OPERATIONAL IMPACT OF RA DOWNLINK: RESULTS OF A REAL-TIME SIMULATION

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Abstract

If the Airborne Collision Avoidance System (ACAS) identifies an imminent collision, it issues a Resolution Advisory (RA). The RA takes precedence of Air Traffic Control (ATC) instructions and the air traffic controller should not interfere with the according collision avoidance manoeuvre. To date, the only source of information for the controller to know about the RA is the pilot report. However, pilot reports of RAs are often incomplete, delayed, incorrect or even missing. This introduces ambiguity about tasks and responsibilities of pilots and controllers. One option to address this problem consists in downlinking RAs for display at the controller working position (CWP). The present paper gives an overview of EUROCONTROL's Feasibility of RA Downlink Study (FARADS) and describes the results of one of the experiments that have been conducted to determine the impact of RA downlink on the controller's performance, situational awareness and workload. The results of the experiment point to operational benefits of RA downlink. Contradictory clearances to aircraft involved in an RA were exclusively observed in the absence of RA downlink. Controllers' recollection of RA events caused by pilot or controller error was superior if RA downlink was provided. Furthermore, there was no evidence for negative effects of RA downlink, such as cognitive tunnelling on the RA event and a lower ability to separate other traffic in the sector.

Introduction

The Airborne Collision Avoidance System (ACAS)[1] is the last resort system safety defence against mid-air collisions. ACAS interrogates the transponders of nearby aircraft in order to determine an imminent risk of collision. If a risk of collision is established, ACAS will issue a 'Resolution Advisory' (RA). An RA provides the pilots with advice on how to change their vertical rate so as to avoid a collision. In case both aircraft involved receive an RA, the RAs are automatically coordinated. The implementation of ACAS was prompted by a number of tragic mid-air collisions in the 1950s and in the late 1970s [1]. Today, the majority of commercial aircraft operating in the European airspace are required to be equipped with ACAS [2].

Implication of RAs for the pilot and controller

The existence of an ACAS RA has direct consequences for the tasks of both the aircrew and the air traffic controller: Pilots are required to immediately comply with all RAs, even if the RAs are contrary to ATC clearances or instructions. Furthermore, as soon as permitted by workload, pilots are required to notify ATC of the RA, including the direction of any deviation from the ATC clearance [3]. The controller, on the other hand, is not allowed to modify the aircraft flight path once a pilot reports a manoeuvre induced by an RA, until the pilot reports returning to the previous ATC clearance [4].

Thus, the occurrence of an RA in the cockpit fundamentally changes the controller's task: In normal conditions (i.e. without an RA), the controller's first and foremost task is to ensure separation of traffic, if required, by actively modifying the aircraft flight path. With an RA, in contrast, the controller should not actively try to ensure separation of the affected aircraft any more.

Currently, a controller only becomes aware of an RA if he/she is informed by the pilot. However, it has been empirically established that pilot reports of an RA are often incomplete, incorrect, delayed, or even missing Analysis of data published by the Swiss Aircraft Accident Investigation Bureau [5] revealed that only 28% of the RAs are reported correctly and timely (see Figure 1).

The main reason for the low reliability of pilot reports is most likely the high level of stress and workload in the cockpit, when an RA is issued [6]. Furthermore, the RA report has a lower priority for the pilot than other RA related tasks, in particular,

[1] The only implementation of the ACAS standard is TCAS II version 7.0. For the understanding of this paper, the terms ACAS (the standard) and TCAS (the implementation) can be considered synonymous.

complying with the RA and trying to avoid a potential collision.

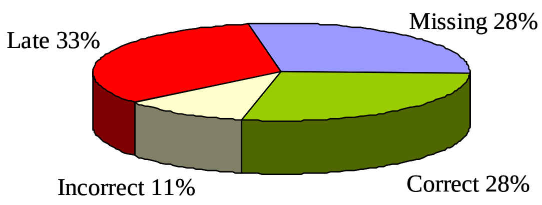

Figure 1. Analysis of RA reports in Switzerland (1999-2003)

RAs and contradictory ATC clearances

If, however, the controller is unaware of the RA, he/she is also unaware of the change in their task, that is, a shift from active control to merely monitoring the conflicting aircraft. In the absence of a timely pilot report, the controller might issue an instruction to the aircraft with the RA. In the worst case, the issued clearance instructs the pilot to manoeuvre in a sense contrary to the RA. Although specifically mandated not to, pilots in some cases follow the ATC clearance rather than the RA [7], [8]. Compliance with a contradictory ATC clearance severely degrades ACAS benefits and, in the worst case, can result in a mid-air collision.

The mid-air collision over Überlingen in July 2002 illustrates such a situation in a tragic way: Ultimately, the collision between the Boeing 757 and the Tupolev 154 was caused by the decision of the Tupolev crew to follow the (contradictory) ATC instruction rather than the RA. The accident investigation report noted that, at the time of issuing the clearance, the controller was unaware that both aircraft had received an RA [9].

Displaying RAs to the controller

In order to make controllers' notification of an RA more reliable, it has been proposed to downlink RA information to the ATC system and display it at the Controller Working Position (CWP). Technically, downlinking RAs is straightforward and, to a certain extent, already in place: Whenever an RA is generated in the cockpit, the aircraft's transponder provides information about the RA [10]. This information is received by the ground station through Mode-S radar. Nevertheless, RA information is not displayed to the controller. So far, it is only used for off-line monitoring and analysis.

Previous work on RA downlink

A number of studies have been conducted in order to assess the feasibility and the operational benefits of RA downlink. In the United States, a series of simulated and live trials were conducted in Baltimore and Boston between 1994 and 1997 [11], [12]. During the Boston trials, RAs that occurred in real traffic were displayed to controllers in charge of the sector. A total of 2652 RAs were downlinked, and the results concerning technical aspects (i.e. the downlink delay) as well as operational aspects (i.e. controllers' perception of benefits) were rather positive. Because of incompatibilities between existing regulations and RA downlink, though, the FAA's Air Traffic Office decided against the implementation of RA downlink: according to the regulations, controllers are not entitled to issue a clearance to an aircraft, once the aircrew has reported an RA. As RA downlink is not an aircrew report, it does not have any relevance for the question of whether the controller is allowed to issue a clearance. In spite of this, RA downlink might mislead the controllers into believing that they are not responsible for separation.

In France, RA downlink was studied by CENA within the VICTOR (Visual Interface for Controllers for the Transfer of Resolution Advisories) project, carried out in 1994. During the project, a real-time simulator mock-up was developed. Following demonstrations to operational staff, it was noted that RA downlink can, in some situations, increase the controller's understanding of the traffic situation. However, it was concluded that the benefits were too limited to consider the implementation of RA downlink [13], [14]. Moreover, and similar to the discussion in the US, it was feared that RA downlink could introduce uncertainty in whether or not the controller is allowed to modify the flight path of the RA aircraft.

In Japan, a near mid-air collision between a DC-10 and a Boeing 747 over Yaizu in January 2001 prompted the Japan Civil Aviation Bureau to investigate the implementation of RA downlink. The Yaizu airprox had been caused by a pilot following an ATC clearance, rather than the ACAS RA suggesting a manoeuvre in the opposite direction. Like in the Überlingen accident, the controller was not aware that the pilot of the aircraft involved had received an RA in the opposite sense [15]. The Japanese study concentrated on technical issues concerning the transmission of Mode-S data. To date, there is no information available on the progress of this study.

Thus, empirical studies on RA downlink are still rather scarce. In case they were conducted, the conclusions (in particular, on benefit limitations and ambiguity in responsibility), do not seem compelling.

First, the introduction of a new service usually requires an adaptation of the associated procedures and regulations. Stating that a service only delivers limited benefits or could introduce ambiguity if the existing procedures and regulation are maintained, does not fundamentally question the benefit of the service as such.

Second, the claim that benefits are very limited appears premature. None of the studies conducted so far systematically contrasted the current situation (i.e. no RA downlink) with RA downlink. Moreover, none of the studies systematically measured operational benefits. One potential benefit that could have been investigated refers to a lower likelihood of contradictory clearances: if the controller is informed by downlink about the RA issued in the cockpit, it is highly unlikely that, given he/she issues a clearance, this clearance is contradictory to the RA. Potential benefits also refer to the controller's improved ability to predict the evolution of the traffic situation, thereby facilitating the detection of follow-up conflicts. Finally, knowledge of the RA potentially decreases the level of workload or stress experienced by the controller, if he/she detects the imminent loss of separation.

The FARADS Project

The Überlingen accident in 2002 has yielded a number of recommendations to investigate in detail the feasibility of RA downlink, most notably from the German Federal Bureau of Aircraft Accidents Investigation [9] and the High-Level European Action Group for ATM Safety (AGAS) [16]. As a consequence of these safety recommendations, EUROCONTROL initiated the Feasibility of ACAS Resolution Advisory Downlink Study (FARADS). FARADS aimed at addressing the following issues:

- Which RA downlink technology is most appropriate (balancing speed and accuracy on the one hand, and costs on the other)?
- Will RA downlink provide controllers with information about RA more reliably and expeditiously then current voice reports?
- Will RA downlink deliver operational benefits, among others, a decreased likelihood of contradictory clearances and a better planning of the post-alert situation?

Within the scope of FARADS, a number of studies have been conducted, including a technical study, a latency study, and a set of empirical studies. The technical study confirmed that RA Downlink is technically feasible [17]. Within the Mode-S coverage area, Mode-S RA reports are the best solution for RA downlink. These Mode-S RA reports are already specified in ICAO Annex 10 [10]. Outside the Mode-S coverage area, the 1090 Extended Squitter can be used for RA downlink.

The latency study served to assess the delay with which the RA downlink information will be displayed at the CWP. Obviously, any operational benefit of RA downlink will depend on the delay with which the according message is delivered. Within the latency study, a mathematical model was developed that served to predict, among other events, the point in time at which the controller would be aware of an RA. With the pilot report of an RA, an en-route controller will be aware of an RA on average 29 seconds after the RA has occurred. With Mode-S RA downlink, the controller will be aware of an RA in 95% of the cases within 8.9 seconds of their occurrence. The study concluded that RA downlink would be sufficiently timely to allow for a significant increase in the controller's awareness of the RA encounter [18].

The empirical studies consisted in a set of experiments – referred to as the Resolution Advisory Downlink Experiments (RADE). An initial experiment – referred to as RADE-1 – took place in November 2003, with a total of 30 participants from ten European Area Control Centres (ACCs). It was found that the majority of participants see operational benefits in the provision of RA downlink. However, the results concerning benefits were limited to controllers' feedback, rather than reflected in performance data. One reason is that, in RADE-1, participants were exposed to "canned" replays of traffic scenarios, and, thus, were not able to actively control the traffic scenarios [19].

For this reason, a further experiment – referred to as RADE-2A – was conducted. This experiment used a monitoring-and-control real-time simulation environment, rather than replays of traffic scenarios. RADE-2A will be described in detail in the remainder of this paper.

The RADE-2A experiment

The RADE-2A experiment was carried out from October to December 2005. The general aim of the experiment was to analyze the impact of RA downlink on the controller's ability to separate traffic in an interactive control setting. In addition, controllers' attitudes on RA downlink and the proposed HMI were investigated. With respect to potential benefits, it was assessed whether RA downlink helps to avoid contradictory clearances to aircraft with an RA. Further, it was investigated whether RA downlink facilitates the controller's understanding of the RA event. However, there are also potential disadvantages of RA downlink. One is referred to as the "cognitive tunnelling hypothesis": according to this hypothesis, the display of RA information narrows the controller's attention to the RA event, on the expense of other traffic in the sector. The RADE-2A experiment also served to investigate this hypothesis [20].

Experimental Variables

Three experimental variables were manipulated in the RADE-2A experiment: (1) RA downlink (present vs. absent), (2) timeliness of pilot report (timely vs. delayed), and (3) controller role (Executive Controller vs. Planning Controller).

RA downlink: baseline vs. experimental condition. In the baseline condition, RAs were not presented on the screen. The only source of information on the RA was the pilot report. In the experimental condition, RAs generated in the cockpit were displayed on the controller screen. In addition, the pilot was still requested to report the RA. The specific HMI chosen for the display of RAs is described below.

Timeliness of pilot report: timely vs. delayed. It can be reasonably assumed that potential benefits of RA downlink are more prominent, if the pilot report is delayed or even missing. For this reason, report timeliness was included as an experimental variable. In the timely report condition, simulation pilots reported the RA as soon as the RA was generated. In the delayed report condition, simulation pilots only reported the RA once the RA situation was resolved (i.e. a clear-of-conflict message was displayed at the pilot position). In both conditions, the pilot reported the RA correctly.

Controller role: Executive vs. Planning Controller. In one condition, the participant was working as the Planning Controller. In the other condition, the participant was working as the Executive Controller.

Given the above mentioned variables, the RADE-2A experiment followed a 2 (RA conditions) x 2 (pilot report timeliness) x 2 (controller roles) repeated measurement design, resulting in eight different experimental conditions.

A variable that was not systematically manipulated in the experiment, but taken into account in the data analysis, was the cause of the RA. Two different types of causes were distinguished: (1) High vertical rate before level off: in this case, the RA was triggered by fast climbing/fast descending aircraft with an aircraft on the adjacent level. (2) Controller/pilot error: in this case, the RA was caused by an incorrect ATC clearance or a pilot not following the ATC clearance.

Measurements

The following measurements were collected during the experiment:

Controller performance. Controller performance was measured in terms of:

- the number of separation losses in the sector,
- the number and type of instructions issued to aircraft involved in the RA.

Situation awareness. Situation awareness (SA) refers to the controllers' understanding of the traffic situation as well as the ability to predict its evolution [21]. For the purpose of this experiment, the controller's SA concerned the understanding of (a) the traffic constellation that yielded the RA, and (b) other traffic in the sector (i.e. not affected by the RA event). SA was measured in terms of:

- a memory test on details of the RA situation, administered immediately after the end of a simulation run,
- the SA self-rating scale SASHA-Q,
- an on-line probe, which consisted of a pilot request for an aircraft not involved in the RA situation.

Workload. In order to assess the level of workload experienced by the controller during a simulation run, participants were required to fill in the NASA-TLX [22] at the end of each simulation.

Controller acceptance. Controller acceptance referred to the concept of RA Downlink and the proposed HMI. Acceptance was measured on the basis of:

- post-experimental questionnaires
- de-briefings at the end of the experiment.

Experimental Setting

Simulator. The RADE-2A experiment was conducted on the early Demonstration and Evaluation Platform (eDEP) situated at the Human Factors Lab of EUROCONTROL Experimental Centre in Brétigny, France. An ACAS server was used for the realistic generation of Resolution Advisories.

Control Centre and airspace. Controllers were told that they were to work in Cottam Centre, a fictitious facility located in Europe. They were on an afternoon shift in the so-called Haren sector. The Haren sector borders with two sectors, one in the North and one in the South. A special characteristic of the airspace was the military area. During the simulations, the status of the military area could change from non-active to active with a restriction on a range of flight levels.

Human-machine interface. The ACAS RA was shown in line 0 of the label, above the aircraft callsign (see Figure 2). The display consisted of the letters “TCAS” presented in yellow on a blue background, together with a graphical sign indicating the direction of the RA[2]. In case of an RA reversal, the previous RA direction was shown in brackets. Usually, TCAS RA information would be displayed for all aircraft involved in the conflict. In case only one aircraft had a TCAS RA, the intruder was shown with a red frame around the callsign.

Operational procedures. According to the operational procedures used in RADE-2A, pilots are required to report an RA by voice, even if RA downlink is provided. There is no change in the controller task in comparison to current ICAO regulation. That is, the controller should not modify the flight path of an aircraft once the pilot reports the RA manoeuvre until the pilot reports returning to the original ATC instruction or clearance.

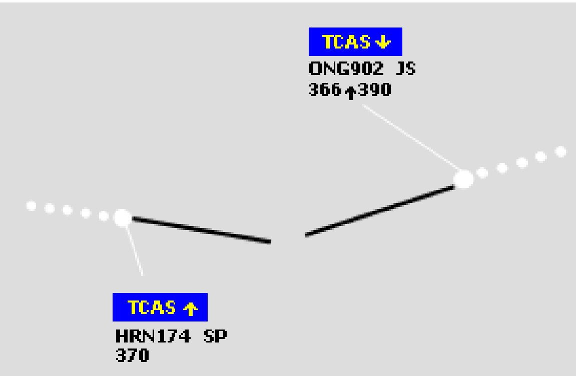

Figure 2. Display of an RA

Participants

A total of 12 controllers participated in the RADE-2A simulation. Six participants were from Maastricht Upper Airspace Centre (MUAC) and two from Marseille ACC, from Langen ACC, and from Rome ACC each. The participants’ age ranged between 28 and 51 years with an average of 35.8 (standard deviation (SD) = 6.2). Experience as a licensed controller varied between 3 and 28 years with an average of 10.8 years (SD = 7.4).

Results and Discussion

Results will be reported in the following order: after a section on the adequacy of the experimental approach, the results pertaining to operational benefits (i.e. controller performance, situation awareness, workload, and acceptance) will be reported.

Adequacy of the experimental approach. One of the major challenges in the RADE-2A experiment was to create RA events in an interactive and realistic setting. This challenge was met satisfactorily, both with regard to the generation of RA events and the simulation realism. RA events were achieved in 48 simulation runs, which is the number of runs required for the realisation of the experimental design. Out of the 48 successful runs, 24 were done without RA downlink, and 24 were done with RA downlink. Controller ratings of various aspects of the simulation realism (i.e. the simulated traffic, the RA event, and the pilot behaviour) were generally positive. Thus, the approach taken in the real-time simulation allows for an assessment of the operational impact of RA downlink.

Controller performance. Controller performance was measured in terms of the number and type of instructions issued to aircraft involved in the RA event and the number of separation losses following the RA.

During the 48 simulation runs, two ATC clearances were issued to aircraft involved in an RA encounter. Both clearances were issued to aircraft that had received an RA caused by pilot/controller error, and they both contradicted the RA. Furthermore, the two clearances were issued in the baseline condition, in which RA downlink was unavailable. One of the clearances was issued in the timely pilot report condition; the other one was issued in the delayed pilot report condition. In both cases, the controllers issued the clearance in an attempt to prevent a third-party aircraft conflict. Although both contradictory clearances occurred in the absence of RA downlink, the number of events is too small to decide conclusively whether the effect of RA downlink is statistically significant or just due to random variation.

Losses of separation that pertained to the aircraft configuration yielding the RA were excluded from the analyses[3]. Other losses of separation occurred in 16 runs (i.e. 33.3% of the total runs). An analysis of these runs revealed that losses of separation were exclusively due to follow-up conflicts occurring as a consequence of the RA manoeuvre. Thus, all losses of separation involved at least one aircraft that was previously involved in the RA encounter. Table 1 shows the distribution of

[2] The word “TCAS” rather than “ACAS” was selected to keep the display consistent with the RA reporting phraseology.

[3] The situation that originally led to the RA was experimentally induced. For this reason, it was unsuitable as an indicator of the controller’s ability to separate traffic in the sector.

separation losses over experimental conditions. As can be seen from the table, the number of separation losses is equally distributed over the four conditions.

		RA Downlink		
		Present	Absent	Total
Pilot report	Timely	4	4	8
	Delayed	4	4	8
	Total	8	8	16

Table 1. Number of Separation Losses as a function of Experimental Conditions

Using the number of separation losses as an indicator of controller performance, there is no evidence for the assumption that RA downlink helps the controller to plan the post-alert situation, resulting in a reduced likelihood of follow-up conflicts. Nevertheless, the absence of separation losses unrelated to the RA event shows that there is no evidence for the cognitive tunnelling hypothesis either. According to this hypothesis, the controller's ability to separate other traffic in the sector is impaired by the presentation of RA information.

Situation Awareness. Situation Awareness (SA) was measured on the basis of a memory probe, an on-line probe, and a self-rating scale.

The SA memory prob*e* consisted of a 10-item memory test that had to be filled in after each simulation exercise. The items in the memory probe addressed the understanding of the conflict geometry, namely: the aircraft involved, their cleared level, their state (climbing, descending, or level flight) prior to the conflict, and their approximate heading. Other items addressed details of the RA event (i.e. whether pilots reported and followed the RA, whether the RA induced a follow-up conflict, and what the sense of the RA was). Figure 3 shows the performance in the memory test depending on the RA downlink condition and the cause of the RA.

Scores were subjected to a three-factorial repeated measurement analysis of variance (ANOVA) using RA downlink (present vs. absent), controller role (Executive Controller vs. Planner), and pilot report (timely vs. delayed) as independent factors. No effect, including the interactions between the three factors, became statistically significant (all F's < 1). A further ANOVA with RA cause (high vertical rate level off vs. pilot/controller error) and RA downlink (present vs. absent) as factors revealed a significant interaction between the two factors ($F(1,11) = 7.18$; $p = 0.02$). This interaction can be interpreted as follows: If an RA is caused by high vertical rate, there is no difference in the SA scores for the two RA downlink conditions ($t(11) = -1.24$; $p = 0.242$). However, if the RA is caused by a pilot/controller error, performance is significantly higher with RA downlink ($t(11) = 2.71$; $p = 0.02$) than without.

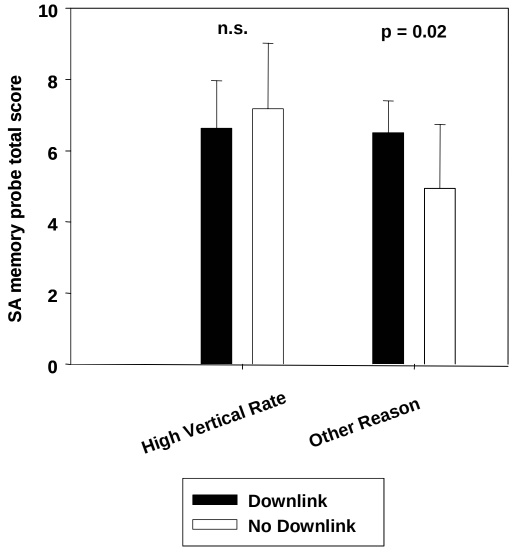

Figure 3. Results in the SA Memory Probe

Thus, there is a beneficiary effect of RA downlink on the understanding of the RA event, in case the RAs were caused by a pilot or a controller error. These are the type of RAs that are usually considered 'real' RAs by the controllers.

EUROCONTROL's SASHA-Q was used as a self-rating scale for SA [23]. SASHA-Q contains specific items referring to the tool or service under investigation, generic items, and an overall SA rating. SASHA-Q was completed by both controllers after each simulation exercise. In the following, only the results referring to the overall SA rating are reported[4].

For the overall SA rating ("How would you rate your overall situation awareness during this exercise?"), an ANOVA with the factor 'RA cause' and 'RA downlink condition' was calculated. This analysis revealed a main effect of the RA cause ($F(1,11) = 5.57$; $p = 0.04$): Controllers rated their situation awareness higher in runs with RAs caused by high vertical rate than in runs with RAs caused by pilot/controller error. Neither the main effect of RA downlink ($F(1,11) < 1$) nor the interaction of RA downlink and RA cause was significant ($F(1,11) = 1.732$; $p = 0.22$).

[4] For the other generic items, none of the factors "RA downlink", "timeliness of pilot report", and "controller role" (or any interaction between these factors) had a significant effect on the ratings.

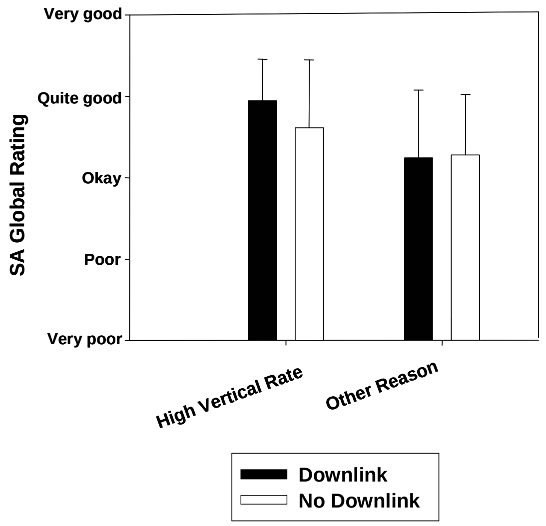

Figure 4. Assessed Overall SA

The measurement of SA on the basis of the on-line probe was carried out as follows: Simulation pilots were instructed to make one request to both the Executive and the Planning Controller immediately after the RA event. These requests concerned level changes, routings, directs, or traffic information, and they were made by pilots of aircraft unaffected by the RA. As the on-line probe captures the controllers' awareness of other traffic in the sector, it serves to assess potential cognitive tunnelling on the RA encounter.

The on-line probe was successfully accomplished in 80 out of the 96 cases (48 runs x 2 CWPs). Of the probes pertaining to the Executive Controller, 34 of the 41 valid probes (i.e. 82.93%) were answered correctly and timely; of the probes pertaining to the Planner 33 of the 39 valid probes (i.e. 84.62%) were answered correctly and timely. Accordingly, seven and six requests were answered delayed or incorrectly by the Executive and the Planning Controller respectively.

The high frequency of correct and timely answers points to a ceiling effect, that is, performance was too high to reveal any impact on SA. Because of the low number of delayed or incorrect responses, no statistical tests were applied. Numerically, though, the number of suboptimal answers is lower with RA downlink (i.e. 5) than without RA downlink (i.e. 7). Thus, even though the high number of correct answers requires a cautious interpretation, there is no evidence for impaired controller performance as a result of RA downlink. Thus, the SA online probe does not provide any evidence for a cognitive tunnelling on aircraft involved in the RA encounter.

Workload. Workload was measured on the basis of subjective ratings collected with the NASA-TLX [22]. The NASA TLX contains six different rating scales. Scores on these scales are usually combined by using a specific weighting technique; however, it has been demonstrated that simply summing up scores also yields valid results [24]. Participants filled in the NASA-TLX at the end of each simulation run.

According to an ANOVA, neither the RA downlink condition nor the timeliness of the pilot report had a significant influence on the total NASA-TLX score. The interaction between the two factors was also not significant (for all effects, $F < 1$). An analysis with the factors "RA downlink condition" and "RA cause" revealed a highly significant main effect of the RA cause on the NASA-TLX score ($F(1,11) = 19.75$; $p = 0.001$). This effect indicates that controllers experienced less workload in runs in which the RA was caused by high vertical rate before level off than in runs with RAs caused by pilot/controller error (see Figure 5).

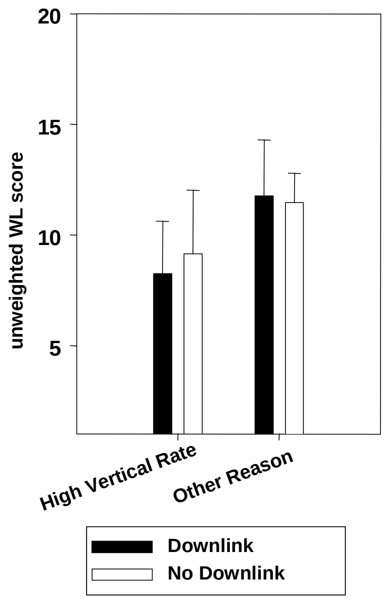

Figure 5. NASA-TLX Scores for RA Downlink Conditions and RA Causes

Controller Acceptance. In the post-experimental questionnaire, participants were asked to rate the usefulness of displaying RA information to the controller. Answers could be given on a scale from 1 (not at all useful) to 5 (absolutely useful). The participants' answers ranged from 1 to 5 with an average of 3.6 (SD = 1.2). Two participants gave ratings on the negative side of the dimension (i.e. 1 or 2), whereas seven participants gave ratings on the positive side of the scale (i.e. 4 or 5). Thus, the majority of participants see benefits in the display of RA information to the controller. Among the benefits named were an increased situation awareness, referring to a better understanding of the RA situation, and a lower likelihood of issuing contradictory clearances to an aircraft involved in an RA. However, the experienced benefits mainly pertain to RAs that yield a deviation from the ATC clearance. These are mainly those RAs that are due to pilot or controller error. RAs that are due to high vertical rate before level-off are regarded by some controllers as nuisance alerts because, in the majority of cases, they do not result in a deviation from the cleared flight trajectory and, thus, are less relevant.

A further issue of concern is the pilot/controller responsibility. Generally, it was acknowledged that RA downlink can clarify responsibility for the controller if a pilot departs from the clearance in compliance with an RA, but fails to report this to ATC. In this case, the controller is not responsible for separation any more, but might not be aware of that. However, participants were concerned that RA downlink would not entirely resolve ambiguity. If the pilot does not follow an RA, the controller is still responsible for the aircraft. RA downlink in this case might mislead the controller to assume that he/she is not responsible any more. This concern, though, is based on the assumption that existing ICAO regulations are not modified if RA downlink is implemented.

The specific HMI proposed for RA downlink information was generally appreciated by the participants. Nevertheless, two issues were mentioned that require further attention. One refers to the fact that the RA information presented in the aircraft label may clutter the screen; the other refers to problems in understanding certain RA symbols (in particular referring to the symbol used for the “adjust vertical speed” RA).

Conclusions

RADE-2A is the first ATC experiment in which RA events were systematically simulated in an interactive environment, contrasting a condition with RA downlink with a condition without RA downlink. The main aim of the experiment was to assess the impact of RA downlink on the controllers and their ability to separate traffic.

The most direct and straightforward indicator of an RA downlink benefit is the absence of controller clearances to aircraft involved in an RA encounter, particularly of clearances that are in contradiction with the RA. In RADE-2A, a total of two clearances – both contradictory – were issued to aircraft involved in an RA encounter. These clearances occurred in runs without RA downlink.

The number of separation losses occurring after the RA event was taken as a further indicator of controller task performance. No effect of RA downlink on the controller’s ability to separate traffic was found. All observed losses of separation were due to follow-up conflicts resulting from the RA manoeuvre, and the number of separation losses was equal with and without RA downlink.

One of the potential problems with RA downlink refers to the phenomenon of cognitive tunnelling: it is feared that the display of RA information narrows the controller’s attention to the RA event, on the expense of other traffic in the sector. Cognitive tunnelling was assessed by using pilot requests that were unrelated to the RA event. It was found that the controllers’ ability to respond to unrelated pilot requests is unaffected by the RA downlink conditions (absent vs. present). Thus, there is no evidence for cognitive tunnelling as a consequence of RA downlink.

With respect to situation awareness, significant results were only found if the type of RA event (i.e. the cause of the RA) was considered in the data analysis. If the RA was due to a high vertical rate before levelling off, there was no difference in the controller’s ability to recollect various aspects of the RA situation. If the RA event was caused by a pilot or controller error, though, RA downlink significantly improved the recollection of the RA situation. This latter finding clearly supports one of the intended benefits of RA downlink, which is to increase the controller’s understanding of the conflict situation.

With respect to workload, there was no clear effect of RA downlink. Controller self-ratings of workload were unaffected by the RA downlink condition, even if the RA cause was taken into account.

Concerning controllers’ acceptance of RA downlink, the majority of participants saw clear advantages of RA downlink. These were: increased situation awareness, and a lower likelihood of issuing contradictory clearances to an aircraft involved in an RA. However, the experienced benefits mainly pertain to RAs that yield a deviation from the ATC clearance. Downlink of RAs that are due to high vertical rate level off was seen as less beneficial. The reason is that, in the majority of cases, such RAs do not result in a deviation from the cleared flight trajectory.

Altogether, the results of the RADE-2A experiment point to some operational benefits of RA downlink. Contradictory clearances to aircraft involved in an RA were exclusively observed in the absence of RA downlink. Controllers’ recollection of RA events caused by pilot or controller error was superior if RA downlink was provided. In contrast, there was no evidence for negative effects of RA downlink, such as cognitive tunnelling on the RA event and a lower ability to separate other traffic in the sector.

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ACAS, TCAS, Resolution Advisory, ATC, safety net, RA downlink, real-time simulation, air traffic controller, conflict avoidance, workload, situation awareness, validation

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