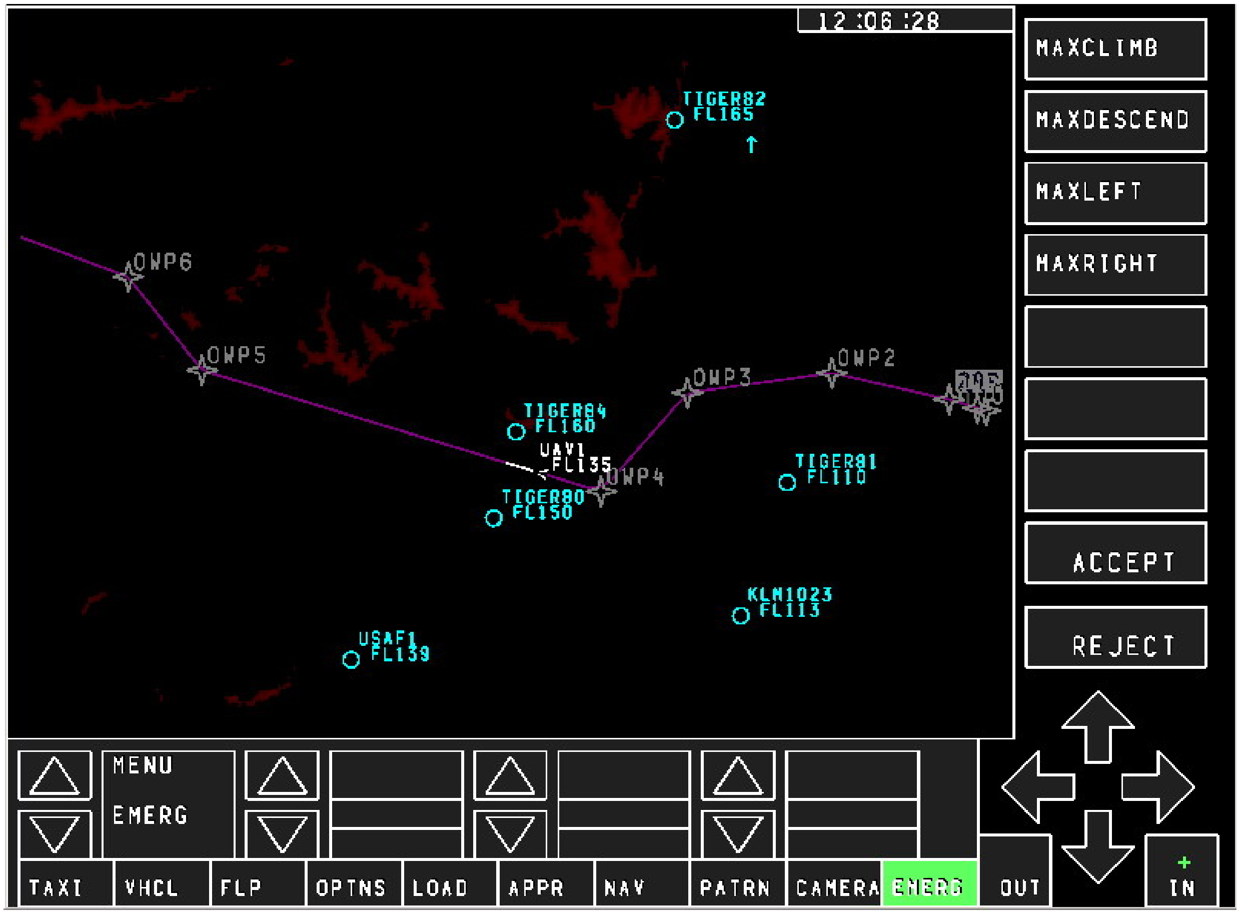

Figure 6. Scenario 1 on Planner Screen

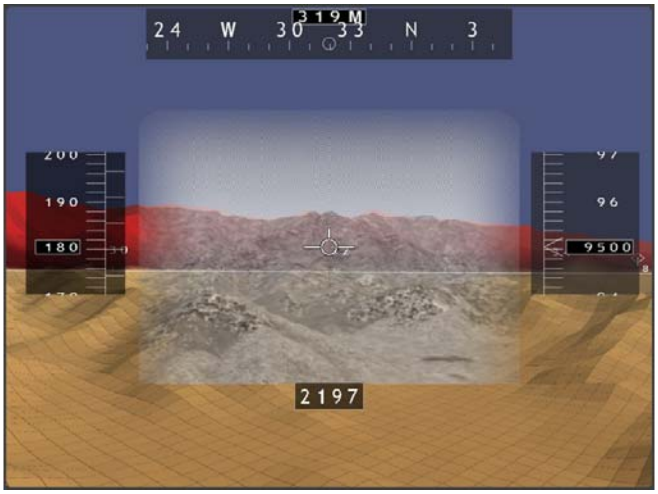

Figure 7. The Ego-view Display

Evaluation

To explore the influence of both the system LoA and the display design of the GCS on operator SA and overall performance, two experiments were conducted. These experiments and their results will be outlined in this section. Since a good understanding of the situation is necessary to perform well, performance in this experiment was considered indicative of SA.

Experiment 1

In the first experiment, the relation between system LoA and operator SA and performance was explored. It was hypothesized that operator SA will be optimal with a medium LoA, because the operator does not have to put effort in functions the system can perform better (information acquisition and analysis), so he can turn his attention to optimal understanding of the situation [8]. With low LoA, operator SA will be average because the operator has to perceive, comprehend and project the information present in the environment for himself [9], leaving less resources available for building up SA. When a function has high LoA the operator is taken out-of-the-loop, which will also result in low operator SA [2].

The extended operator support functions discussed earlier are used to investigate the effect of system LoA on operator SA and overall performance.

Participants

Participants of the experiment were 12 male students of the Netherlands Defence Academy (NLDA), ranging in age from 19 to 31 years, with an average of 25 years. None of them were pilots and all had a technical background.

Apparatus

The GCS concept demonstrator shown in Figure 5 has been developed during our research in this field [11,12,13]. In the experiments, the surroundings of Kabul, Afghanistan were used to create a plausible UAV reconnaissance environment. Participants sat on the right side of the demonstrator, using the two screens in front of them.

Procedure

Participants each performed three runs of about 12 minutes. Each run consisted of an approach to, or a departure from Kabul airport. The routes in the runs were all different to prevent area recognition. In one run, both functions worked at their basic authority level, referred to as LoA 4/3 (LoA assigned to traffic avoidance function/LoA assigned to terrain avoidance function). In the other runs, both functions worked on authority level 6 (LoA 6/6) and authority level 8 (LoA 8/8), respectively.

During each run, three events (unexpected by the participant) occurred, necessitating manoeuvres to avoid a traffic or terrain conflict. When a participant wanted to execute a manoeuvre in order to avoid a supposed conflict, he first had to ‘contact ATC’ using a button on the roller-ball to get clearance for the desired manoeuvre. When this button was pushed (referred to as user intervention), the system ‘held’, meaning the simulation was paused by the system. When an imminent conflict was not timely detected by the participant, the system itself would hold (system intervention). In both the LoA 4/3 and the LoA 6/6 condition, the system held on the moment the alert was given. In LoA 8/8, the system held when the function executed a manoeuvre. When the system held, either due to a user intervention or a system intervention, the participant was given a questionnaire, consisting of six questions concerning his knowledge of the current situation. In the hold-mode, the displays were blank. Upon finishing the complete experiment, the participants were given another questionnaire in which they were asked to rate their SA, performance and workload on a 7-point scale.

The actions that could follow after a system hold can be divided into the following categories:

- Correct system action: the manoeuvre the participant chose to execute was the same as the time-critical system would have executed.
  It is important to note, that a correct manoeuvre is not necessarily a timely manoeuvre. When an action, which is by itself a correct action and therefore classified as such, is not timely executed, this may not result in enough separation to prevent the time-critical system from being triggered and issueing a Traffic Advisory and maybe even a Resolution Advisory.
- Correct non-system action: the manoeuvre the participant chose to execute is not the same as the time-critical system would have executed. However, the manoeuvre did solve the conflict. This type of manoeuvre may not have been according to rules of the air; this aspect was not taken into account.
- Incorrect action: the manoeuvre the participant chose to execute did not solve the conflict and/or caused a new conflict.
- Unnecessary action: the participant performed a manoeuvre, although there was no imminent conflict.

- Action performed by system: this category applies after a system intervention in LoA 8/8, because at that moment, the system has already executed the manoeuvre.
- No action required: it is possible that a participant unnecessarily intervenes in the scenario, when he misjudges a certain situation. As a consequence, the participant may miss an event that other participants did handle. When this happened, this is incorporated as ‘no action required’.

If a manoeuvre was followed by a second manoeuvre (for example in case the participant concluded he had executed an incorrect manoeuvre and tried to improve the situation), only the first manoeuvre was included in the experiment data.

Independent Variable

The independent variable is the level of authority for the traffic avoidance and the terrain avoidance functions respectively, and has three levels: LoA 4/3, LoA 6/6 and LoA 8/8. Participants perform each run in a different LoA condition.

Dependent Variables

SA and performance were measured through the type of interventions and manoeuvres (actions), the number of RAs given, as well as the questionnaire. The questionnaire consisted of six questions concerning the nature and location of the (possible) conflict in relation to the own vehicle and what kind of manoeuvre the subject wanted to execute in order to avoid the conflict. Scores could range from 0 to 6.

Results

At each LoA, more user interventions occurred than system interventions, indicating that participants often detected a conflict in the tactical time-domain, especially in LoA conditions 4/3 and 6/6. Figure 8 shows the number of system and user interventions per LoA, summated over events and participants. When interpreting this Figure, the differences between LoA 8/8 on one hand and LoAs 4/3 and 6/6 on the other hand must be kept in mind: In LoA 4/3 and 6/6, a system intervention occurs at the moment of the Traffic Advisory. In LoA 8/8, a system intervention occurs after the autonomous execution of the RA. Thus, it is possible for a user to intervene after the TA in level 8/8. The user interventions that occurred after this moment are shown in the orange bar. The grey bar shows the number of system interventions, whereas the green bar shows the number of user interventions.

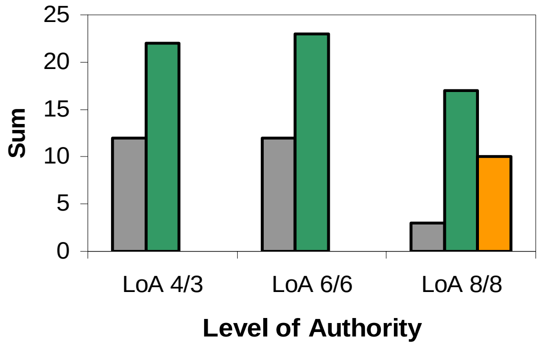

Figure 8. Frequencies of System and User Interventions

The total number of interventions is not necessarily equal for all conditions. In certain situations, participants made an unnecessary intervention, causing them to miss the event that was planned after this unnecessary intervention. This phenomenon will be discussed later.

Most actions performed by the participants were correct system actions. The distribution of the types of actions is similar across the different LoAs.

For each event, an untimely detection or incorrect action could result in a traffic-conflict situation in which case an RA was issued by the system. In Experiment 1, a total of 108 events occurred, 36 per LoA condition. Overall, 31 of these events resulted in an RA: 8 in LoA condition 4/3; 10 in LoA 6/6; and 13 in LoA 8/8.

There were two situations in which many participants made an unnecessary intervention to prevent a supposed conflict; one at the beginning of scenario 1, the other at the beginning of scenario 3. Table 2 shows the number of times participants performed an unnecessary user intervention, followed by an unnecessary action.

Table 2. Frequency of Unnecessary User Interventions and Terrain Conflicts

Frequency of unnecessary user interventions, followed by unnecessary actions			
LoA	Scenario 1	Scenario 3	*Total*
4/3	2	3	*5*
6/6	2	2	*4*
8/8	3	1	*4*
Frequency of terrain conflicts			
LoA	Scenario 1	Scenario 3	*Total*
4/3	1	3	*4*
6/6	3	3	*6*
8/8	1	2	*3*

Since every run was performed by four participants in each LoA condition, the maximum frequency of the unnecessary user interventions and the terrain conflicts for each condition per run was ‘4’.

Also shown in this table are the number of times a terrain conflict occurred. In the experiment, two situations were set up so that the time-critical system would advise or execute a descend manoeuvre to avoid other traffic flying above the UAV (one in scenario 1, the other in scenario 3). However, this manoeuvre could lead to a terrain conflict. To avoid the terrain conflict, participants had to do an alternative (non-system) manoeuvre to avoid the traffic, or timely return to the planned route after the descend (system) manoeuvre. In the first situation, the terrain conflict occurred five times, four of which were preceded by a user intervention for the traffic conflict. In the second situation, the terrain conflict occurred eight times, all preceded by a user intervention for the traffic conflict.

In Table 3, the mean scores and standard deviations on the objective questionnaires are shown for the different LoAs. Since the questionnaire consists of six questions, scores could range from 0 to 6. The high mean scores indicate that participants were able to correctly answer most of the questions concerning the situation at hand. The answers of the questionnaires show no significant differences between the LoAs ($\chi^2(2) = 1.135$, $p > .05$).

Table 3. Objective Questionnaire Mean Scores and SD

	Mean	SD
LoA 4/3	4.82	1.20
LoA 6/6	5.26	0.95
LoA 8/8	5.31	0.75

The results of the subjective questionnaire showed no significant differences between the different LoAs. The mean score on SA was 4.8, averaged over conditions and participants.

Discussion

Often, participants detected imminent conflicts in the tactical time domain, which is reflected by the fact that user interventions occurred more often than system interventions. This applies to all three LoA conditions. Furthermore, user actions were similar across the different LoAs. The results concerning type of action were influenced more by the events and by interpersonal differences, than the LoA. The frequency with which unnecessary user interventions occurred did not show any clear differences between the LoA conditions, and the same applies to the terrain conflicts. Finally, the scores participants obtained on the objective questionnaires were not significantly influenced by LoA either. Therefore, based on the results concerning user interventions, actions, and the objective questionnaires, it cannot be concluded that LoA had any influence on operator SA and performance.

High mean scores on the questionnaire indicate a good perception of the situation (good level 2 SA). Also, in 63% of the events, participants had enough level 3 SA (projection of current state into the future) to detect an upcoming conflict before the time-critical system was triggered. Although most actions following the interventions were correct system actions, it also frequently occurred that participants executed a manoeuvre that led to a new conflict. For example, a participant would correctly assess a situation as an upcoming traffic conflict, but then avoid this traffic in a way that led to a terrain conflict. Furthermore, participants also performed many unnecessary actions, apparently misjudging a safe situation as an upcoming conflict. These results indicate that participants often did not have a good enough understanding of the situation to decide whether or not a manoeuvre was necessary, and if so, what action to undertake to avoid conflict without causing a new conflict. It was therefore decided to investigate whether and how unnecessary manoeuvres, or manoeuvres leading to a new conflict, could be prevented.

In order to prevent conflicts without stimulating unnecessary actions, two options are available. First, procedures can be developed on how and when the operator is allowed to interfere with the system. Although this can prevent unnecessary interference, it also limits the operator in his ability to find creative solutions the system is not capable of. Another option is redesigning the interface in order to improve operator SA in the tactical time domain. We chose to follow the latter option and made several modifications to the GCS displays.

Display Modifications

On the planner screen, a map was integrated in the background to provide the operator with information on the area the UAV is flying above. To support the operator in interpreting the course of other traffic, a directional symbol was used for traffic instead of a circle. To facilitate the operator in predicting the vertical component of the UAV route, the altitude and speed belonging to each waypoint were shown on the planner screen. This showed the operator the altitude and speed the UAV would have at each waypoint according to the planned route. The modified planner display, in case of a TA, is shown in Figure 9.

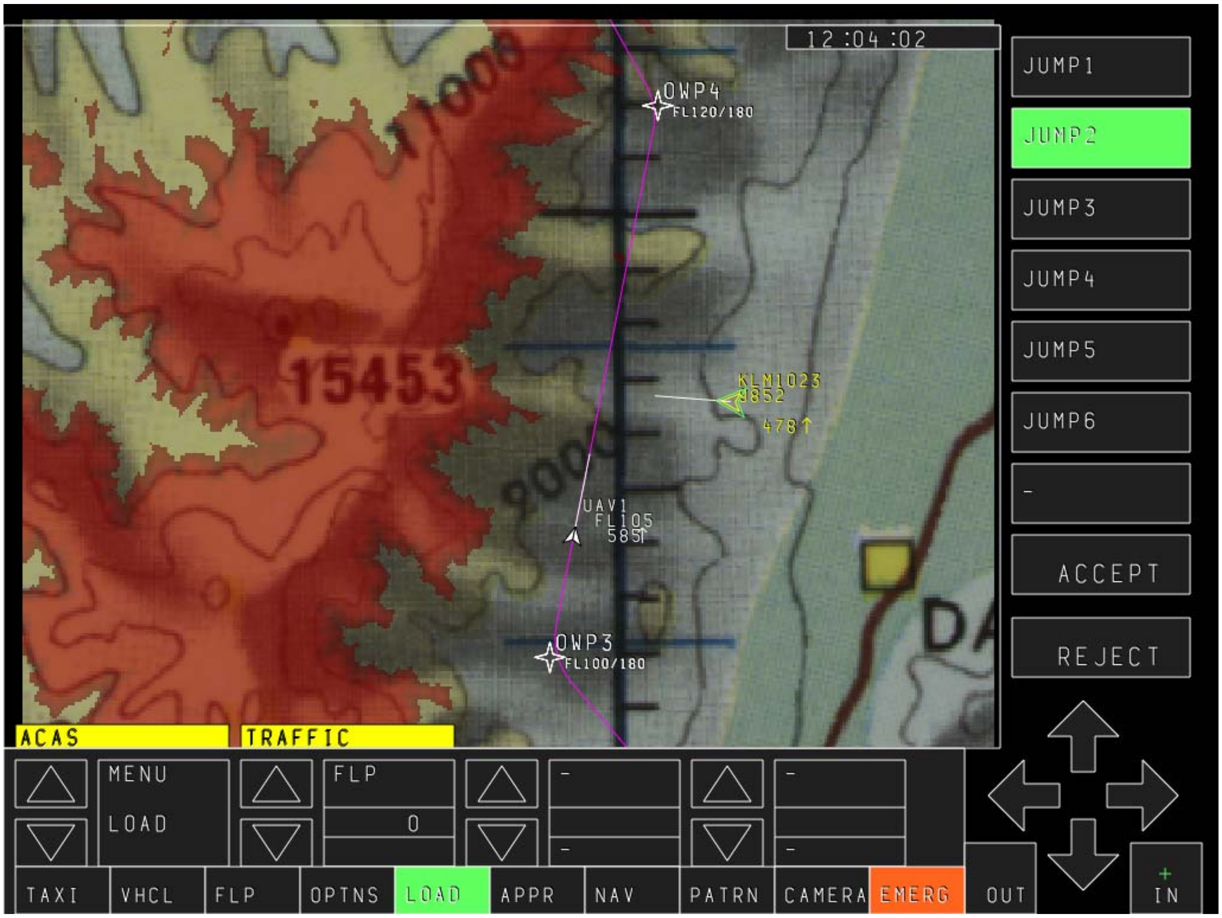

Figure 9. The Modified Planner Display

In the ego-view display, the future flight path was integrated, depicted as a tunnel to give the operator more insight in the planned route in its environment. Besides the ego-view display, two other elements were shown in the upper screen. Under the ego-view, we added a so-called Vertical Profile Display (VPD) to give the operator extra insight in the profile of the terrain below the planned route. Also, the ACAS display which in the setup of the first experiment showed up in case of an alert was now integrated in the upper right corner of the screen. On this display, the intruding traffic was marked yellow in case of a TA and red in case of an RA. Traffic not causing a system alert was shown in blue, as on the planner screen. The modified upper screen, in case of a TA, is shown in Figure 10. An overview of all display modifications and their goal is given in Table 4.

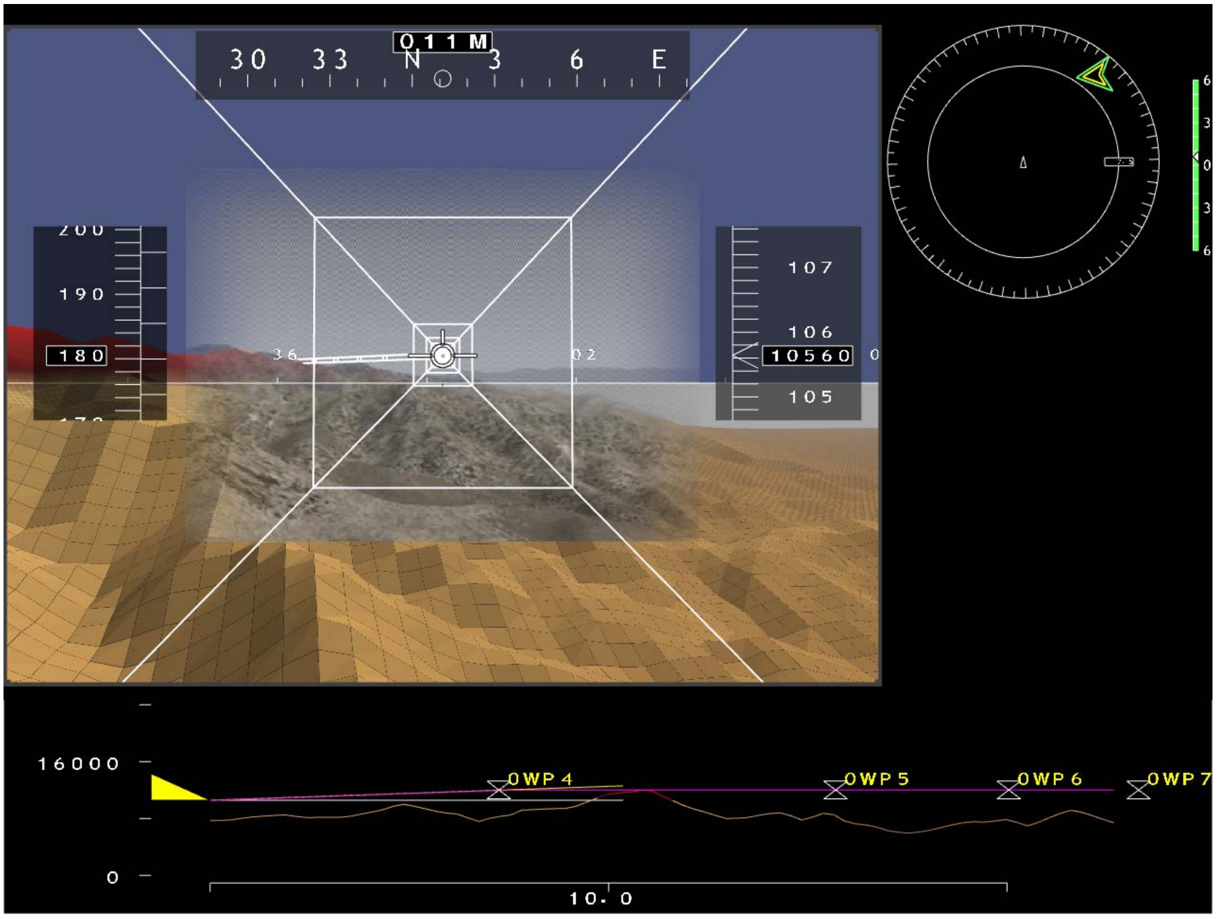

Figure 10. The Modified Upper Screen

Table 4. Display Modifications and Their Goal

	Modification	Goal
1	Improved terrain awareness, supporting level 2 SA	Integrate map in background planner display
2	Support the operator in achieving level 3 SA in the vertical dimension to better assess potential terrain conflicts	Integrate VPD in upper screen and tunnel in ego-view display
3	Support the operator in achieving level 3 SA in the vertical dimension to better assess potential traffic separation violations	Show altitude and airspeed planned at each waypoint on planner screen, integrate tunnel
4	Support the operator in achieving level 3 SA in the horizontal dimension to better assess potential traffic separation violations	Use directional symbol to depict traffic on planner screen, integrate tunnel in ego-view display
5	Emphasize nearby traffic for focused attention, supporting level 2 SA	Integrate ACAS display in upper screen

Experiment 2

In order to test the influence of the modified displays on operator SA and performance, a second experiment was conducted. To make comparison of the results with the ‘old’ displays possible, the apparatus, scenarios and events used in Experiment 2 were equal to those of Experiment 1. In Experiment 2, the possible influence of LoA on operator SA and performance using the new display designs was also investigated.

Participants

Participants were eight male students of the Netherlands Defence Academy (NLDA), ranging in age from 22 to 26 years, with an average of 23 years. None of them were pilots and all had a technical background.

Procedure

The procedure was similar to Experiment 1, except for participants each performing two runs instead of three. Since this experiment was primarily focused on evaluating the display modifications made to support operator SA, the highest level of authority, LoA 8/8, was not included in this experiment. Thus, each participant did two runs, one in conditions LoA 4/3, and one in LoA 6/6. To be able to compare the results between the experiments, scenarios 1 and 2 from Experiment 1 were used in Experiment 2.

Results

Included in this paragraph are the results of Experiment 2, as well as the results from the comparison between Experiment 1 and 2. For this comparison, data from Experiment 1 that concern LoA 8/8 and scenario 3 are excluded. These analyses thus only concern the conditions and scenarios that were used in both experiments.

The number of user interventions and system interventions, summated over events and participants, in Experiment 2 is shown in Figure 11.

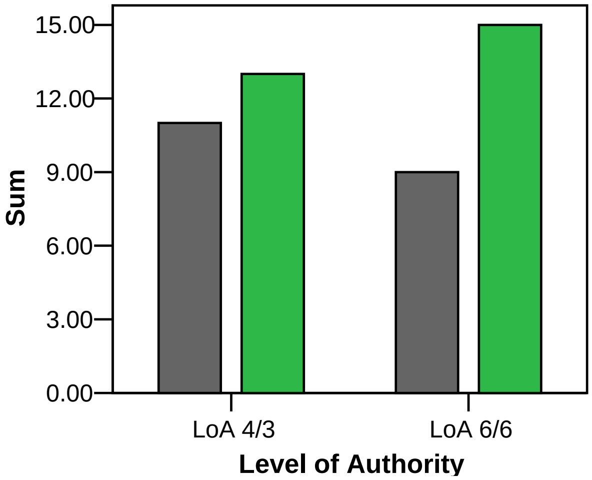

Figure 11. Frequencies of System and User Interventions

In both LoA conditions, more user interventions than system interventions occurred. Although this difference was greater in LoA 6/6 than LoA 4/3, this difference was not significant (z = -.71, p = .48). In both LoA 4/3 and LoA 6/6, less user interventions occurred in Experiment 2 than in Experiment 1. However, these differences were not significant for LoA 4/3 (U = 22.00, p = .27, r = -.39), nor for LoA 6/6 (U = 22.50, p =.29, r = -.37).

Most of the manoeuvres executed by the participants in Experiment 2 were correct system actions. As in Experiment 1, the patterns of results across both LoAs are very similar. The distribution of the actions has been compared between Experiments 1 and 2. Using the Mann-Whitney test, no significant differences were found for any of the categories with values of U between 24 and 32 and p-values between .26 and 1.0.

In total, 48 events occurred in Experiment 2 (24 events per LoA condition). Each event could result in an RA, due to an untimely detection by the participant, or incorrect action. Eight of these events resulted in an RA: six in LoA condition 4/3; and two in LoA 6/6. More RAs were given in LoA 4/3, than in LoA 6/6. Figure 12 shows the frequencies of RAs received after the different events. The data in this Figure are summated over the participants, divided per LoA and event.

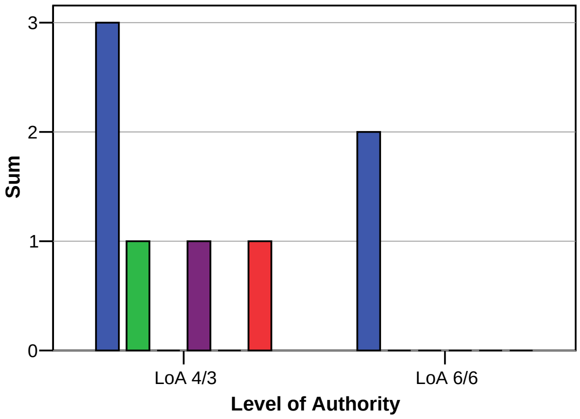

Figure 12. Frequencies of RAs

Although the difference was not significant, (z = -1.63, p = .10, r = -.41), there is a trend that less RAs were given in the higher LoA condition.

Table 5 shows the number of Resolution Advisories in both experiments. In LoA 4/3, more RAs occurred in Experiment 2 than in Experiment 1, whereas in LoA 6/6, less RAs occurred with the new display designs. The comparison is further complicated, because of two missing values ('RA not applicable') in Experiment 1. These cases are caused by the fact that due to unnecessary manoeuvres of the participants before the event, they missed the actual event.

Table 5. Number of RAs in Both Experiments, per LoA

		frequency of RAs	
	LoA	RA	RA n/a
Exp 1	4/3	3	1
	6/6	3	1
Exp 2	4/3	6	0
	6/6	2	0

Table 6 summarizes the results of Experiment 1 and 2 concerning the unnecessary user interventions and terrain conflicts. For comparison between the two experiments, data from LoA 8/8 and scenario 3 from Experiment 1 are excluded. With the new display design in Experiment 2, not one participant executed a manoeuvre that led to a conflict with terrain. Only one participant made an unnecessary intervention, followed by an unnecessary action.

Table 6. Frequency of Unnecessary User Interventions and Terrain Conflicts for Both Experiments

Frequency of unnecessary user interventions, followed by unnecessary action		
	Scenario 1	
LoA	Experiment 1	Experiment 2
4/3	2	0
6/6	2	1
Frequency of terrain conflicts		
	Scenario 1	
LoA	Experiment 1	Experiment 2
4/3	1	0
6/6	3	0

Since every run was performed by four participants in each LoA condition, the maximum frequency of the unnecessary user interventions and the terrain conflicts for each condition per run was '4'.

On the objective questionnaires measuring situation knowledge, the mean score was somewhat higher in condition LoA 6/6 (M = 5.4) than in LoA 4/3 (M = 5.2). However, this difference was not significant. (z = -1.153, p > .30 , r = -.29). The mean scores were higher in Experiment 2 than in Experiment 1 for both LoA 4/3 and 6/6, however, the differences were small.

In the subjective questionnaire, the mean score on SA was higher in LoA 6/6 than in LoA 4/3. Although the difference is not significant (*z* = -1.97, *p* = .06, *r* = -.99), there is a trend that participants feel they have a better SA in LoA 6/6.

When comparing the scores in Experiment 1 and Experiment 2, it shows that the participants rated their workload significantly lower in Experiment 2 than in Experiment 1 in the LoA 4/3 condition (U = 22.5, p < .05). In LoA 6/6, the rating is also lower in Experiment 2, however, this difference is not significant (U = 31.5, p > .90). The scores on SA and performance show no significant differences between the experiments.

Discussion

No significant differences were found between LoA 4/3 and LoA 6/6 concerning the number of user interventions, RAs, and the number and sorts of manoeuvres, nor in the answers on the questionnaires. However, the size of the difference in number of RAs between the LoA conditions does suggest that participants were able to find a better and/or more timely solution to imminent conflicts in LoA 6/6 than in LoA 4/3. High mean scores on the questionnaire indicate good perception of the situation (good level 2 SA). Also, there is a trend that participants rate their SA higher in the LoA 6/6 condition than in LoA 4/3.

The comparison of results between Experiment 1 and 2 paints a mixed picture. Somewhat more user interventions occurred in Experiment 1, but this difference was far from significant. The results concerning the manoeuvres performed by the participants are very much the same across both experiments. The number of RAs issued was higher with the new display designs in LoA 4/3, but lower in LoA 6/6. Unfortunately, the missing values in Experiment 1 make it impossible to further analyse the data by summating across LoA conditions. The number of both unnecessary interventions and interventions leading to a terrain conflict was lower with the new display designs in Experiment 2. Participants scored well on the objective questionnaires in both experiments, with slightly higher mean scores in Experiment 2. The subjective questionnaires indicate a lower workload in Experiment 2 in LoA 4/3, indicating that the modified displays make a larger difference when participants need to perform more actions themselves than when the systems work autonomous in a time-critical situation.

Summary and Conclusions

The research described in this paper concerned on one hand the influence of LoA on the SA and performance of participants operating the UAV GCS simulator, and on the other the effect of the redesigned displays. Experiment 1 was conducted to compare the influence of three different LoAs on several different measures of performance and SA. None of these measures yielded significant differences between the LoA conditions. The hypothesis that operator SA, and thus performance, is optimal with an intermediate LoA could therefore not be confirmed. The data gathered in this experiment did however arouse our interest in another way. We noticed that although participants scored well on a questionnaire measuring their understanding of the situation at hand, and often timely detected imminent conflicts, they were not always able to correctly solve a conflict. Sometimes, a manoeuvre executed to solve one conflict, directly led to a new conflict. In other cases, participants misjudged safe situations as upcoming conflicts, causing them to perform unnecessary actions to avoid the supposed conflict. In other words, participants often did not have a good enough SA to decide whether or not it was necessary to intervene, and if so, exactly what action to undertake.

In order to better support participants’ SA in the tactical time domain, allowing them to intervene timely (i.e. before the system intervenes) and correctly, an effort was made to improve the interface design of the GCS. Several different display properties were modified or added, to enhance the information presented to the participants. It was hypothesized that if the new displays indeed better supported participants’ SA, this effect would show up in their performance. They would be better able to assess the situation correctly, intervening only when necessary, and if so, in a problem-solving way and not a (new)-conflict-creating way. This was investigated in a second experiment. In this experiment only two different LoAs were compared, leaving the highest LoA out of consideration. The results of this experiment are very consistent with the first. Again, no significant differences between the LoAs were found on any of the measures, although there did seem to be a trend of less RAs issued in LoA 6/6 than in LoA 4/3. Also, participants scored well on the questionnaire concerning their knowledge and understanding of the situation, in both LoA conditions. The results of the subjective questionnaire show a trend towards a higher SA in the LoA 6/6 condition.

In order to keep the comparison between Experiments 1 and 2 straightforward, the data from Experiment 1 concerning LoA condition 8/8 and scenario 3 (neither of which was included in Experiment 2) were excluded from the analyses. The analyses may have been straightforward, the outcome certainly was not. No meaningful differences were found concerning number of user interventions, types of actions, number of RAs and questionnaire scores. We were interested to find out whether the new displays would cause the participants to intervene correctly in case of an upcoming conflict, and not intervene when this was unnecessary. And indeed, on both counts, the measures were in favour of the new display designs. An unnecessary intervention occurred only once, and a manoeuvre to avoid traffic never resulted in a terrain conflict. This leads to the conclusion that the modified display design provided the participants with better terrain awareness (level 2 SA) and better level 3 SA in the vertical dimension, thus achieving goals 1, 2 and 3 as mentioned in Table 4.

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