EUROCONTROL

# RADE-2A Experimental Report

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|---|---|---|
| Edition Number | : | 1.1 |
| Edition Date | : | 29-05-2007 |
| Status | : | Released |
| Intended for | : | EATM Stakeholders |

EUROCONTROL

# DOCUMENT CHARACTERISTICS

## TITLE

# RADE-2A Experimental Report

| | | |
|---|---|---|
| | **ALDA Reference:** | 07/05/31-23 |
| **Document Identifier** | **Edition Number:** | 1.1 |
| | **Edition Date:** | 29-05-2007 |

**Abstract**

The present report describes the conduct and the results of RADE-2A, an experiment that was conducted to assess the impact of displaying simplified ACAS Resolution Advisories (RAs) to the controller. The RADE-2A experiment took place from October 4 to December 1, 2005 and involved 12 controllers from 4 different European ACCs.

Three experimental variables were manipulated in the experiment: (1) RA downlink (present vs. absent), (2) timeliness of pilot RA report (timely vs. delayed), and (3) the controller role (Executive Controller vs. Planning Controller). Data collected pertained to: controller performance, situation awareness, workload, and controller acceptance of RA downlink.

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. Controller's 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.

**Keywords**

| | | | |
|---|---|---|---|
| RA Downlink | ACAS | Simulation | RA |
| TCAS | Experiment | FARADS | |

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## STATUS, AUDIENCE AND ACCESSIBILITY

| Status | | Intended for | | Accessible via | |
|---|---|---|---|---|---|
| Working Draft | ☐ | General Public | ☐ | Intranet | ☐ |
| Draft | ☐ | EATMP Stakeholders | ☑ | Extranet | ☐ |
| Proposed Issue | ☐ | Restricted Audience | ☐ | Internet (www.eurocontrol.int) | ☐ |
| Released Issue | ☑ | | | | |

## ELECTRONIC SOURCE

| Path: | | |
|---|---|---|
| Host System | Software | Size |
| Windows XP | Microsoft Word 11.0 | 2616 Kb |

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# DOCUMENT APPROVAL

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| FARADS Project Manager | Stanislaw Drozdowski | 10/4/07 |
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| | | |
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# DOCUMENT CHANGE RECORD

The following table records the complete history of the successive editions of the present document.

| EDITION NUMBER | EDITION DATE | REASON FOR CHANGE | PAGES AFFECTED |
|---|---|---|---|
| 1.0 | 10-Apr-2007 | First release | All |
| 1.1 | 29-May-2007 | Editorial corrections, formatting changes | All |
| | | | |
| | | | |
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# EXECUTIVE SUMMARY

EUROCONTROL's Feasibility of ACAS Resolution Advisory Downlink Study (FARADS) is investigating the feasibility of displaying simplified ACAS RAs on controller screens. As part of FARADS, a set of experiments – referred to as Resolution Advisory Downlink Experiments (RADE) were conducted. The present report describes the conduct and the results of the RADE-2A experiment.

The general aim of the RADE-2A experiment was to analyse 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, the proposed operational concept and the HMI were investigated. The RADE-2A experiment was designed to continue the evaluation work done in the RADE-1 experiment, which employed replays of traffic scenarios, rather than an interactive control setting.

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

Data pertaining to the following topics were collected:
- Perceived realism of the simulation
- Controller performance (measured in terms of separation losses, instructions issued to aircraft involved in the RA, and provision of traffic information)
- Situation awareness and cognitive tunnelling
- Workload
- Controller acceptance (concerning RA Downlink, the proposed operational concept and the proposed HMI).

The RADE-2A experiment took place from October 4, 2005 to December 1, 2005. A total of 12 controllers from 4 different European ACCs and of 7 different nationalities participated in the RADE-2A simulation.

One of the major challenges in the RADE-2A experiment was to assess the impact of RA downlink in a real-time simulation covering an area control sector. This challenge was achieved 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.

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. However, no effect was found with respect to the impact of RA downlink information on the controller's ability to separate traffic was found. All observed losses of separation involved aircraft directly affected by RA event, and the number of separation losses was equally distributed 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 speed 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; however, 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. Results concerning controllers' performance on a secondary task (which was assumed to be an inverted indicator of workload) did not show a conclusive pattern of results.

Concerning controllers' acceptance of RA downlink, the vast 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 speed level offs 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.

An issue of concern is the pilot/controller responsibility. According to the existing ICAO regulation, the controller's responsibility to provide separation ceases if 'an aircraft departs from the current ATC clearance in compliance with an RA'. This regulation can cause ambiguity in the transfer of responsibility if the controller is unaware of an aircraft departing from the clearance in compliance with an RA (e.g. in case of a delayed or missing pilot report). Although RA downlink can help to make the controller aware that a deviation from the clearance is a consequence of an RA manoeuvre, RA downlink still leaves room for ambiguity. For instance, if a pilot does not follow the RA, RA downlink can mislead the controller to assume that he or she is not responsible for the aircraft anymore. Note, however, that this ambiguity is not inherent to the concept of RA downlink, but arises from an interaction of RA downlink and current ICAO regulations.

Taken together, 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. Controller's 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.

## LIST OF ABBREVIATIONS & TERMS

| | |
|---|---|
| ACAS | Airborne Collision Avoidance System<br>*ACAS provides “Resolution Advisories” in the vertical plane advising the pilot how to regulate or adjust his vertical speed so as to avoid a collision.* |
| ACC | Air Traffic Control Center |
| AGAS | EUROCONTROL Action Group on ATM Safety |
| AIP | Aeronautical Information Publication |
| ATC | Air Traffic Control |
| ATCo | Air Traffic Controller |
| ATM | Air Traffic Management |
| AudioLAN | Innovative Internet Technology-based Voice Communication System |
| COC | Clear of Conflict<br>*ACAS annunciation to the flight crew to indicate that the aircraft is clear of conflict with all threatening aircraft.* |
| CWP | Controller Working Position |
| EATMP | European Air Traffic Management Programme |
| EC | Executive (radar) Controller |
| eDEP | Early Demonstration and Evaluation Platform |
| FARADS | Feasibility of ACAS Resolution Advisory Downlink Study |
| FIR | Flight Information Region |
| FL | Flight Level |
| HMI | Human Machine Interface |
| ICAO | International Civil Aviation Organization |
| InCAS | Interactive Collision Avoidance Simulator |
| ISA | Instantaneous Self Assessment |
| M | Mean |
| NASA | National Aeronautics and Space Administration (United States) |
| NOTAM | Notice to Airmen |

| | |
|---|---|
| NLR | Nationaal Lucht- en Ruimtevaartlaboratorium (National Aerospace Laboratory – The Netherlands) |
| PC | Planning Controller |
| RA | Resolution Advisory |
| | *An ACAS alert advising the pilot how to regulate or adjust his vertical speed so as to avoid a collision.* |
| RADE | RA Downlink Experiments |
| RADE-2A | RA Downlink Experiments for Area Control |
| RADE-2P | RA Downlink Prototype Experiments |
| RADE-2T | RA Downlink Experiments for Terminal Control |
| R/T | Radio Telephony |
| SA | Situation Awareness |
| SAGAT | Situation Awareness Global Assessment Technique |
| SARPs | ICAO Standards and Recommended Practices |
| SASHA | Situation Awareness Rating Scale for SHAPE |
| SD | Standard Deviation |
| SHAPE | Solutions for Human Automation Partnership in European ATM |
| SME | Subject Matter Expert |
| SPO | Single Person Operations |
| STCA | Short Term Conflict Alert |
| | *A ground based system alerting controllers to conflicts.* |
| SYSCO | System Co-ordination |
| TA | Traffic Advisory |
| | *An ACAS alert warning the pilot of the presence of another aircraft that might become the subject of an RA.* |
| TCAS | Traffic Alert and Collision Avoidance System |
| | *TCAS is a specific implementation of the ACAS concept. TCAS II Version 7 is currently the only available equipment that is fully compliant with the ACAS SARPs.* |
| TLX | Task Load Index |

| | |
|---|---|
| UAC | Upper Area Control (Center) |

# 1. Introduction

## 1.1 Background

The high level European Action Group on ATM Safety (AGAS) aims to determine how to make European ATM safer, particularly following the mid-air collision over Überlingen on 1 July 2002. Following the recommendations made by AGAS, EUROCONTROL's Feasibility of ACAS Resolution Advisory Downlink Study (FARADS) was initiated [21].

Airborne Collision Avoidance System (ACAS)[1] is the last line of defence against mid-air collisions. If a risk of collision is established, ACAS will issue a 'Resolution Advisory' (RA).

Currently, air traffic controllers are only aware that an RA has been issued if and when notified by the pilot by radio. Being unaware about the RA, the controller might instruct the aircraft to manoeuvre in a sense contrary to the RA. Although specifically mandated not to, pilots in some cases follow an ATC clearance which severely degrades collision avoidance.

To address this problem, FARADS is investigating the feasibility of showing simplified indications of ACAS RAs on controller screens [5], [6]. Potential benefits of showing RAs on the controller screen are:

- Avoiding contradiction between guidance of air traffic controllers and RAs
- Improving the controllers' awareness of the traffic situation, including evasive manoeuvres by pilots that follow the RAs
- Reducing the risk of follow-up conflicts and facilitating planning of the post-alert situation (e.g. support controllers in the revision of the sector plan).

As part of FARADS, a set of experiments – referred to as Resolution Advisory Downlink Experiments (RADE) were conducted. RADE-1 took place from 17 November to 28 November 2003, with a total of 30 controllers from ten European Area Control Centres participating in the experiment. The main aim of RADE-1 was to get controller feedback on the concept of RA downlink as well as on the different HMIs for RA downlink. In addition, the effect of RA information on controllers' understanding of the traffic situation was investigated.

RADE-1 showed that the majority of the participants see operational benefits in the provision of RA information to the controller. These benefits relate to a potential decrease in the likelihood of a contradictory ATC clearance and a better anticipation of aircraft manoeuvres in response to the RA. Nevertheless, RADE-1 failed to find any clear evidence that the RA downlink, in fact, yields a better understanding of the further development of the traffic situation (supported by better scores in a Situation Awareness Test).

[1] Also commonly referred to as TCAS – Traffic Alert and Collision Avoidance System. TCAS is a specific implementation of ACAS. TCAS II Version 7 is currently the only available equipment that is fully compliant with the ACAS SARPs. In this document, the terms TCAS and ACAS are used synonymously.

One of the limitations of RADE-1 can be seen in the fact that participants were exposed to “canned” replays of real traffic scenarios involving RAs. Thus, controllers could only monitor, but not control the traffic scenarios. The RADE-2A experiment – which is described in the present report – aimed to overcome this limitation by using a monitoring-and-control real-time simulation environment. Like in RADE-1, the objective of the RADE-2A experiment is to investigate the impact of Resolution Advisory (RA) downlink on controller performance, situation awareness, and workload. In order to assess the impact of RA downlink, the RADE-2A experiment employed a specific HMI and an operational concept for RA downlink [9]]. This HMI and the operational concept were assessed on the basis of controller feedback.

The RADE-2 set of experiments consist of the following studies:

- An initial or prototype study in which the viability of the proposed interactive real-time simulation approach was tested (RADE-2P),
- An experiment in which the impact of RA Downlink is assessed for Area Control (RADE-2A), and
- An initial experiment in which the impact of RA Downlink is assessed for Terminal Control (RADE-2T).

The conduct and the results of RADE-2P are documented in Ref. [11]. The present document describes the experimental objectives, the conduct, and the results of the RADE-2A experiment. Note that the experimental plan for RADE-2A can be also found in Ref. [10].

## 1.2 Structure of the Report

The structure of the report is as follows:

- Chapter 1 is this introduction.
- Chapter 2 describes the aims and objectives of the RADE-2A experiment.
- Chapter 3 outlines the experimental variables, their combinations (to obtain the experimental conditions), as well as the assignment of participants and traffic scenarios to experimental conditions.
- Chapter 4 lists the measurements that were taken in order to assess the objectives.
- Chapter 5 describes the conduct of the experiment, including the simulation environment, the methods chosen for facilitating an RA event, the participants, the training and the time schedule.
- Chapter 6 describes the results of the RADE-2A experiment; these results pertain primarily to the assessment of objectives, but also refer to the degree to which the experiment could be realised as planned.
- Chapter 7 summarises and discusses the results of RADE-2A.
- In Chapter 8, recommendations for future work are given.

# 2. AIMS AND OBJECTIVES OF RADE-2A EXPERIMENT

## 2.1 General Aim

The general aim of the RADE-2A experiment was to analyse the impact of RA downlink on the controller and his/her ability to separate traffic in an interactive control setting, using a specific HMI and an operational concept for RA downlink (see [10]). In this way, the RADE-2A experiment was designed to continue the evaluation work as done in the RADE-1 experiment. In addition, controllers' attitudes on RA downlink, the proposed operational concept and the HMI were investigated.

RADE-2A investigated RA downlink in an Area control environment. A further study, RADE-2T, will investigate the feasibility of RA downlink in a Terminal Control environment.

## 2.2 High- and Low-Level Objectives

The overall validation aim can be broken down into a number of high-level validation objectives. For each high-level objective, a set of low-level objectives (taking the form of research questions) were investigated:

| Objective 1: |
|---|
| Evaluate the benefits of RA downlink for controller performance, situation awareness, and workload. |

Within Objective 1, the following low-level objectives were addressed:

1. Does RA downlink prevent the controller from issuing contradictory clearances to an aircraft involved in the RA?
2. Does RA downlink facilitate the planning of the post-alert situation? That is,
   - is the controller more likely to provide instructions to third-party aircraft?
   - is the controller more likely to provide traffic information to conflict and third-party aircraft?
3. Does RA downlink have an impact on the likelihood of follow-up conflicts?
4. Does RA downlink improve the controllers' situation awareness? That is,
   - does it increase the understanding of the conflict that caused the RAs?
   - does it increase the understanding of the RAs and their influence on the further development of the traffic situation?
5. Does RA downlink have an impact on controller workload?
6. Does RA downlink capture the controllers' attention for a duration that is longer than optimal, at the expense of neglecting other aircraft under their control?

| **Objective 2:** |
|---|
| Evaluate the benefits of RA downlink for different operational scenarios (i.e., timeliness of pilot report, and RA cause). |

Within Objective 2, the following low-level objectives were addressed:

1. Does the effect of RA downlink depend on the timeliness of the pilot report (timely vs. delayed)?
2. Does the effect of RA downlink depend on circumstances that created the RA situation (controller error, pilot error, etc.)?

| **Objective 3:** |
|---|
| Evaluate controller acceptance of RA downlink, the implemented operational concept, and the proposed HMI. |

Within Objective 3, the following low-level objectives were addressed:

1. What is the controllers' opinion of RA downlink? Which benefits and issues do they see?
2. What is the controllers' opinion of the proposed operational concept for RA downlink? What changes, if any, do they suggest?
3. How do controllers evaluate the RA downlink HMI, including the information content and the information display?

# 3. 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),
3. Controller role (Executive Controller vs. Planning Controller).

The choice of the experimental variables was influenced by the findings from the RADE-2P experiment, and is dealt with in more detail in the RADE-2P experimental report [11]. The way in which these three variables were manipulated is described in the following section.

## 3.1 RA Downlink Condition

There are two RA downlink conditions, relating to the baseline condition and the experimental condition:
- RA downlink absent (baseline condition): In the baseline condition, RAs were not presented to the controller on the screen. The only source of information on the RA is the pilot report.
- RA downlink present (experimental condition): In the experimental condition, RAs generated in the cockpit were displayed on the controller screen. The specific HMI chosen for the experimental condition was based on the feedback obtained in RADE-1. It consists of a visual alert indicating that a pair of aircraft received an RA, together with the sense of the RA (either an upward or downward pointing arrow, or a vertical line). For more information on the HMI, see Chapter 5.1.2.

## 3.2 Timeliness of Pilot Report

Timeliness of the pilot report was included as a variable, as it can be reasonably assumed that potential benefits of RA downlink depend on whether the pilot report is timely or delayed. Benefits of RA downlink should be more prominent, if the pilot report is delayed or even missing.

The feasibility of this manipulation was shown during the RADE-2P experiments: Subject Matter Experts (SMEs) acting as pseudo-pilots were able to reliably manipulate the reporting delay (see [11]).

Thus, the pilot report was manipulated on two levels:
- Immediate report (pseudo-pilots report as soon as they see the RA)
- Delayed pilot report (pseudo-pilots only report once they see on the screen the clear of conflict message).

In both conditions, the pilot reported the RA correctly. As there was only one RA per simulation run, the timeliness of the pilot report (i.e., either immediate or delayed) was kept constant for each simulation run. That is, in one simulation run, the reporting delay was either “timely” or “delayed”.

## 3.3 Controller Role

The controller role was manipulated on two levels:

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

During the prototype experiment, the option to run simulations with only one controller in the sector (i.e., Single-Person Operation, SPO) was rejected in favour of a setting that involves an Executive and a Planning Controller. This situation reflects the sector staffing in the majority of control rooms.

Some of the post-run measurements (e.g. workload ratings) were taken from both controllers. For these measurements, data were analysed depending on the controller role. Other measurements were taken either only for the PC/EC team (e.g., losses of separation) or naturally pertain to the Executive Controller only (e.g., number of instructions issued). For these measurements, the controller role was not included in the data analysis.

## 3.4 Moderating Variable: Cause of an RA

Moderating variables are variables that are not directly manipulated in an experiment, but have an effect on the pattern of results. With respect to the RADE-2A experiment, it is recognised that the impact of RA downlink on the controller may depend on other variables beyond those that were systematically controlled as independent variables.

One important moderating variable for the impact of RA downlink is the cause of an RA. In the prototype experiment (RADE-2P), three different RA causes were considered:

- Cause I (High vertical speed level off): the RA is triggered by fast climbing/fast descending aircraft.
- Cause II (ATC error): an incorrect ATC clearance, instruction or action causes the RA.
- Cause III (pilot error): the pilot does not follow an ATC clearance or instruction (e.g. cleared level bust), which results in an RA being issued.

RADE-2P showed that the opportunities for the facilitation of a ‘Cause I’ RA were far more frequent than for the other two causes. Therefore, the idea of systematically crossing RA causes with the other experimental variables was rejected. Instead, it was decided to include the cause of an RA as a moderator variable in the data analysis.

## 3.5 Combination of Experimental Variables

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. As each participant needed to be exposed to all conditions, this required a total of eight simulation runs per participant.

The combination of experimental variables is depicted in Table 3-1. Note that one simulation run serves to realise two conditions at the same time (i.e., the cells for the Executive Controller and the Planner). This is due to the fact that controllers always work as a team in one simulation run.

| | | RA – Downlink | | | |
|---|---|---|---|---|---|
| | | Downlink | | No Downlink | |
| | | CWP | | CWP | |
| | | Executive | Planner | Executive | Planner |
| Pilot Report Timeliness | Timely | *A1* | *A2* | *B1* | *B2* |
| | Delayed | *C1* | *C2* | *D1* | *D2* |

**Table 3-1: 2-by-2-by-2 Experimental Design**

## 3.6 Assignment of Participants and Traffic Samples to Experimental Conditions

The table below (Table 3-2) shows the planned simulation schedule as a balanced Latin Square used to assign pairs of controllers (Planner and Executive Controller) to different presentation orders of the 8 experimental conditions (as labelled in Table 3-1).

In order to realise a full Latin square for the experiment, 16 controller (i.e., 8 controller teams) would have been required as participants for each experiment. Given the restriction on participant numbers (i.e., 12 controllers for RADE-2A), a full Latin Square could not be achieved. This means that the presentation order and the traffic sample were not fully balanced over controller teams and experimental conditions. This slight imbalance, however, does not affect the comparison between the two RA conditions: runs with and without RA downlink are both presented on average on position 4.5[2] and, thus, perfectly balanced. There is a slight imbalance of runs with timely and delayed pilot report, though: The average position for runs with timely report is 4.125, as compared to an average position of 4.875 for runs with delayed timely report. This difference, which points to a small advantage of runs with delayed pilot report in terms of potential training effects, however, is unlikely to affect the interpretation of the results.

In order to realise the eight experimental conditions, a homogenous set of at least 8 different traffic samples was needed (see also [13] and [14]). The traffic samples are referred to as S1 to S8. Table 3-2 also shows the assignment of traffic samples to experimental conditions.

[2] Note that the average presentation position in a sequence of n = 8 runs is 4.5.

| Pair # | ATCo \ Run # | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | *A1* | *A2* | *D2* | *B1* | *D1* | *B2* | *C2* | *C1* |
| | 2 | *A2* | *A1* | *D1* | *B2* | *D2* | *B1* | *C1* | *C2* |
| | **Traffic Sample** | **S1** | **S2** | **S8** | **S3** | **S7** | **S4** | **S6** | **S5** |
| 2 | 3 | *A2* | *B1* | *A1* | *B2* | *D2* | ***C1*** | *D1* | *C2* |
| | 4 | *A1* | *B2* | *A2* | *B1* | *D1* | ***C2*** | *D2* | *C1* |
| | **Traffic Sample** | **S2** | **S3** | **S1** | **S4** | **S8** | **S5** | **S7** | **S6** |
| 3 | 5 | *B1* | *B2* | *A2* | *C1* | *A1* | *C2* | *D2* | *D1* |
| | 6 | *B2* | *B1* | *A1* | *C2* | *A2* | *C1* | *D1* | *D2* |
| | **Traffic Sample** | **S3** | **S4** | **S2** | **S5** | **S1** | **S6** | **S8** | **S7** |
| 4 | 7 | *B2* | *C1* | *B1* | *C2* | *A2* | *D1* | *A1* | *D2* |
| | 8 | *B1* | *C2* | *B2* | *C1* | *A1* | *D2* | *A2* | *D1* |
| | **Traffic Sample** | **S4** | **S5** | **S3** | **S6** | **S2** | **S7** | **S1** | **S8** |
| 5 | 9 | *C1* | *C2* | *B2* | *D1* | *B1* | *D2* | *A2* | *A1* |
| | 10 | *C2* | *C1* | *B1* | *D2* | *B2* | *D1* | *A1* | *A2* |
| | **Traffic Sample** | **S5** | **S6** | **S4** | **S7** | **S3** | **S8** | **S2** | **S1** |
| 6 | 11 | *C2* | *D1* | *C1* | *D2* | *B2* | *A1* | *B1* | *A2* |
| | 12 | *C1* | *D2* | *C2* | *D1* | *B1* | *A2* | *B2* | *A1* |
| | **Traffic Sample** | **S6** | **S7** | **S5** | **S8** | **S4** | **S1** | **S3** | **S2** |

**Table 3-2: Planned Assignment of Participants to Experimental Conditions**

The table is to be read as follows: The condition referring to the lightly shaded cells in Table 3-2 (run 2-6, i.e. pair 2 and run 6) means that controller pair #2 was presented with traffic sample S5, received RA downlink, and encountered a delayed pilot report. ATCo #3 worked as executive controller and ATCo #4 worked as planner.

Deviations between the planned schedule (as presented in Table 3-2) and the actual simulation schedule are presented in Section 6.1.2. These deviations were due to unsuccessful runs that needed to be repeated. In order to do so, three spare traffic samples were constructed for RADE-2A (S9 – S11).

# 4. MEASUREMENTS AND ANALYSIS SPECIFICATION

This chapter addresses the measurements collected during the RADE-2A experiment. The measurements fall into the following categories (see also [10]):

- Perceived realism of the simulation
- Controllers' (primary) task performance
- Workload
- Situation Awareness
- Controller acceptance (concerning RA Downlink, the proposed operational concept and the proposed HMI).

## 4.1 Realism of the Simulation and the RA Event

During the post-exercise and post-experiment interviews, participants were asked to rate the realism of the exercise (see Appendix G). These ratings were made separately for:

- The traffic situation
- The RA event, and
- The pilot response.

Note that the data pertaining to the realism of the simulation do not directly relate to the experimental objectives but serve to ensure that the collected data can be sensibly interpreted.

The data were captured in the interview recording sheet by the Human Factors expert conducting the interview. Data were also recorded with a Dictaphone.

## 4.2 Controllers' Task Performance

Indicators of controllers' primary task performance concern the handling and separation of aircraft in the sector. Two types of controller behaviour were measured:

1. the instructions given to aircraft involved in the RA, and

2. the traffic information given to aircraft involved in the RA and third-party aircraft.

In addition, the number of separation losses was taken as an indicator of controller performance.

### 4.2.1 Controller Instructions to Aircraft Involved in the RA.

If a pilot manoeuvres an aircraft in response to an RA yielding a deviation from the ATC clearance (see ICAO guidelines in Appendix K), the controller ceases to be responsible for separation of this aircraft and should not to interfere with the RA [23]. Thus, the controller should not issue any clearances to the aircraft involved in the RA. In order to assess to which extent the controller complies with this, the following measurement was taken:

- Number and type of clearances issued to RA aircraft.

For all clearances issued to aircraft involved in an RA, it was analysed whether they corresponded with or contradicted the RA. Measurements were contrasted for the baseline (no RA downlink) and the experimental condition (RA downlink).

The measurements concerning R/T instructions were captured in the SME and Human Factors Expert Notebooks (see Appendix D and Appendix E) and in the system recordings. Information from different sources was consolidated as part of the RADE-2A Data Analysis (see [12]).

### 4.2.2 Provision of Traffic Information

Although the controller should refrain from issuing clearances to aircraft involved in the RA, he or she can provide traffic information to aircraft involved in the RA or other aircraft affected by the RA manoeuvre (i.e., third-party aircraft). The provision of traffic information is not mandatory; however, it can be tentatively taken as an indicator of the controllers' ability to understand the conflict geometry and to anticipate the impact of the RA manoeuvres on other aircraft.

For this reason, the following measurements were taken:

- Number of R/T instructions involving traffic information to conflicting aircraft
- Number of R/T instructions involving traffic information to third-party aircraft

Measurements were contrasted for the baseline (no RA downlink) and the experimental condition (RA downlink). The measurements concerning provision of traffic information was captured in the SME and Human Factors Expert Notebooks (see Appendix D and Appendix E) and in the system recordings. Information from different sources was consolidated as part of the RADE-2A Data Analysis (see [12]).

### 4.2.3 Losses of Separation

The number of separation losses can be taken as an indicator of how well the controller fulfils his/her task of separating aircraft in the sector.

For this reason, the following measurement was taken:

- Number of separation losses.

Of particular interest is the controllers' efficacy to separate traffic after the RA event. It is often suggested that RA downlink could create a "cognitive tunnelling", meaning that the controller focuses on the RA event on the expense of other traffic in the sector. The controller's ability to separate other aircraft in the sector immediately after the RA event (measured in terms of separation losses to other aircraft) is therefore a good indicator for assessing the cognitive tunnelling hypothesis.

With respect to benefits of RA downlink, it is assumed that RA downlink can improve the planning of the post-alert situation. In other words, the controller should be better able to prevent third-party aircraft that occur as a result of the RA manoeuvre. The controller's ability to separate third-party aircraft from the RA aircraft (measured in terms of separation losses to these aircraft) is therefore a suitable measure for testing this assumption.

Both indicators specified above refer to the controllers' efficacy to separate traffic after the RA event. In contrast, there is no reason to expect that the number of separation losses before an RA is related to any of the experimental conditions under investigation. Therefore, the number of separation losses was scored separately for the period before and after the RA event.

The number of separation losses was captured in the system recordings.

## 4.3 Situation Awareness

Situation Awareness (SA) refers to the "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" [17], [20]). SA was measured on the basis of self-rating scales, a memory test, and an online probe.

### 4.3.1 Self-rating Scales (SASHA)

The self-rating scale used in the RADE-2A experiment is a modified version of SASHA (Situation Awareness for SHAPE), EUROCONTROL's rating scale for situation awareness. The scale consists of a set of questions on different aspects of situation awareness that need to be answered on a 5-point rating scale (see Appendix C). Some of the questions in the self-rating scale specifically address the impact of the new system feature (in this case, RA downlink) on SA. These questions were suppressed in the 'No RA downlink' condition.

The data were captured by requesting the Planner and the Executive Controller to fill in an electronic form after each simulation run.

### 4.3.2 Memory Test

A memory test (see Appendix B) on details of the RA situation was administered after each exercise. The memory test served to assess whether the controller fully understood the situation that led to the RA, as well as the type of RAs issued and the pilot's response to it.

The data were captured from both the Planner and the Executive Controller in an electronic form. They were evaluated on the basis of a comparison with the logged system data and the recordings made during the replay.

### 4.3.3 On-line Probe

Situation awareness was also measured on the basis of an on-line probe. As soon as the pseudo-pilot announced ‘clear of conflict’, the controller received an R/T request of a pilot who was not involved in the RA encounter. Pilot requests concerned level or heading changes, the latter for weather avoidance. The controller’s correct and timely response to the request is considered as an indicator of the controller’s awareness of the overall traffic situation in the sector, in particular, pertaining to aircraft not involved in the RA.

SMEs acting as pseudo-pilots were in charge of making the requests and taking notes on controller responses (see Appendix E). The technique is similar to the Situation Present Assessment Method (SPAM) developed by Durso et al. and the SASHA-online query [2], [20].

Data pertaining to the requests were captured in the SME and HF Expert notebooks and in the system recordings.

## 4.4 Controller Workload

### 4.4.1 Subjective Workload Ratings

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 at the end of each simulation run (see Appendix H). Measurements were contrasted for the various experimental conditions.

The data were captured in an electronic form with slide bars indicating workload on a scale from 0 to 20 between the respective endpoints (usually low and high).

### 4.4.2 Secondary Task Performance

Another way of measuring workload consists in analysing performance on a secondary (i.e., lower priority) task. The assumption is that with increasing workload, controllers allocate their resources pre-dominantly to high-priority tasks (that is, tasks related to separation provision), yielding a performance decrease on low-priority tasks. Therefore, performance on the secondary task provides an objective indicator (i.e., an indicator that is not based on self-assessment) of the controller workload.

For the purposes of the RADE-2A experiment, the number of missed or late transfers of aircraft to the downstream sectors was chosen as an indicator for secondary task performance. This indicator is thought to reflect the workload of the Executive Controller.

The data were captured by performing post run off-line analysis of the recorded traffic situation.

## 4.5 Controller Acceptance

During the de-briefing sessions that took place at the end of the experiment, controllers' opinions on the following topics were gathered:

- RA downlink in general (advantages and disadvantages)
- The proposed operational concept for RA downlink
- The specific HMI for RA downlink

The data were also collected electronically in the post-experiment questionnaires (see Appendix G).

# 5. CONDUCT OF THE EXPERIMENT

With respect to the conduct of the RADE-2A experiment, information on the following topics will be given: the simulation environment, the methods chosen for facilitating an RA event, the participants, the training and the time schedule. These topics will be covered in separate chapters.

## 5.1 Simulation Environment

### 5.1.1 The 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. For the experiment, eDEP was configured to facilitate a small-scale simulation environment, and a TCAS server[3] was used for the realistic generation of TCAS events. The EUROCONTROL AudioLAN system was used for communication between experimental participants on the one hand and pseudo-pilots and adjacent control sectors on the other. Adjacent sectors were controlled by Subject Matter Experts (SMEs).

During the RADE-2A experiment, the platform was used in two different configurations, a single and a dual configuration. In the single configuration, the two Controller Working Positions (CWP) were operated independently. This configuration was exclusively used for the training sessions.

[3] A computer tool replicating TCAS logic in the ground system and generating RAs.

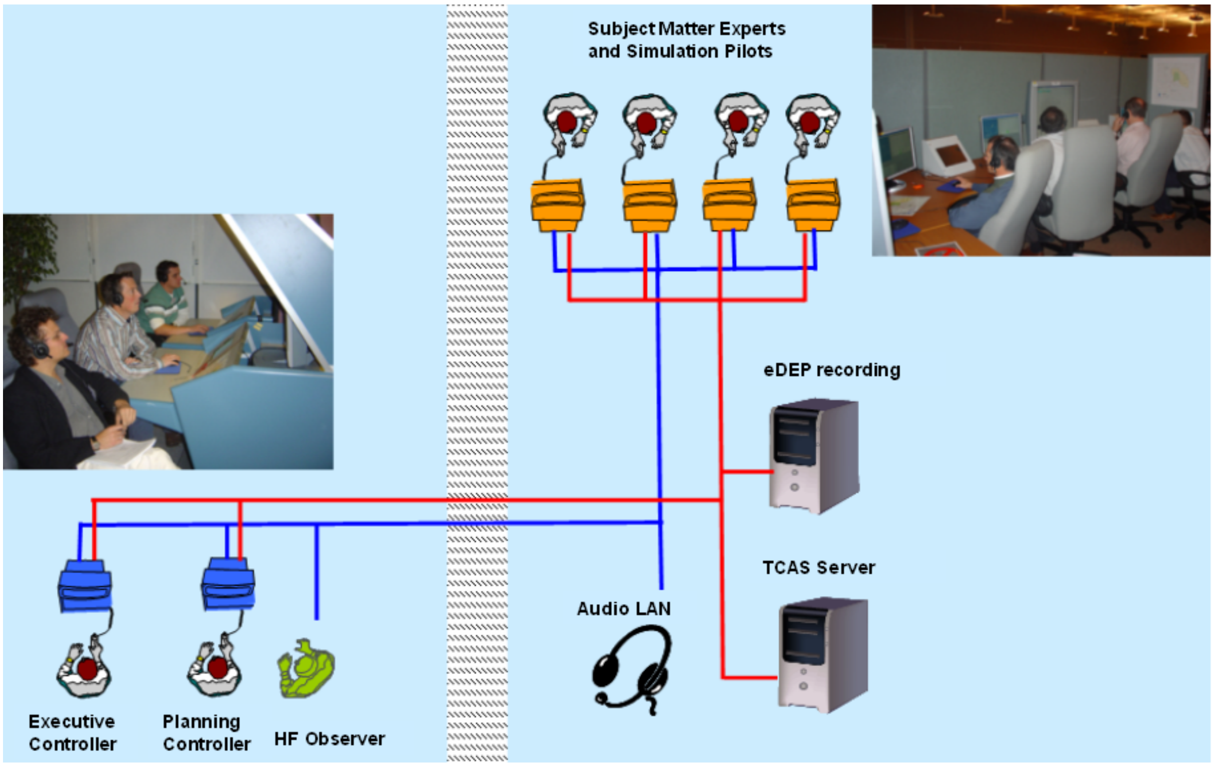


**Figure 5-1: RADE-2A Configuration**

The dual configuration (see Figure 5-1) allowed for a single simulation environment with CWPs for an Executive and a Planning Controller. While the Executive Controller was responsible for separation of aircraft in the sector and radio communication with the pilots, the Planning Controller was responsible for resolving planning conflicts, co-ordinating with other sectors by phone, and assisting the executive controller in the provision of traffic separation. The dual configuration was used for all measured runs.

In addition to the simulation platform, a tool for ACAS event analysis was available. The Interactive Collision Avoidance Simulator (InCAS) was used to read the radar data recorded on the simulation platform and rebuild aircraft trajectories. In that way, TCAS behaviour could be recreated, so that it was possible to display and analyse TCAS events that occurred during a simulation run.

### 5.1.2 Human-Machine Interface

The controller HMI used for the experiment was based on the standard EATMP HMI. This HMI is described in the eDEP design document and the RADE-2P document (see [7] and [11]). In the following, only specific aspects of the TCAS and STCA alerts display are described.

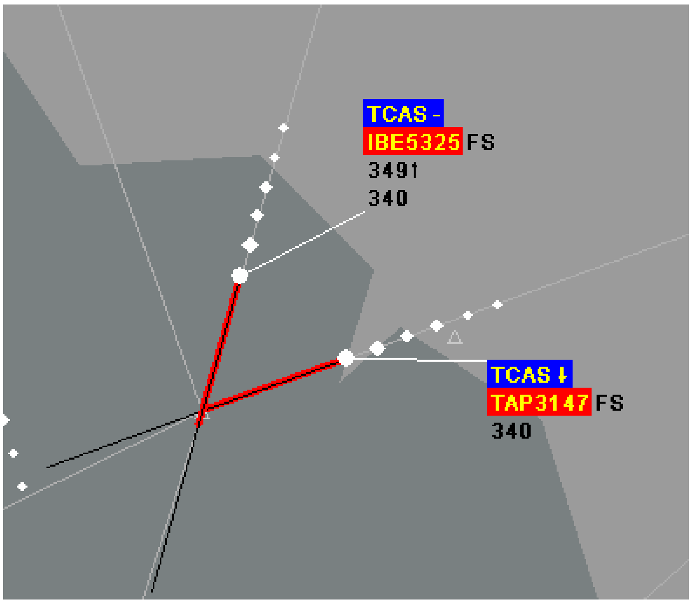


**Figure 5-2: STCA and TCAS RA Display**

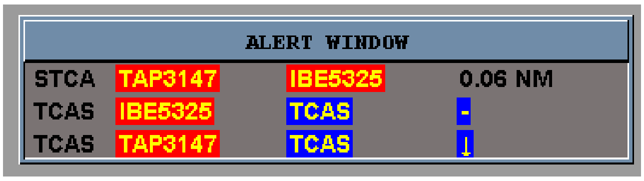


**Figure 5-3: STCA and TCAS RA Indication in the Alert Window**

Short-term conflict alerts (STCAs) were shown on the CWP by visually enhancing the callsign part of the label with a red background and yellow letters. In addition, the track vector was displayed in red and extended to the predicted point of closest horizontal approach (see Figure 5-2). There was also an alert window that showed the STCA, with the callsigns of aircraft involved and the distance at the predicted point of closest horizontal approach (see Figure 5-3).

Figure 5-2 also shows the presentation of a TCAS RA. The TCAS RA was shown in line 0 of the label, above the aircraft callsign. 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. In case of an RA reversal, the previous RA direction was shown in brackets (see Figure 5-4). Usually, TCAS RA information would be displayed for all aircraft involved in the conflict. In case only one aircraft had a TCAS RA (i.e., because the other aircraft only received a TA[4]), the intruder was shown with a red frame around the callsign (see Figure 5-5).

[4] For the purpose of the experiment, all aircraft were TCAS equipped.

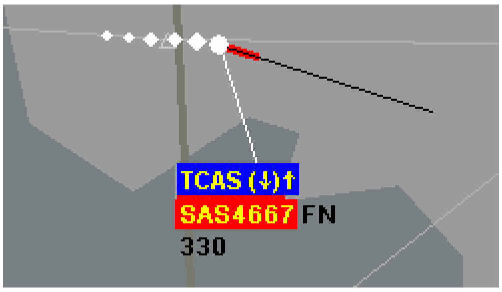


**Figure 5-4: Reversal TCAS RA Display**

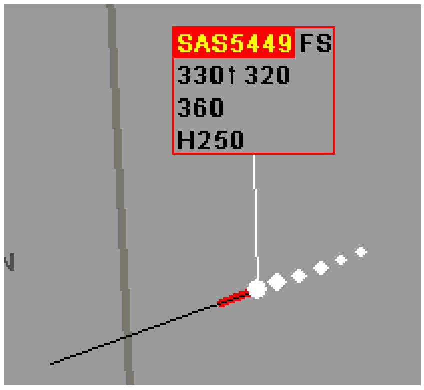


**Figure 5-5: TCAS TA Display**

RA information was also shown in the alert window. More information on the presentation of TCAS RAs can be found in the Appendix J and in the FARADS Operational Concept document [9].

### 5.1.3 Control Centre and Airspace

In RADE-2A, controllers were told that they were to work in Cottam Centre which is a fictitious facility located somewhere in Europe. They were on an afternoon shift in the so-called Haren sector (see Figure 5-6). The Haren sector borders with two sectors, one in the North and one in the South. For the purpose of the experiment, the adjacent sectors were automatically controlled by the simulation system and an SMEs located in a separated room acted as “human interface” to the other sectors. Co-ordination with these sectors was done via a designated AudioLAN telephone connection or using System Coordination (SYSCO).

A special characteristic of the airspace was the military area (green quadrangle in the middle of Figure 5-6). 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.

There were major crossing points for traffic streams at CAV, BRC, BIB and ROPUR which would ask the controllers’ special attention. Main traffic flows were presented to the controllers during the briefing session before the simulations (see also [13]). They are listed below:

- from BYNOP to MUTRO on odd levels with some outbound traffic descending to FL190
- from MUTRO to BYNOP on even levels with some inbound traffic climbing to requested FL
- from BIB to XCAV on odd levels with some inbound traffic climbing to requested FL
- from BIB to MYDAX on odd levels requesting change to even level after sector entry
- from MYDAX to BIB on odd levels changing to FL280 (even level) before exit
- from MYDAX to BRL on odd levels
- from LNU to MYDAX on even levels
- from LANDA to IMEON on even levels.

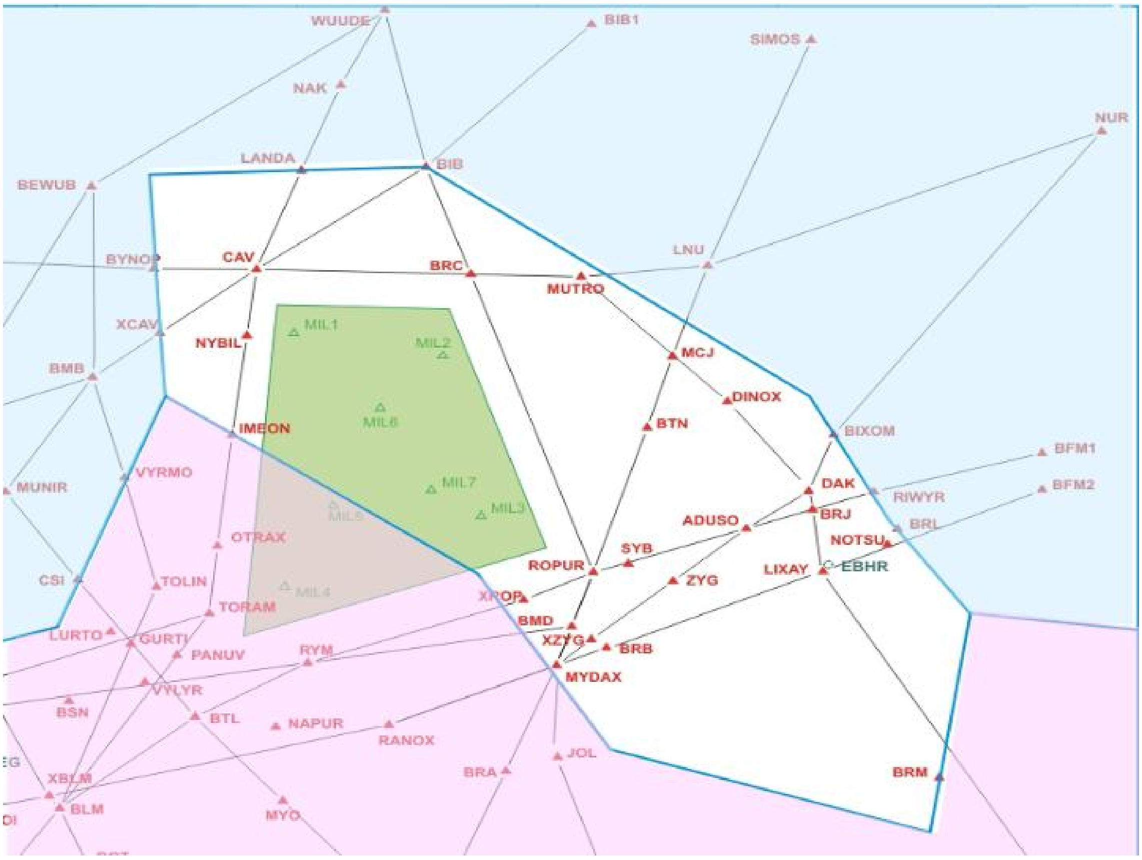


**Figure 5-6: RADE-2A Simulated Airspace - Haren Sector in Cottam Centre**

## 5.2 RA Facilitation Method

One of the major challenges in RADE-2 was to facilitate RAs in a realistic way. In an interactive setting, a participant acting as Executive or Planning controller would do everything possible to avoid an RA event. Therefore, a specific method had to be devised to achieve RAs in a real-time simulation.

### 5.2.1 The Role of the Subject Matter Experts

Subject Matter Experts (SMEs) were situated at the pseudo-pilot positions and closely observed the evolution of the traffic scenario. SMEs were current or former air traffic controllers specially trained and briefed for this simulation. Their task was to predict likely controller actions and to identify traffic situations that may allow for the generation of an RA. Depending on the identified opportunity for an RA, SMEs would then instruct the pseudo-pilot to behave in a certain way (i.e., busting the FL, or choosing a high vertical speed). SMEs were specifically instructed not to create situations that would compromise simulation realism or could negatively affect controllers' self-esteem.

In RADE-2P, it was noticed that the interaction between the SMEs and the pseudo-pilots was quite demanding. A more viable option, which was chosen during the RADE-2A experiment, was to have SMEs acting as pseudo-pilots, rather than letting them communicate their plan for creating an RA event to the pseudo-pilot. For the RADE-2A experiment, two SMEs were employed as pseudo-pilots, with a third SME acting as a counterpart of the planner in the feed sectors. A further pseudo-pilot, without an ATC background, controlled aircraft and followed instructions from other SMEs to create RA situations when required.

### 5.2.2 Facilitation of RA Events Depending on the Cause of the RA

There were three different causes for RAs in the RADE-2A experiment. The facilitation of RA events is described separately for these three causes.

#### 5.2.2.1 Controller Error

In case a suitable traffic situation for the facilitation of an RA event emerged, the SMEs (acting as pseudo-pilots) took actions to increase workload that may eventually lead to controller error. Examples are:

- Requesting a change of flight level due to turbulence
- Requesting direct routing
- Delaying pilot response
- Giving incorrect read-backs
- Blocking of frequency through pilot requests during critical situations
- Diverting attention to different parts of the sector through pilot requests

#### 5.2.2.2 Pilot Error

Another means to facilitate an RA event consists in deliberately implementing a wrong or unsafe pilot action in a conflict-prone situation. A direct way for implementing a pilot error that would very likely result in the generation of an RA was to have the aircraft bust the cleared level with traffic on the level above or below. Alternatively, the aircraft could make a turn that did not comply with ATC instruction (e.g. heading 030 instead of 330).

#### 5.2.2.3 High Vertical Speed Level off

In order to create an RA that is due to a high-vertical speed before level off, the pseudo-pilot would maintain a high speed of climb or descent close to levelling-off at the cleared level. This would serve to induce a conflict pattern with a proximate aircraft at an adjacent flight level.

### 5.2.3 Briefing of Participants

In order to avoid a negative impact of the RA events on controllers' self-esteem, it was emphasised that the traffic scenarios were specifically designed to create opportunities for RA events. This concerned both the traffic load used in the simulation as well as the amount of conflicts between the planned aircraft trajectories.

In addition, it was pointed out that the RA events would not be used to make judgements on the performance of individual controllers. The only aim of the experiment was to assess the *differences* in controller behaviour that arise as a consequence of showing RA information to the controller. In line with this, the post-exercise debriefing would aim at receiving feedback on the usefulness of RA downlink in this particular situation rather than reflecting on when and how the controller could have made decisions to avoid the RA beforehand.

## 5.3 Participants

A total of 12 controllers participated in the RADE-2A simulation. Before the start of the experiment, all participants filled in an electronic questionnaire which contained questions on personal data and experience (see Appendix A). Figure 5-7 and Figure 5-8 display the nationalities and the home ACCs of the participants.

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). Of the 12 controllers, 11 also worked as instructors, with an instructing experience ranging between 1 and 24 years (M = 6.4, SD = 6.7).

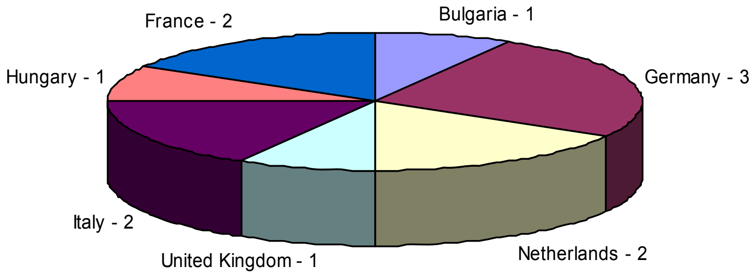


**Figure 5-7: RADE-2A Participants by Nationality**

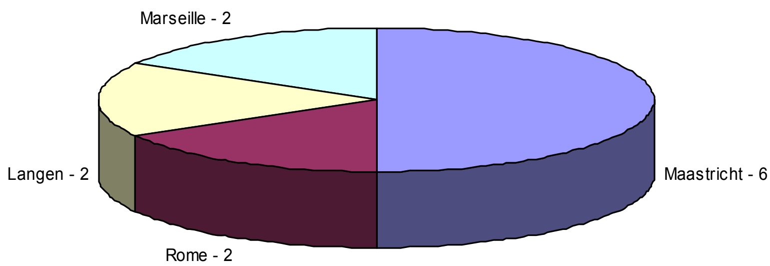


**Figure 5-8: RADE-2A Participants by Home ACC**

All 12 controllers had witnessed at least one incident with a serious violation of separation minima, either involving traffic under their own responsibility or the responsibility of an adjacent sector or a colleague. The number of incidents witnessed ranged between 2 and 10 with an average of 3.8 (SD = 2.2).

Nine out of the 12 controllers reported that in at least one of the above incidents, RAs were generated. The number of witnessed RA events ranged between 1 and 4 with an average of 2.1 (SD = 0.9).

Seven participants stated that they had experienced cases in which the pilot reported an RA that was due to fast climbing or descending aircraft. The reported numbers ranged between 2 and 10 with an average of 4.6 (SD = 2.9). Six participants stated that they were each at least once informed by pilots about false RAs, that is, RAs that were triggered when no other traffic was in the vicinity of the aircraft. Observed cases ranged between 1 and 5 with an average of 2.8 (SD = 1.5).

## 5.4 Time Schedule

The RADE-2A experiment took place from October 4, 2005 to December 1, 2005. Six different controller teams participated in the experiment, each for four subsequent days. The exact simulation dates are presented below (see Table 5-1).

| | | |
|---|---|---|
| RADE-2A | Group 1 | 04-Oct-2005 – 07-Oct-2005 |
| | Group 2 | 11-Oct-2005 – 14-Oct-2005 |
| | Group 3 | 24-Oct-2005 – 27-Oct-2005 |
| | Group 4 | 08-Nov-2005 – 11-Nov-2005 |
| | Group 5 | 14-Nov-2005 – 17-Nov-2005 |
| | Group 6 | 28-Nov-2005 – 01-Dec-2005 |

**Table 5-1: Simulation Schedule for Controller Groups in RADE-2A**

Each group stayed at the Experimental Center for 3½ days and followed the same daily schedule (see Table 5-2).

| | | |
|---|---|---|
| Day 1 | Morning | Training briefings and equipment familiarization |
| | Afternoon | Training runs |
| Day 2 | Morning | 2 measured runs |
| | Afternoon | 2 measured runs |
| Day 3 | Morning | 2 measured runs |
| | Afternoon | 2 measured runs |
| Day 4 | Morning | Spare runs & de-briefing |

**Table 5-2: Daily Schedule for Controller Groups in RADE-2A**

## 5.5 Training

For each controller group, training took place on the first day of the simulation. Training started in the morning with a briefing of approximately two hours, distributed over two sessions with a 15-minute break in-between. The briefing covered the following aspects:

- Introduction of the RADE-2 team
- Background information on the question: *Why RA Downlink?*
- Objectives of RADE-2
- ACAS operational briefing
- RA downlink operational concept
- Introduction to the main features of the HMI
- Main characteristics of the fictitious control sector
- Simulation schedule

After the briefing, controllers had time to familiarise themselves with the working equipment. In the afternoon, at least three training runs were carried out. In these training runs, controller were coached individually by one SME each (see Section 5.1). After each run, a debriefing was performed, during which controllers had the opportunity to ask questions.

# 6. RESULTS

The results obtained in the RADE-2A experiment will be reported in the following order: After a section on results pertaining to the quality of the experiment conduct, the results pertaining to experimental objectives (i.e., controller task performance, situation awareness, workload, and acceptance) will be reported.

## 6.1 Adequacy of the Experimental Approach

In this section, data are reported that serve to ensure the adequacy of the chosen experimental approach. These concern: the training sufficiency, the extent to which the planned exercises and RA events could be realised, and the realism of the simulation. These data provide the basis for judging whether the data pertaining to the experimental objectives can be sensibly interpreted.

### 6.1.1 Sufficiency of Training

As part of the post-experimental questionnaire, controllers were asked if they felt sufficiently trained before progressing to the measured exercises. Controllers could assess the training sufficiency on a scale ranging from 1 (poor) to 5 (very good). Results are shown in

Figure 6-1.

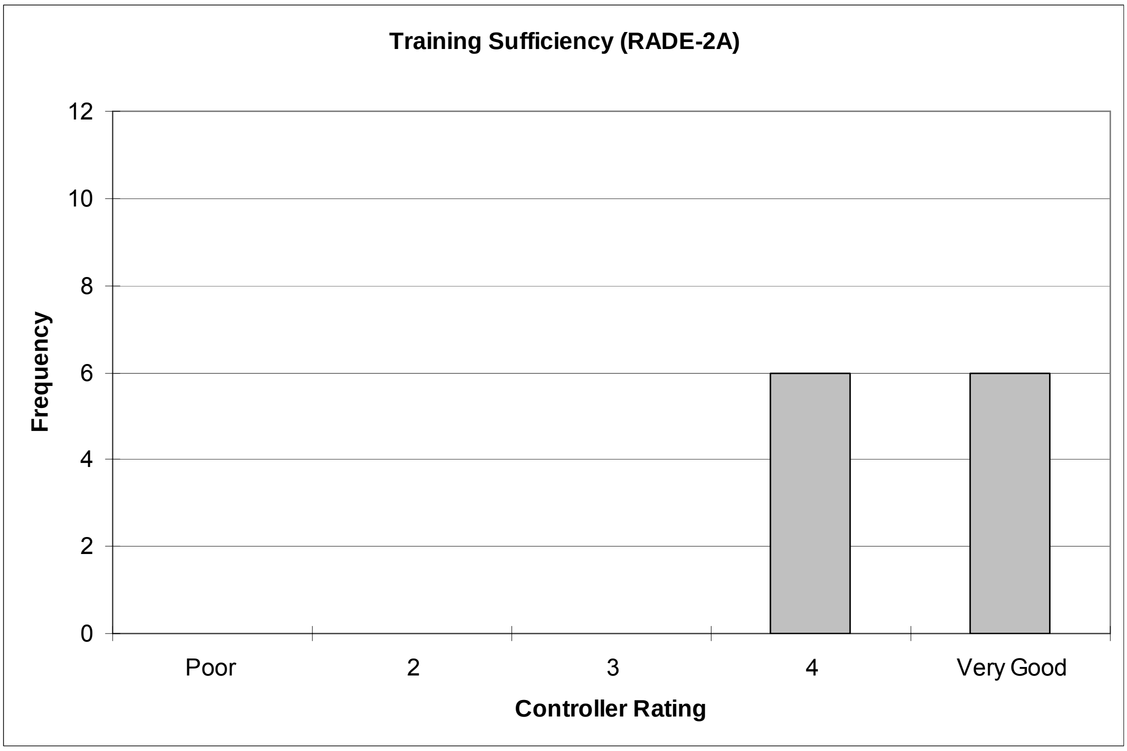


**Figure 6-1: Training Sufficiency Ratings**

As the minimum rating was 4 (M = 4.5, SD = 0.5), it can be concluded that all controllers felt sufficiently trained before progressing to the measured exercises.

### 6.1.2 Duration of Exercises

**A total of 48 successful runs (i.e., 8 runs for each of the 6 controller groups) were conducted during RADE-2A. They lasted almost 27 hours, with a mean duration of 33.5 minutes.**

Table 6-1 gives an overview of the total exercise time during the experiment as well as minimum, maximum and mean exercise duration with standard deviation.

| Duration | RADE-2A | Group 1 | Group 2 | Group 3 | Group 4 | Group 5 | Group 6 |
|---|---|---|---|---|---|---|---|
| Total exercise | 26:48:23 | 4:38:31 | 4:24:58 | 3:56:54 | 5:19:32 | 4:34:12 | 3:54:16 |
| Minimum | 0:05:48 | 0:20:50 | 0:26:45 | 0:19:16 | 0:22:43 | 0:16:13 | 0:05:48 |
| Maximum | 1:01:08 | 0:58:07 | 0:48:24 | 0:37:40 | 1:01:08 | 0:57:21 | 0:45:44 |
| Mean | 0:33:30 | 0:34:49 | 0:33:07 | 0:29:37 | 0:39:56 | 0:34:16 | 0:29:17 |
| Standard deviation | 0:11:02 | 0:10:48 | 0:06:38 | 0:06:02 | 0:12:14 | 0:13:18 | 0:11:24 |

**Table 6-1: Duration of Exercises (hh:mm:ss)**

### 6.1.3 Number and Type of Repeated Exercises

Out of the 48 planned runs, 12 runs (25%) had to be repeated because of violations of one of the success criteria. A simulation run was deemed unsuccessful if one of the following occurred: no RA generated, loss of realism (as determined by the SMEs), technical problems, or errors made by pseudo-pilots.

Table 6-2 provides an overview of unsuccessful runs that had to be repeated. Each entry shows the run identifier (with the first digit indicating the team number and the second digit indicating the run number), the experimental conditions (i.e., RA downlink and pilot report timeliness), the original traffic sample, and the spare traffic sample used as a replacement. At the end of each entry, the reason is given why the run was considered unsuccessful by the simulation team.

All unsuccessful runs were repeated successfully in the same configuration but with a spare traffic sample. They were not completed immediately after the unsuccessful run, but usually at the end of Day 3 or on Day 4.

| | RA-Downlink | Pilot Report | Traffic Sample | Successful Spare Traffic Sample | Reason |
|---|---|---|---|---|---|
| Run 1-6 | No | Timely | S4 | S9 | No RA generated |
| Run 1-8 | Yes | Delayed | S5 | S11 | AudioLAN problem |
| Run 2-2 | No | Timely | S3 | S9 | No RA generated |
| Run 2-5 | No | Delayed | S8 | S11 | AudioLAN problem |
| Run 3-1 | No | Timely | S3 | S11 | Technical problem |
| Run 3-4 | Yes | Delayed | S5 | S9 | ACAS server problem |
| Run 3-8 | No | Delayed | S7 | S10 | Pseudo-pilot error |
| Run 4-4 | Yes | Delayed | S6 | S10 | Technical problem |
| Run 5-1 | Yes | Delayed | S5 | S11 | Loss of realism |
| Run 5-7 | Yes | Timely | S2 | S9 | ACAS server problem |
| Run 6-2 | No | Delayed | S7 | S9 | ACAS server problem |
| Run 6-7 | No | Timely | S3 | S11 | Loss of realism |

**Table 6-2: Reasons for Unsuccessful Simulation Runs**

### 6.1.4 Generation of TCAS Resolution Advisories

The major challenge in RADE-2A was to facilitate the evolvement of a situation during which a TCAS resolution advisory can be elicited. There were three different ways in which RAs were elicited, referred to as the “RA causes”: (1) pilot error, (2) controller error, and (3) high vertical speed level off (see Section 5.2).

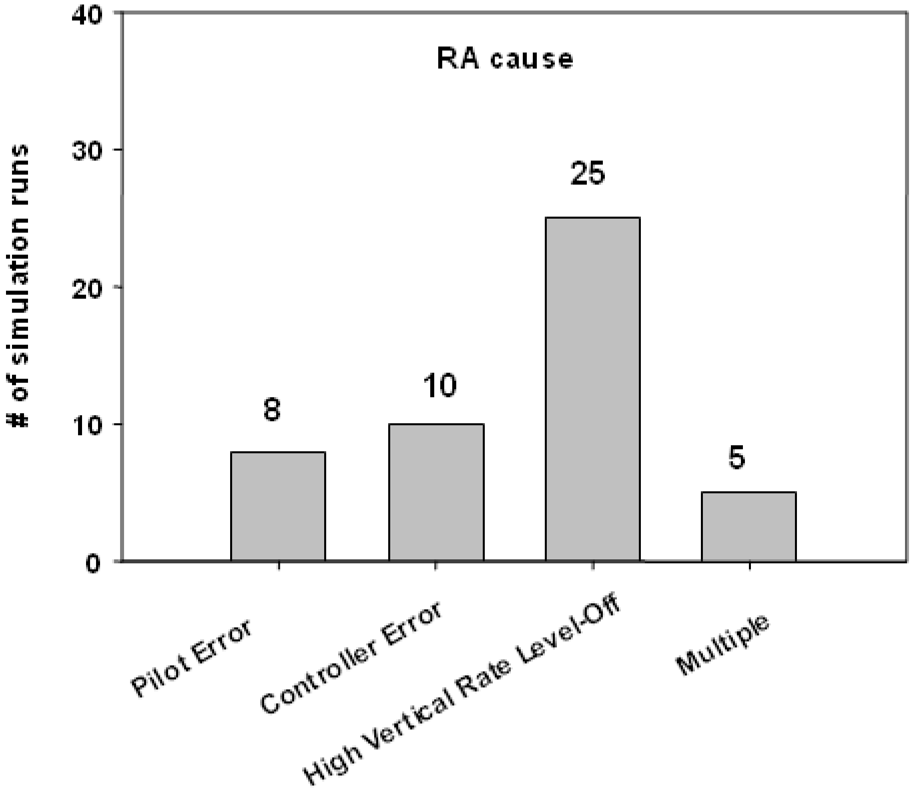


**Figure 6-2: Distribution of Simulation Runs over RA Causes**

Because there was one RA event in every run considered as successful, there was a total of 48 RAs in the RADE-2A experiment. Figure 6-2 shows the distribution of the 48 RAs across the RA causes. A fourth RA category 'multiple' was defined if more than one cause – usually a combination of pilot and controller error - led to the RA. As can be seen, about half of the RAs (n = 25) were caused by a high vertical speed level off (after a climb or descent). The second most frequent cause was controller error (n = 10), followed by pilot error (n = 8) and multiple (n = 5). This distribution pattern reflects the fact that there were far more opportunities to elicit an RA by using a high vertical speed level off than by creating a pilot or controller error.

| | | RA Cause | | | | Total |
|---|---|---|---|---|---|---|
| | | Pilot Error | Controller Error | High Vertical speed | Multiple | |
| RA Downlink | Downlink | 3 | 5 | 13 | 3 | 24 |
| | No Downlink | 5 | 5 | 12 | 2 | 24 |
| Total | | 8 | 10 | 25 | 5 | 48 |

**Table 6-3: Distribution of RA Causes over Simulation Conditions**

In Table 6-3 the frequencies shown in Figure 6-2 are cross-tabulated against the presence or absence of RA downlink information. A chi² test showed that the distribution of runs over RA causes did not differ between the two RA downlink conditions (chi² (3) = 0.74, p = 0.86). Thus, there is no confounding of RA downlink conditions with RA causes.

The distribution of runs over RA causes was also tested with respect to the pilot report timeliness (timely vs. delayed). According to a chi² test, the different RA causes are sufficiently balanced over the two report timeliness conditions (chi² (3) = 2.74, p = 0.43).

In order to simplify the data analysis pertaining to the experimental objectives (see below), two categories of RA causes were defined. The first category contains RAs that are due to high vertical speed level off, the second category contains the other three RA causes and is referred to as ‘other cause’. These two categories comprise 25 and 23 runs respectively.

### 6.1.5 Scenario Realism

Scenario realism was assessed on the basis of controller ratings and comments in the post-exercise de-briefing (held after each successful run) as well as in the post-experimental de-briefing (held at the end of the experiment).

#### 6.1.5.1 Post-exercise Debriefing

In the post-exercise de-briefing, controllers were requested to rate the realism of the preceding simulation run with respect to three aspects:

a) overall traffic situation,
b) the RA event, and
c) the pilot response.

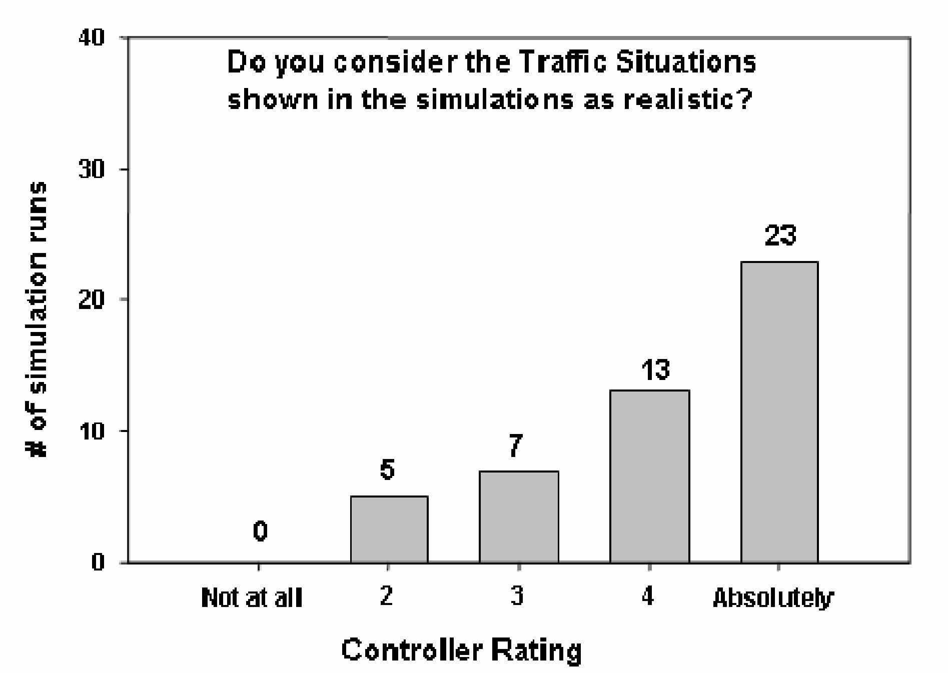


**Figure 6-3: Perceived Realism of Traffic Situations (Post-exercise)**

Answers were given on a five-point scale ranging from 1 (not at all) to 5 (absolutely) with three unlabelled intermediary points. Note that the post-exercise debriefing was done with the Executive Controller only, yielding a total of 48 responses (i.e. one response per exercise). The distributions of ratings over the five response categories are shown in Figure 6-3 to Figure 6-5.

For all of the three aspects, the most frequently chosen rating was 5, indicating a high degree of realism. As a tendency, the pilot responses to the RA were rated as the most realistic aspect (M = 4.56, SD = 0.80), followed by the traffic situation (M = 4.10, SD = 1.02) and the RA event itself (M = 3.92, SD = 1.26).

In those cases where realism of any of the three aspects was rated low (i.e. ratings of 1 or 2), controllers had the impression that traffic load was too high, aircraft performance was unrealistic, pseudo-pilots did not comply well enough, or nuisance alerts distracted them from the real problem.

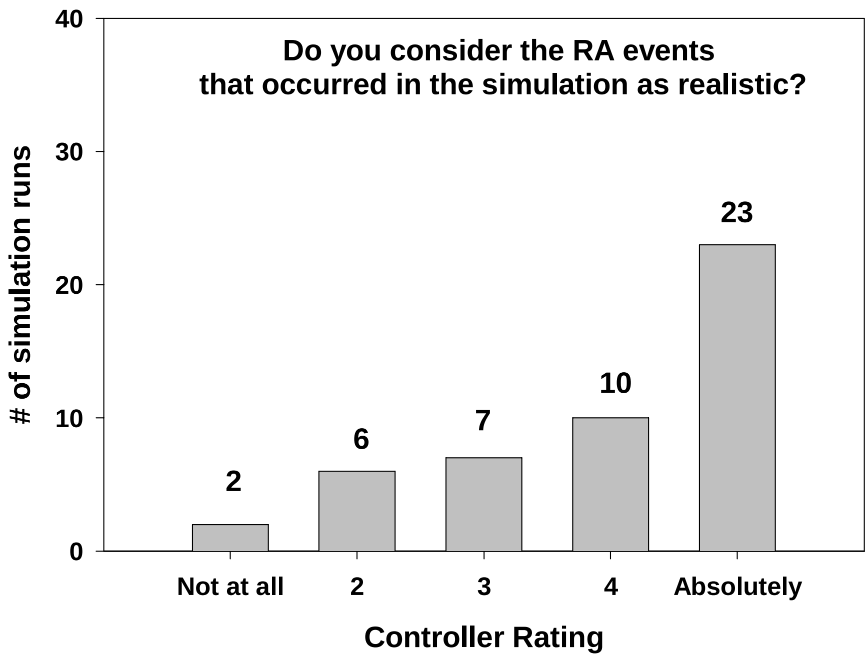


**Figure 6-4: Perceived Realism of RA Events (Post-exercise)**

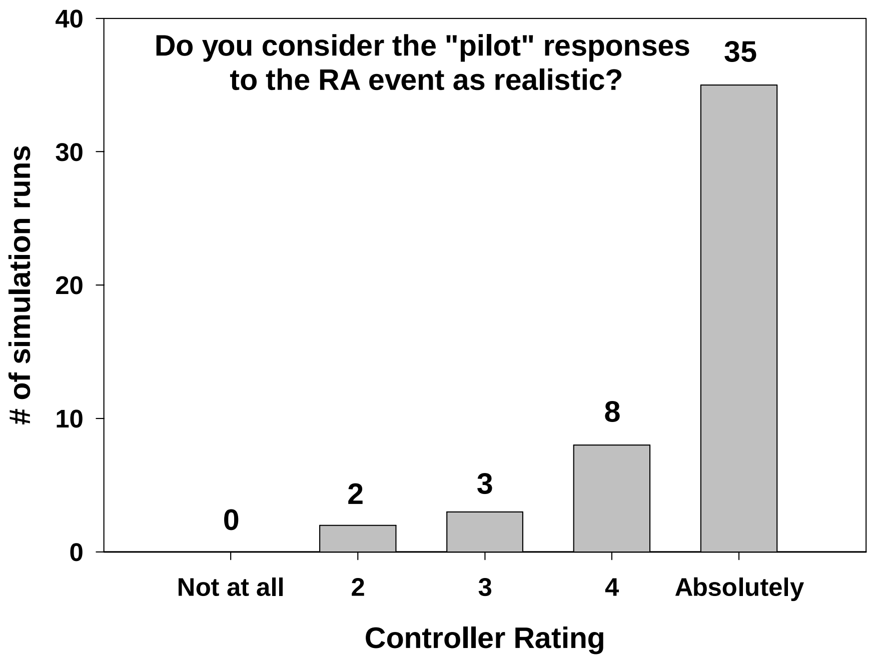


**Figure 6-5: Perceived Realism of Pilot Responses (Post-exercise)**

#### 6.1.5.2 Post-experiment Questionnaire and Debriefing

After attending the experiment, controllers were asked to fill in an electronic questionnaire with questions on simulation realism (Appendix G). Realism ratings collected at the end of the experiment reflect the perceived realism of the simulation in general, rather than the realism of a specific exercise. Note that all of the 12 participants filled in the post-experiment questionnaire individually, yielding a total of 12 responses.

Again, participants were asked to rate the realism on a rating scale from 1 (not at all realistic) to 5 (absolutely realistic). The answers are displayed in Table 6-4.

| Item | Mean | Standard Deviation |
|---|---|---|
| Realism of traffic situations | 3.4 | 0.8 |
| Realism of RA event | 3.9 | 0.5 |
| Realism of pilot response to the RA | 4.3 | 0.7 |

**Table 6-4: Realism Ratings for Different Aspects of the Simulation (Post-experiment)**

Although the average ratings are still on the positive side of the scale, it is noticeable that the ratings collected at the end of the simulation are lower than the ones collected after a particular exercise (see 6.1.5.1). This holds especially for the rated realism of the traffic situations (see Figure 6-6).


**Figure 6-6: Post-experiment Ratings for Realism of the Traffic Situations**

Additional comments given in the questionnaire reveal certain characteristics of the traffic scenarios that were experienced as compromising the realism. These were:

- aircraft performance in the simulator (not variable enough),
- high traffic load,
- the rigidness of adjacent units regarding transfer conditions of aircraft,
- high speeds of climb, and
- sector characteristics (too much opposite traffic, too large, and too many conflict points).

A possible explanation for the differences in post-exercise and post-experiment ratings can be seen in the fact that during the post-exercise interviews, controllers were focussing to a larger extent on the RA event when giving their ratings. Furthermore, the ratings in the post-exercise debriefing reflect the view of the Executive Controller only. The Executive Controller is much more focussed on the traffic inside the sector, while the Planner had to co-ordinate with adjacent units and military ATC, thus having to cope with the peculiarities of the airspace.

To conclude, controller ratings of various aspects of the simulation realism were generally positive. Some factors were mentioned that were considered as compromising the realism. However, these factors were in the vast majority of cases inherent to the generation of an RA, such as high traffic load, sector design, and slow pilot responses.

## 6.2 Controller Task Performance

Indicators of controllers' (primary) task performance concern the handling and separation of aircraft in the sector. Two types of controller behaviour were measured:

1. the instructions given to aircraft involved in the RA, and

2. the traffic information given to aircraft involved in the RA and third-party aircraft.

In addition, the number of separation losses was used as an indicator of controller task performance.

### 6.2.1 Controller Instructions to Aircraft Involved in the RA Encounter

If an aircraft manoeuvre, initiated in response to an RA, yields a deviation from the ATC clearance, the controller ceases to be responsible for separation of this aircraft. Also, the controller should not issue any clearances to an aircraft reporting an RA [23].

The following criteria were applied for an instruction to qualify as an 'instruction to aircraft involved in the RA':

- The instruction was issued to an aircraft that had received an RA (no distinction was made between RAs that yield or do not yield a deviation from the ATC clearance),
- The instruction was issued between the time of RA generation in the aircraft and the pilot's report of 'clear of conflict'.

During the 48 simulation runs, two clearances were issued to aircraft involved in an RA encounter. Both clearances were issued to aircraft that had received a corrective RA[5], and they both contradicted the RA. Both clearances were issued in the no RA downlink condition. 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. The detailed description of these events can be found in Appendix L.

Although both runs with (contradictory) clearances occurred in the absence of RA downlink, the number of events is too small to decide whether the effect of RA downlink is statistically significant or just due to random variation.

When interpreting the results, it needs to be taken into account that participants issued clearances, even though they were reminded during the pre-experiment briefing to adhere to the current ICAO regulations. Thus, it appears reasonable to assume that the frequency of instructions to RA aircraft observed in RADE-2A is a conservative estimate of this frequency in real operation (where controllers are less likely to just have received a briefing on RA related procedures).

[5] An RA that advises the pilot to deviate from the current flight path [23].

### 6.2.2 Provision of Traffic Information

Although the provision of traffic information to aircraft involved in an RA is not mandatory [23], it can be tentatively taken as an indicator of the controllers' ability to understand the conflict geometry and to anticipate the impact of the RA manoeuvres on aircraft in the sector.

The simulation recordings were inspected for traffic information provided by the controller to the conflicting or to third-party aircraft. Traffic information was provided 23 times, and occurred in 17 of the 48 simulation runs (i.e. 35.4%). Out of these 23 instances traffic information to a third-party aircraft was provided only once.

Table 6-5 displays the distribution of runs with traffic information over the RA downlink conditions and the timeliness of the pilot report. According to a chi$^2$ test, traffic information was more likely when RA downlink information was absent (n = 12 runs) than when it was present (n = 5 runs) (chi$^2$ (1) = 4.46, $p = 0.04$). Table 6-5 also suggests that traffic information is more likely if the pilot report is timely (n=10 runs) than if it is delayed (n = 7 runs). However, this difference did not achieve significance (chi$^2$ (1) = 0.82, $p = 0.35$).

No significant impact of the RA cause on the frequency of traffic information was found as that the number of runs with and without given traffic information was perfectly balanced across the two categories of RA cause (chi$^2$ (1) = 0.27, $p = 0.61$): In 8 runs in which traffic information was given, the RA was caused by high vertical speed before level-off; in 9 runs in which traffic information was given, the RA was caused by a pilot or controller error, or a combination of both.

| | | RA Downlink | | |
|---|---|---|---|---|
| | | Present | Absent | Total |
| Pilot report | Timely | 3 | 7 | 10 |
| | Delayed | 2 | 5 | 7 |
| | Total | 5 | 12 | 17 |

**Table 6-5: Distribution of Runs with Traffic Information over Experimental Conditions**

Thus, there is evidence for a negative effect of RA downlink on the frequency of traffic information issued to the conflict aircraft. Possible explanations for this pattern of results will be provided below (see Chapter 7.3).

### 6.2.3 Losses of Separation

A loss of separation after an RA 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 6-6 shows the distribution of runs with separation losses over experimental conditions. As can be seen from the table, the number of runs with 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 6-6: Distribution of Runs with Separation Losses over Experimental Conditions**

Thus, using the number of separation losses as an indicator of controller performance, there is no evidence for the “cognitive tunnelling hypothesis”. According to this hypothesis, the controller’s ability to separate other traffic in the sector is impaired by the presentation of RA information.

Nevertheless, there is also no evidence for the assumption that RA downlink information helps the controller to plan the post-alert situation, resulting in a reduced likelihood of follow-up conflicts.

## 6.3 Situation Awareness

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

### 6.3.1 Situation Awareness Memory Probe

After each simulation exercise, both controllers were requested to fill in a 10-item memory test that assessed the controllers’ understanding of the RA event (see Appendix B). This test was conducted on a computer.

The first four items in the memory probe addressed the understanding of the conflict geometry, namely:

- callsign (or at least the three letter ICAO code) of the aircraft involved,
- their cleared level,
- their state (climbing, descending, or level flight) prior to the conflict, and
- their approximate heading.

The remaining six questions addressed other details of the RA event (i.e. whether pilots reported and followed the RA, whether the RA induced a follow-up conflict, what the sense of the RA was, and whether the RA sense reversed).

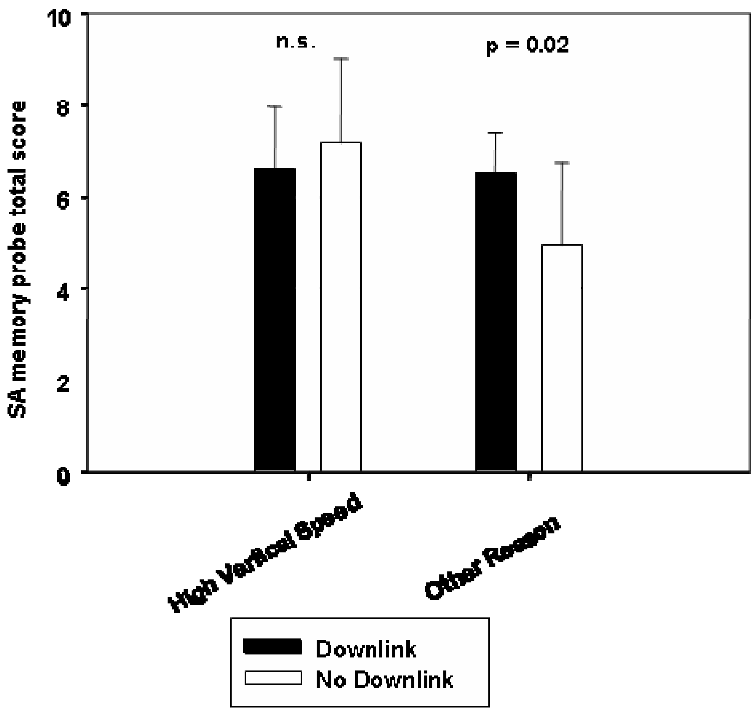


**Figure 6-7: Situation Awareness Memory Scores**

An item was considered correct if the answers to both contributing aircraft were correct. This scoring principle resulted in a maximum score of ten correct items.

Scores were subjected to a three-factorial repeated measurement analysis of variance (ANOVA) using RA downlink (present vs. absent), controller role (Executive vs. Planner), and pilot report (timely vs. delayed) as independent factors. No effect, including the interactions between the three factors, became statistically significant (all $F < 1$).

A further ANOVA was calculated that with RA cause (high vertical speed level off vs. pilot/controller error) and RA downlink (present vs. absent) as factors. The analysis revealed a reliable main effect of the RA cause on the SA memory score ($F(1,11) = 11.34$; $p = .006$). In contrast, the effect of RA downlink on the SA memory score was not significant ($F(1,11) = 1.30$, $p = 0.279$).

However, the interaction between the two factors achieved significance ($F(1,11) = 7.18$; $p = 0.021$), which changes the interpretation of the main effect. According to two paired t-tests, the interaction can be interpreted as follows: If an RA is caused by high vertical speed, there is no difference in the SA scores for the two RA downlink conditions ($t(11) = -1.235$; $p = 0.242$). However, if the RA is caused by a pilot/controller error, performance is significantly higher with RA downlink ($t(11) = 2{,}714$; $p = 0.020$) than without. Figure 6-7 shows the average SA memory scores as a function of RA downlink condition and RA cause.

Thus, there is a beneficiary effect of RA downlink on situation awareness for RAs that are caused by a pilot or a controller error. These are the type of RAs that are usually considered ‘real’ RAs by the controllers. Note that the measure of situation awareness that was used to find this effect is an objective measurement, as it is based on performance rather than on subjective self-assessment.

### 6.3.2 SASHA-Q Situation Awareness Self-rating Scale

Situation Awareness was also measured on the basis of a modified version of EUROCONTROL's Situation Awareness for SHAPE Questionnaire [20]. SASHA-Q contains generic items, specific items referring to the tool or service under investigation, and a global SA rating. For the RADE-2 experiment, five specific questions on the effect of RA information on Situation Awareness were included (see Appendix C).

SASHA-Q was completed by both controllers after each simulation exercise. Items that were specifically addressing RA downlink were suppressed in the 'No RA downlink' condition. Answers to the SASHA-Q items are generally given on a 5-point rating scale, with one being the negative and 5 being the positive end of the scale.

*Ratings of general items.* The SASHA-Q contains six generic items that can be answered for all experimental conditions. These are:

1. Did you have the feeling that you were ahead of the traffic and able to predict the evolution of the traffic?
2. Did you have the feeling that you were able to plan and organise your work as you wanted?
3. Have you been surprised by an a/c call that you were not expecting?
4. Did you have the feeling of starting to focus too much on a single problem and/or area of the sector?
5. Did you forget to transfer any aircraft?
6. Did you have any difficulty finding an item of (static) information?

For these items, separate ANOVAs with the factors "RA downlink condition", "timeliness of pilot report", and "controller role" were calculated. The analysis showed that differences between experimental conditions were small and statistically insignificant (for all effects: $F < 1$). Thus, none of the factors "RA downlink", "timeliness of pilot report", and "controller role" (or any interaction between these factors) had an effect on the controller ratings.

For the global SA rating ("How would you rate your overall situation awareness during this exercise?") a further ANOVA with the factor 'RA cause' and "RA downlink condition was calculated. This analysis revealed a main effect of the RA cause ($F(1,11) = 5.57$; $p = 0.038$): Controllers rated their situation awareness higher in runs with RAs caused by high vertical speed than in runs with RAs caused by pilot/controller error (see Figure 6-8). Neither the main effect of RA downlink ($F(1,11) < 1$) nor the interaction of RA downlink and RA cause was significant ($F(1,11) = 1.732$; $p = 0.215$).

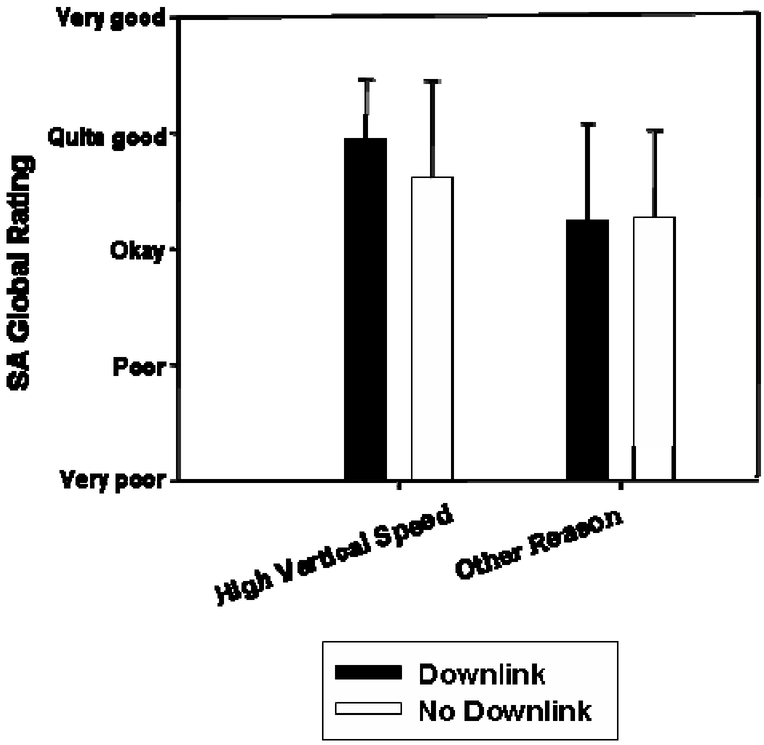


**Figure 6-8: Assessed Overall Situation Awareness**

*Ratings of RA-specific items.* Responses to the following RA-specific items were analysed:

1. Did the RA information help you to have a better understanding of the situation?
2. Did the RA information help you to focus on the safety-relevant aspects of the traffic situation?
3. Did you have any difficulty in interpreting the sense of the RA?
4. Did you feel distracted by the RA information (from attending other relevant aspects of the traffic situation)?

For the items that specifically address the impact of RA information on situation awareness, frequency distributions over the five response categories were computed (see Figure 6-9 to Figure 6-11). Note that these items were only filled in after runs with RA downlink; therefore, data cannot be contrasted for the two RA downlink conditions (absent vs. present). As each controller completed four simulation exercises with RA downlink, a total of 48 ratings (i.e. 4 runs x 12 participants) were collected.

The frequencies for the question “Did the RA information help you to have a better understanding of the situation?” display a distinct bimodal distribution: 14 and 5 ratings in the two lowest categories reflect a complete rejection of such a benefit, while 16 and 6 ratings in the two highest categories express a clear agreement (Figure 6-9). In order to examine whether the divergence in ratings is caused by the controller role or the timeliness of the pilot report, chi² tests were calculated. According to these tests, the bimodal pattern cannot be explained by the fact that RA downlink is experienced differently for timely vs. delayed pilot reports or different controller roles.

A similar bimodal frequency distribution was also obtained for the question “Did the RA information help you to focus on the safety-relevant aspects of the traffic situation?” (Figure 6-10). There was a highly significant correlation of r = 0.74 between the controllers’ ratings on this item and the previous item. This indicates that the rejection-affirmation split in the ratings was due to the same controllers.

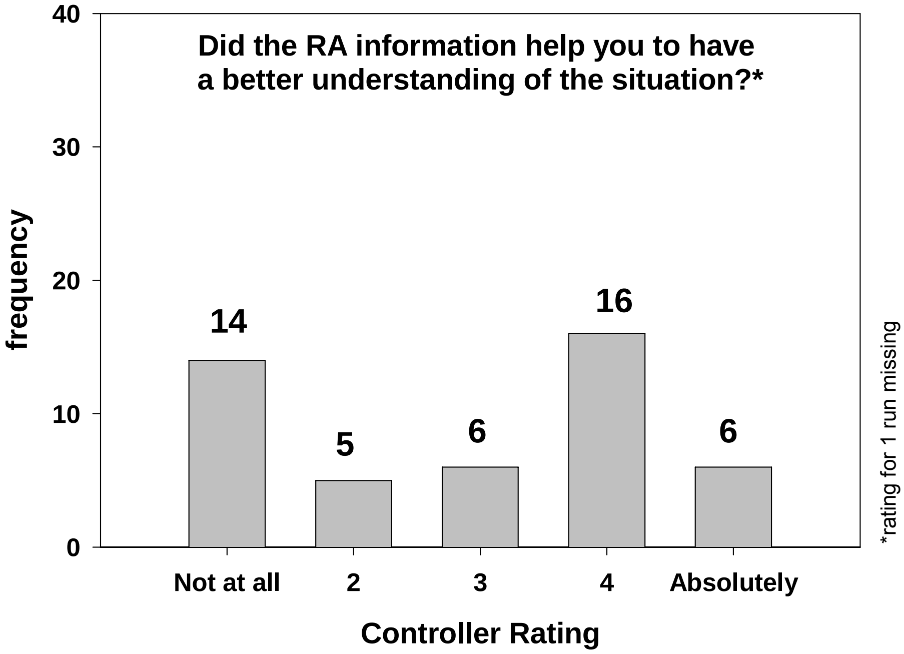


**Figure 6-9: RA Information and Understanding of Traffic Situation**

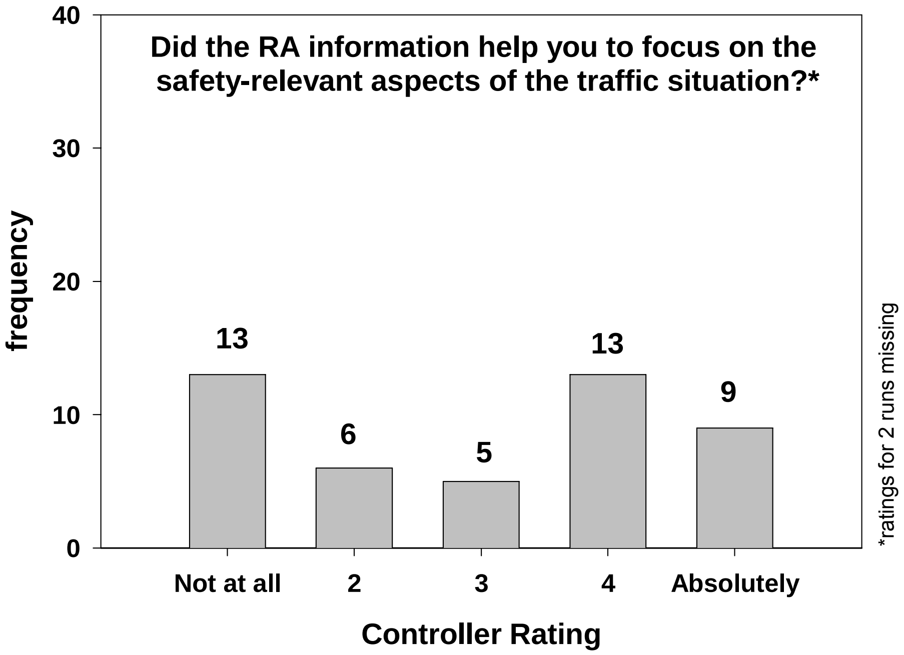


**Figure 6-10: RA Information and Focus on Safety-Relevant Aspects**

Responses to the question "Did you have any difficulty in interpreting the sense of the RA?" also displayed bimodality, albeit much weaker (Figure 6-11). Most of the ratings indicate that there were no problems with the interpretation of an RA sense. However, 12 ratings in the two higher categories (i.e. categories 4 and 5) indicate that there were sometimes problems with the interpretation of RA information.

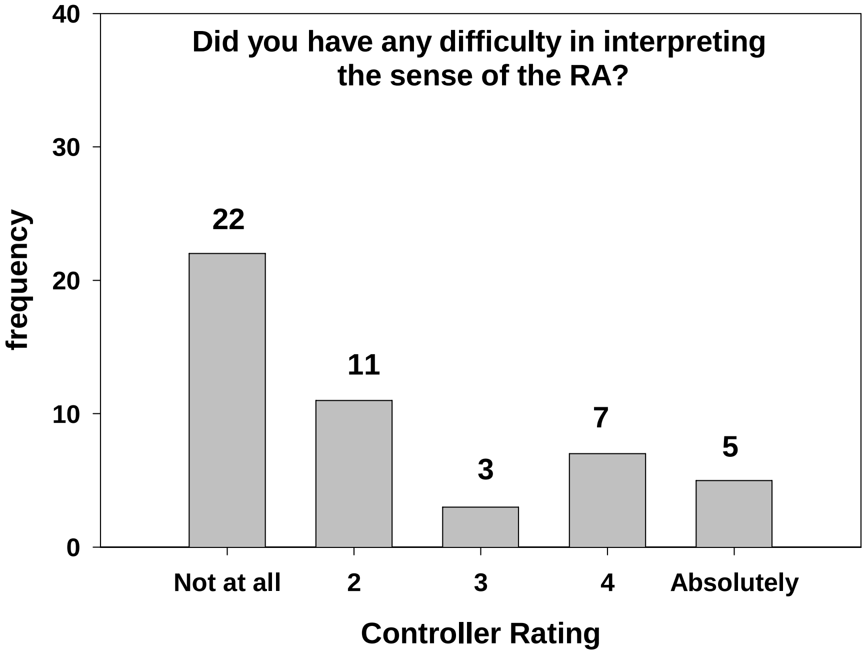


**Figure 6-11: Difficulties in Understanding RA Information**

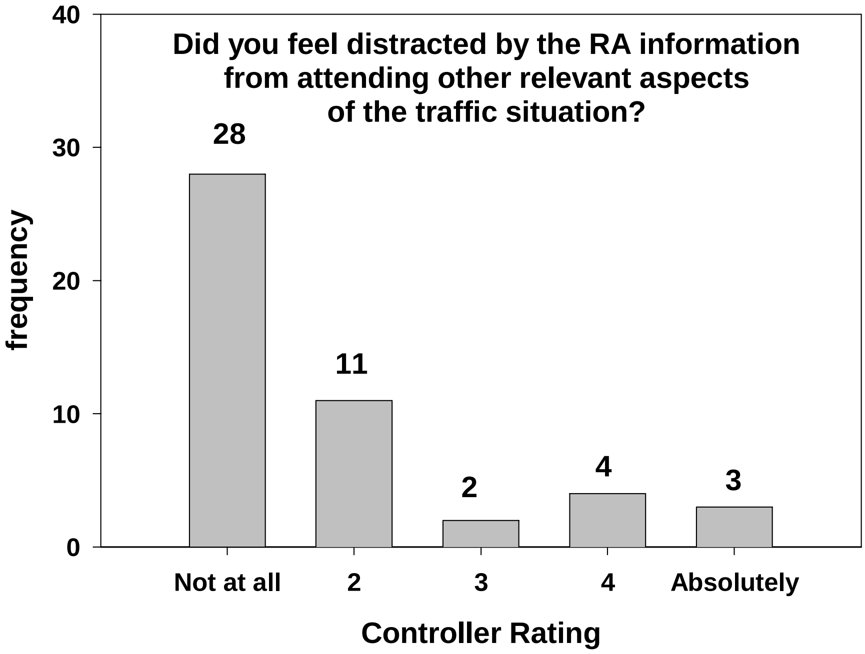


**Figure 6-12: Experienced Distraction by RA Information**

Finally, the vast majority of participants indicated that RA information did not distract them from attending to other relevant aspects of the traffic situation (Figure 6-12).

### 6.3.3 On-line Probe

SMEs were instructed to make one request to the Executive and one request to the Planning Controller after the pilots' clear-of-conflict message had been received. These questions were supposed to capture the controllers' awareness of other traffic in the sector and, thus, served to assess potential "cognitive tunnelling" on the RA encounter.

Requests had to be tailored to the actual situation and, hence, could not be pre-scripted. In most cases, SMEs requested a level change or a direct routing, or asked for general traffic information. SMEs recorded the requests and coded the controllers' answers by assigning them to one of four categories: (1) correct and timely; (2) correct and delayed; (3) incorrect and timely; (4) incorrect and delayed.

This procedure was successfully accomplished in 80 out of the total 96 cases (48 runs x 2 CWPs). Thus, 16 scores were missing, either due to a failure to make a request or to an incomplete recording. Seven scores were missing for the Executive Controller and 9 scores were missing for the Planning Controller. For the 80 successful runs, the distribution of responses over response categories and RA downlink condition is displayed in Table 6-7.

| | Response Category | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|
| | Correct & Timely | | Correct & Delayed | | Incorrect & Timely | | Incorrect & Delayed | |
| | No RA downlink | RA downlink | No RA downlink | RA downlink | No RA downlink | RA downlink | | |
| Executive Controller | 18 | 16 | 2 | 3 | 2 | 0 | 0 | 41 |
| Planning Controller | 16 | 17 | 3 | 2 | 1 | 0 | 0 | 39 |

**Table 6-7: Responses to SA On-line Probe**

The analysis of the 80 valid probes revealed that category 1 (correct and timely) was by far the most frequently coded category. Of the probes pertaining to the Executive Controller, 34 of the 41 valid probes (i.e. 82.93%) were correct and timely; of the probes pertaining to the Planner 33 of the 39 valid probes (i.e. 84.62%) were correct and timely. Accordingly, 7 and 6 requests were answered suboptimally by the Executive and the Planning Controller respectively.

The high frequency of correct and timely answers points to a ceiling effect, that is, questions were too easy – and, hence, performance too high – to reveal any impact on situation awareness. Because of the low number of suboptimal 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).

Even though the high number of correct answers requires a cautious interpretation of the results, it can be concluded that there is no evidence for impaired controller performance on the on-line probe as a result of RA downlink. Thus, the SA online probe does not provide any evidence for an attentional narrowing on aircraft involved in the RA encounter.

## 6.4 Controller Workload

Workload was measured on the basis of subjective workload ratings (i.e. controllers' self-ratings) as well as on the basis of performance on a secondary task.

### 6.4.1 Subjective Workload Ratings

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 [15] at the end of each simulation run. The NASA TLX involves answers to the following six rating scales

- mental demand (low to high)
- physical demand (low to high)
- temporal demand (low to high)
- performance (perfect to failure)
- effort (low to high), and
- frustration (low to high).

All but one of the NASA TLX scales range from 0 to 20, with 0 indicating the lower end and 20 indicating the higher end of the scale. The only exception is the scale for "performance" where 0 indicates perfect performance and 20 indicates failure.

Scores on these scales can be combined into a single score by using a specific weighting technique. In order to simplify the procedure, the NASA TLX was used without the weighting technique. It has been demonstrated [22] that such a procedure also yields valid results.

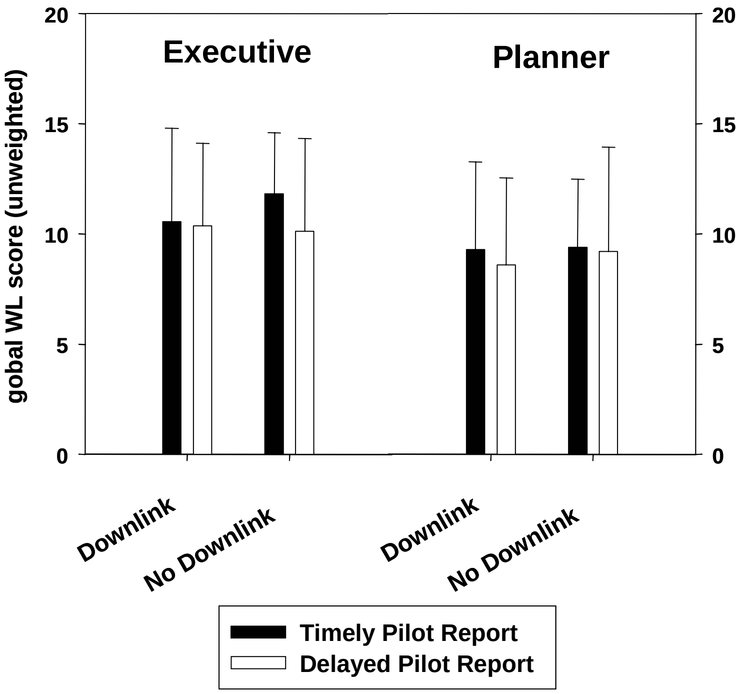


**Figure 6-13: Total NASA-TLX Scores as a Function of Experimental Conditions**

Figure 6-13 depicts the mean scores (and standard deviations) plotted as a function of the experimental conditions. Neither the RA downlink condition nor the timeliness of the pilot report had a significant influence on the total NASA-TLX score (for both effects: $F < 1$). In contrast, the controller role had a marginally significant effect on the experienced workload ($F(1,11) = 4.29$; $p = 0.063$), indicating that workload was rated lower on the planner position than on the executive position. None of the first-order interactions were significant ($F < 1$). This also holds for the second-order interaction of RA condition x pilot report timeliness x controller role ($F(1,11) = 1.92$, $p = 0.19$).

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 speed before level off 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 ($F(1,11) = 1.88$, $p = 0.20$). Figure 6-14 shows means and standard deviations for the total NASA-TLX score as a function of RA cause and RA downlink condition.

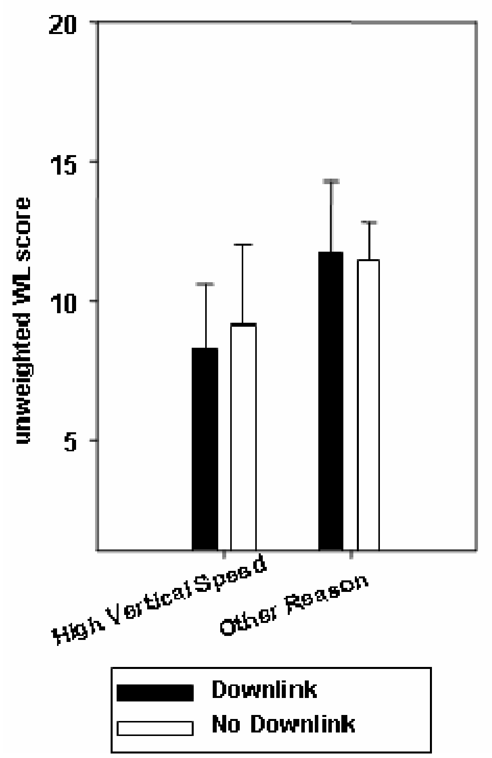


**Figure 6-14: Total NASA-TLX Scores for RA Downlink Conditions and RA Causes**

### 6.4.2 Secondary Task Performance: Late Transfers

Workload can also be measured in terms of performance on a secondary (i.e., lower priority) task. With increasing workload, controllers allocate their resources pre-dominantly to high-priority tasks (that is, tasks related to separation provision), yielding a performance decrease in low-priority tasks. Therefore, performance in the secondary task provides an objective indicator (i.e., an indicator that is not based on self-assessment) of controller workload. For RADE-2A, the number of missed or late transfers of aircraft to the downstream sectors was chosen as an indicator of secondary task performance. This indicator is thought to reflect the workload of the Executive Controller.

An event was coded as a late or missed transfer if an aircraft entered the downstream sector (either Feed North or Feed South) while still being on the Haren frequency. The number of late transfers was measured at four time points:
(1) three minutes before the first RA alert to the conflicting aircraft,
(2) at the RA event,
(3) at clear of conflict (COC), and
(4) two minutes after COC (which coincided with the end of most simulation runs).

Figure 6-15 depicts the mean number of late transfers as a function of the four measurements times, the RA downlink condition, and the timeliness of the pilot report.

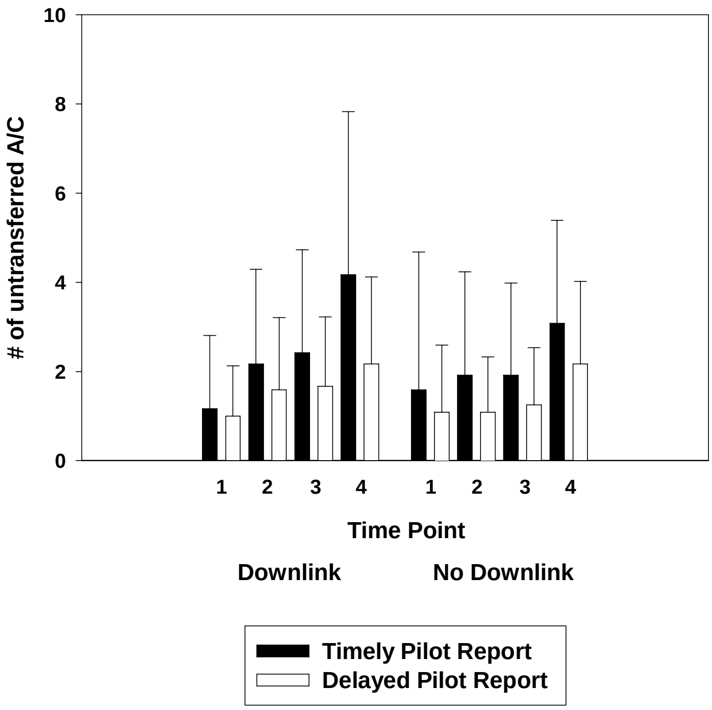


**Figure 6-15: Number of Late Transfers at four measurement times as a function of experimental conditions**

Data were analysed using a repeated measurement ANOVA with measurement time, RA downlink condition and timeliness of the pilot report as factors. According to this analysis, the number of late transfers increased towards the end of the simulation, resulting in a highly significant effect of measurement time ($F(3,33) = 23.33$; $p < 0.001$). The effect of RA downlink was not significant ($F < 1$). As a tendency, there was a higher number of late transfers with a timely pilot report ($M = 2.3$) than with a delayed pilot report ($M = 1.5$; $F(1,11) = 3.473$; $p = 0.089$).

Numerically, the increase of late transfers over time seems to be more pronounced for RA downlink runs than for non-RA downlink runs. However, this pattern could not be confirmed statistically: The interaction of measurement time and RA downlink condition was not significant ($F(3,33) = 1.862$, $p = 0.19$).

In order to assess the effect of the RA cause on the number of late transfers, an ANOVA with the factors “RA downlink condition” and “RA cause” was calculated. This analysis only took into account the measurement points from the onset of the RA. The reason is that, before the RA onset, the RA downlink condition cannot possibly influence the number of late transfers. Even at the RA onset, any differences in the two RA downlink conditions are unlikely to be caused by the RA information: a late transfer will only manifest itself with some delay, that is, when the non-transferred aircraft enters the downstream sector.

The ANOVA revealed a highly significant main effect of the RA cause ($F(1,11) = 22,12$, $p = 0.001$). This effect was caused by a three times higher number of late transfers if the RA was caused by pilot/controller error than if it was caused by a high vertical speed before level-off.

This effect was qualified by an interaction between the RA cause and the RA downlink condition: if RAs were caused by high vertical speed level-off, the mean number of late transfers was (numerically) higher if RA downlink was absent. If RAs were caused by pilot or controller error, the mean number of late transfers was (numerically) higher if RA downlink was present (see Figure 6-16). Post-hoc paired t-tests contrasting the two RA downlink conditions, however, did not yield significant effects (high-vertical speed RAs: $t(11) = -1.33$; $p = 0.21$; pilot/controller error RAs: $t(11) = 1.41$, $p = 0.19$). Thus, the main source for the interaction is the sign change of the two contrasts.

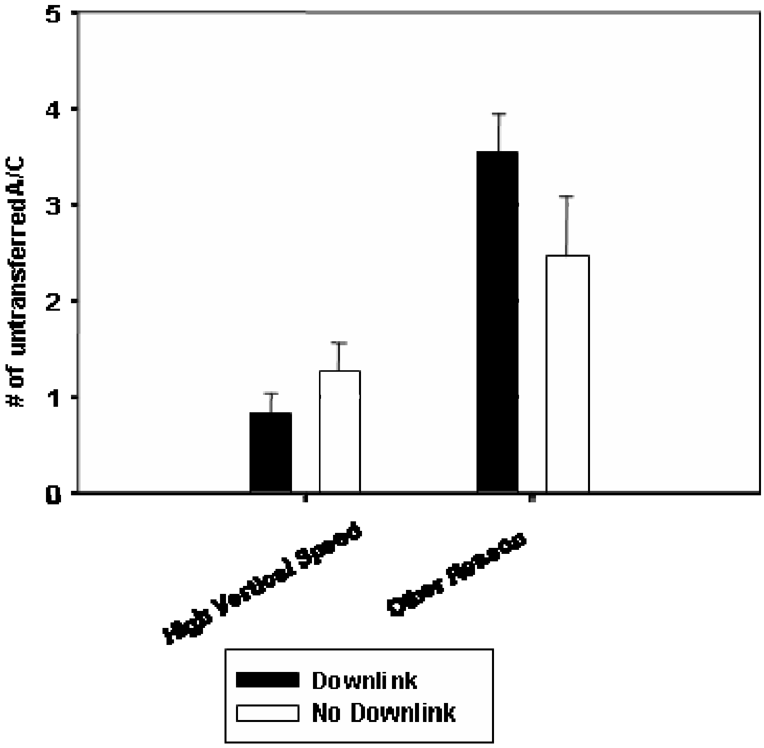


**Figure 6-16: Number of Late Transfers as a function of RA downlink separated for RA cause**

The higher number of late transfers in runs in which RAs were caused by pilot or controller error is consistent with the findings concerning controllers' experienced workload (see 6.4). Thus, there is agreement between the subjective and the objective measurements of workload. The results concerning the effect of RA downlink on late transfers, however, are not entirely conclusive. It seems that a slight (i.e., non-significant) workload advantage of RA downlink for RAs that are due to high vertical speed before level-off turned into a slight (i.e., non-significant) disadvantage for RAs that are due to pilot/controller error.

## 6.5 Controller Acceptance

Controller feedback on their general attitude on RA downlink, the proposed operational concept for RA downlink procedures, and the Human Machine Interface (HMI) was collected in the post-experiment questionnaires (Appendix G) and in the de-briefing sessions at the end of the experiment. De-briefing sessions were carried out with one controller group (i.e., two participants) at a time. The sections below contain a synopsis of controllers' feedback given in the questionnaire and in the de-briefing.

### 6.5.1 General Attitude on RA Downlink

In the post-experiment questionnaire, participants were asked to rate the usefulness of displaying RA information to the controller (see Figure 6-17). 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). Thus, the majority of participants see benefits in the display of RA information to the controller.

Participants also think that RA downlink helps to avoid issuing instructions to an aircraft involved in an RA. Answers to this item ranged from 3 to 5 with an average of 4.1 (SD = 0.9) (see Figure 6-18). In the same way, participants think that RA downlink helps to provide traffic information to aircraft involved in a conflict (see Figure 6-19). Answers ranged from 2 to 5 with an average of 4.1 (SD = 1.1). This perceived benefit, however, is not supported by objective data on the provision of traffic information (see 6.2.2).

Qualitative feedback was obtained by asking participants about the advantages and disadvantages as well as the potential and the limitations of RA downlink. Three out of six controller groups mentioned that RA downlink would help controllers to identify aircraft involved in an RA event. This holds particularly for those situations in which the conflict is masked by either pilots not reporting or an intruder aircraft only having a TCAS alert that is not reported. Thus, RA downlink could take away the surprise of unexpected RA manoeuvres and increase situation awareness. There was one controller among the participants, though, who did not see any benefits of RA downlink and clearly rejected the concept.

The second major advantage is seen in the fact that RA downlink provides additional information (i.e., complementing the information received in the pilot report). In case the RA downlink is earlier than the pilot report, RA downlink can prevent the controller from issuing clearances that are contradictory to the RA. One controller stated that RA downlink can prevent the controller from issuing any instruction (not only contradictory), since pilots were obliged to follow the RA anyhow. Even if the pilot report is received earlier than RA downlink, RA downlink can serve as a confirmation of what was reported. According to another controller group, RA downlink would be of special value when the frequency was blocked or overloaded and the pilot report could not come through.

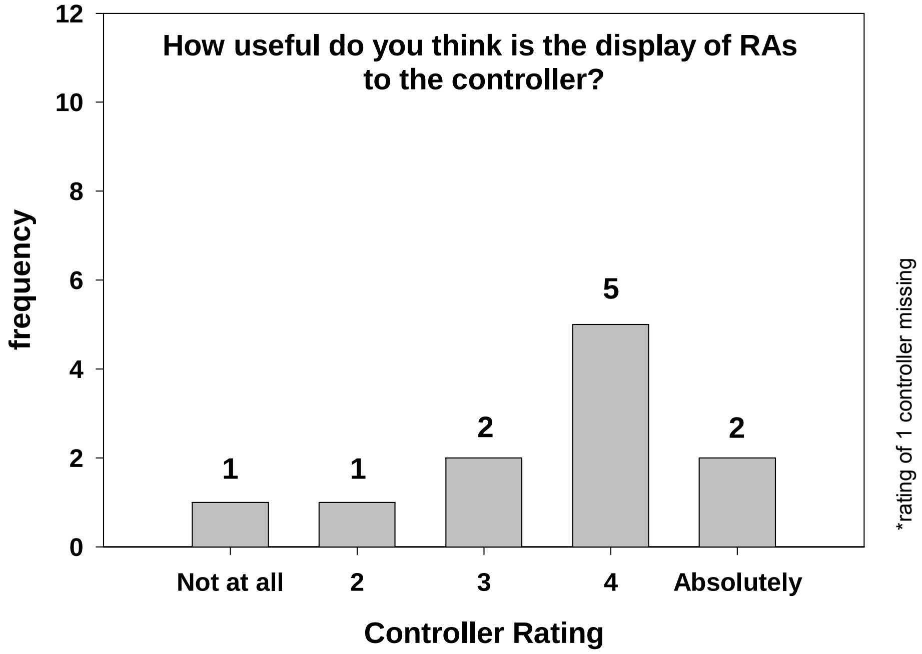


Figure 6-17: Controller Responses to Item 3

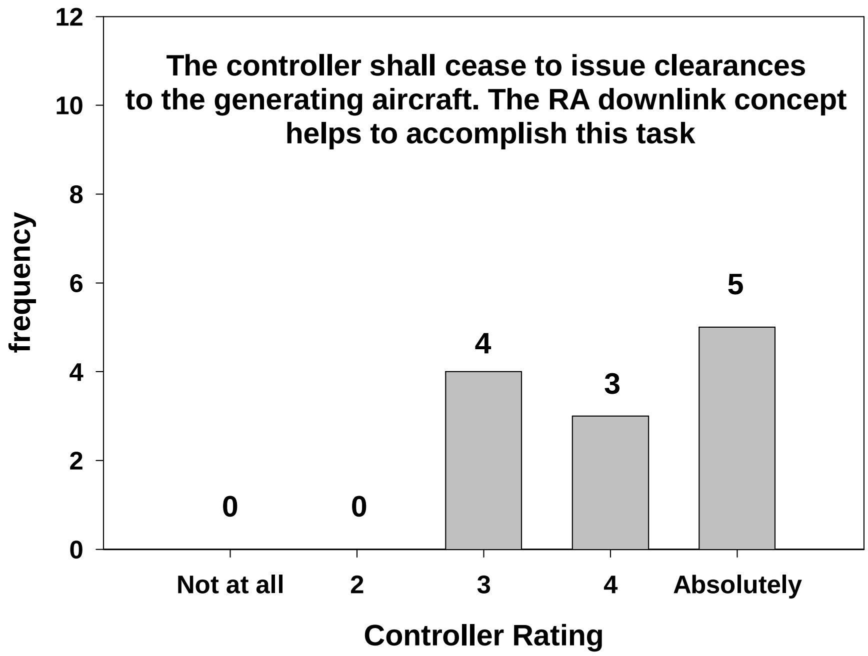


Figure 6-18: Controller Responses to Item 12

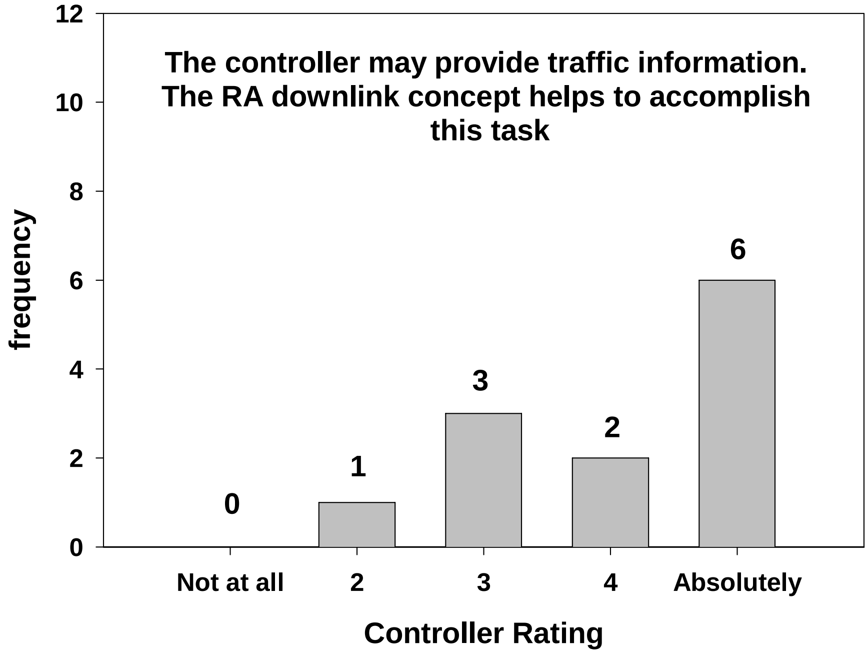


**Figure 6-19: Controller Responses to Item 13**

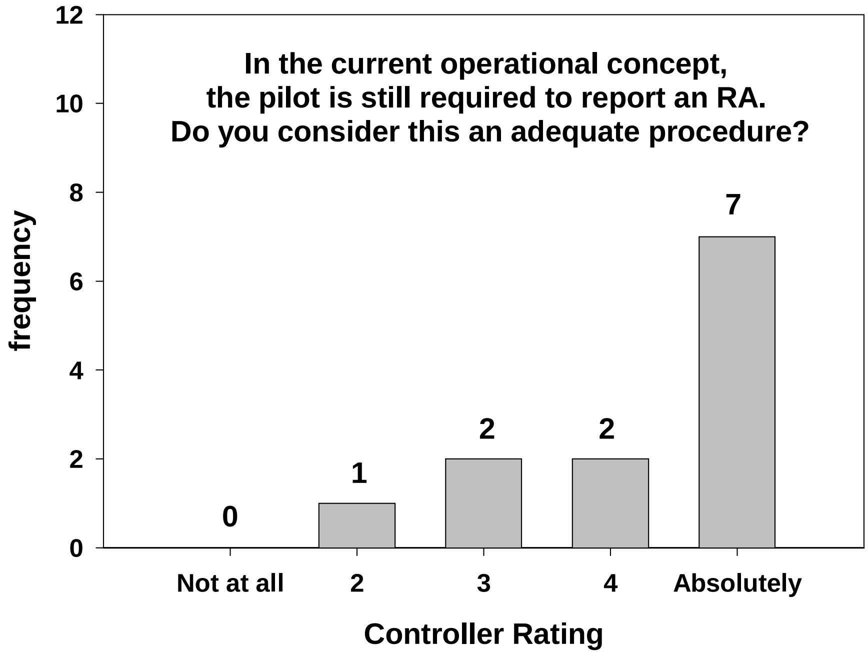


**Figure 6-20: Controller Responses to Item 14**

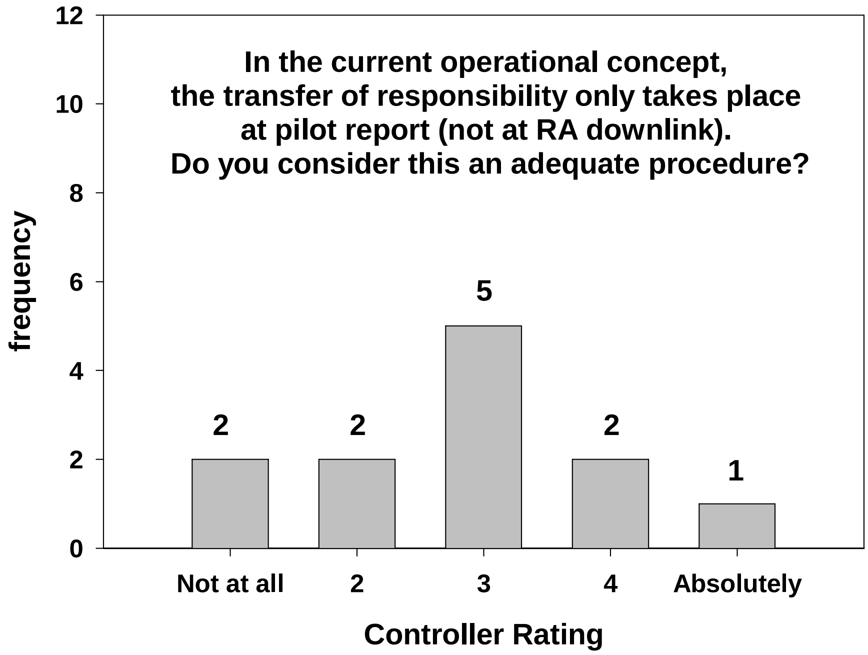


**Figure 6-21: Controller Responses to Item 15**

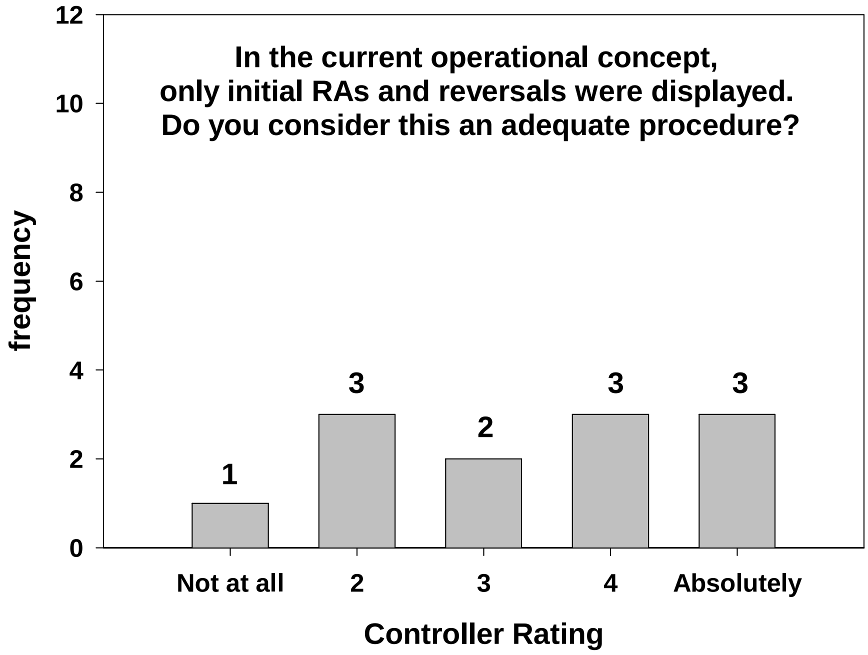


**Figure 6-22: Controller Responses to Item 14**

With respect to disadvantages of RA downlink, participants mentioned the issue of responsibility. It was unclear whether controllers were obliged to take actions in case they see a pilot not conforming with the RA. Another disadvantage mentioned concerned those RAs that are considered nuisance by some controllers. These RAs are caused by high vertical speed before level off and therefore cannot be considered real conflict situations. Downlink of these RA can distract the controller or can result in de-sensitisation towards 'real' RAs. Two controllers mentioned as potential disadvantages additional stress, superfluous information and screen clutter. One controller group also pointed out that RA downlink would require proper training: a warning usually indicates a need for an action, whereas RA downlink indicates the need to refrain from an action. Another controller group could not think of any disadvantages of RA Downlink at all.

**Participants were asked to describe situations in which RA downlink has strengths and situations in which it has limitations.**
Table 6-8 lists controllers' responses to these questions.

| Situations in which RA downlink | |
|---|---|
| **Would work well** | **Would not work well** |
| • If the pilot follows the RA.<br>• If the pilot fails to report the RA.<br>• In case an intruder (without RA) has to be identified.<br>• If the conflict situation was undetected by STCA<br>• In case of level busts.<br>• In all situations experienced in the simulation.<br>• If the conflict situation is complex. | • If the pilot does not respond to the RA.<br>• In case of fast climbing / fast descending aircraft (nuisance alerts).<br>• In case of a false downlink of an RA (RA displayed on CWP, no RA in the cockpit).<br>• If the pilot responds to the RA in the opposite sense.<br>• If the conflict situation is complex. |

**Table 6-8: Situations in which RA downlink would / would not work well**

To conclude, the vast majority of participants see clear advantages of RA downlink. These were, in particular, an increased situation awareness due to additional information, and a lower likelihood of issuing contradictory clearances to an aircraft involved in an RA. However, there are also some concerns regarding RA downlink. These mainly refer to nuisance alerts and the pilot/controller responsibility. With respect to the latter, it is feared that a failure to act on a conflict aircraft could have severe safety impacts in case of a spurious RA downlink or a pilot who does not follow the RA.

### 6.5.2 Operational Concept for RA Downlink

Feedback on the operational concept for RA downlink (see Appendix J) mainly concerned two issues: (1) the point at which responsibility for separating aircraft in the sector is passed from the controller to the pilot, and (2) the display of follow-up RAs.

#### 6.5.2.1.1 Transfer of Responsibility to the Pilot.

According to the proposed concept for RA downlink, pilots are still required to report an RA by voice. Participants were asked whether they considered this an adequate procedure (see Figure 6-20). On a scale from 1 (not at all) to 5 (absolutely), answers ranged between 2 and 5 with an average of 4.3 (SD = 1.1). This means that participants consider it as adequate to keep the pilot report in addition to the RA downlink.

In the operational concept proposed in RADE-2, the transfer of responsibility only takes place with the pilot report and not at RA downlink. Controllers' responses as to whether this procedure is adequate or not are not clear (see Figure 6-21). Answers ranged between 1 and 5 with an average of 2.8 (SD = 1.2). This indicates that (a) there are quite disparate views in the participant groups (as indicated by the broad range of answers), and (2) the majority of controllers neither have a positive or a negative view on this issue (as indicated by a mode of 3).

In the de-briefing, the determining event for a shift of responsibility (i.e., pilot report vs. RA downlink) was further discussed. Three out of six controller groups stated that RA downlink should not replace the pilot report for the change of responsibility. Two further groups believed that responsibility should be transferred on either RA downlink or pilot report, whichever would occur first. Their argument was that the pilot had the final responsibility for the safe navigation of the aircraft and is expected to follow the RA anyhow. Therefore, even if there is only the RA downlink (indicating to a lesser extent than the pilot report that the pilot intends to follow the RA), the controller should be out of the loop. This view was supported by a further group who maintained that controller responsibility for separation should cease with RA downlink, even though an RA display is not a confirmation of an according pilot manoeuvre. The subject of responsibility shift after the conflict (i.e., from the pilot back to ATC) was not discussed during the de-briefings.

#### 6.5.2.1.2 Display of Strengthening RAs.

Within the proposed operational concept, only initial RAs and reversal RAs are displayed. Strengthening RAs, in contrast, are not displayed. Controllers were asked if they considered this as appropriate (see Figure 6-22). Participants' answers ranged between 1 and 5 with an average of 3.3 (SD = 1.4). The distribution of answers indicates that there were diverging opinions in the participant group (as indicated by the broad range of answers),. Further, most of the controllers are unsure about how to answer this question (i.e. "3" was the most frequently chosen answer, that is, the mode).

The de-briefing provided more information as to why participants' had reservations about the decision to display initial and reversal RAs, but not to display follow-up RAs. Three out of the six controller groups stated that they wanted to see all follow-up RAs, including strengthening RAs, with the direction of the strengthening.

To summarise, controllers appreciated the fact that verbal pilot reports are still required in the proposed operational concept. With respect to the event triggering the transfer of responsibility, however, opinions diverged. Some controllers consider the pilot report as the adequate event for such as shift, whereas others would like to see the RA downlink as an event to trigger shift of responsibility. In any case, the operational concept needs to be very clear on the point at which the transfer of responsibility occurs.

### 6.5.3 The Human-Machine Interface (HMI)

The post-experimental questionnaire contained one item on the overall evaluation of the HMI for RA downlink, that is, the way in which RA information is presented to the controller. On a scale from 1 (poor) to 5 (very good), answers ranged between 2 and 5 with an average of 3.6 (SD = 0.8). This means that the majority of participants assessed the RA downlink HMI as positive.

Nevertheless, in the de-briefing some points for improvements were mentioned. Three out of the six participant groups mentioned label cluttering in the conflict areas as an HMI problem. In the HMI chosen for the simulation, aircraft labels are generally transparent. However, in case of an STCA, the aircraft identifier (i.e., callsign) is displayed on a red background, thus rendering this part of the label solid. With the downlink of RA information, a further solid line (i.e., line 0), is added to the label. Thus, the RA information does not only increase the size of the label, but also increases the solid part of it. In order to limit this effect, some suggestions were made. These were: a smart integration of STCA and RA downlink information (for instance, by suppressing the STCA in case an RA is displayed for the aircraft), and rendering the part of the label in which RA information is displayed transparent.

In the post-experimental questionnaire, participants were also asked whether they had "ever been confused about the RA information presented in the simulations". Seven out of 12 participants stated that they had been confused about the RA information at least once during the simulation. The following reasons were named:

- Uncertainty about the position of the aircraft involved due to label cluttering
- Problems in identifying the intruder aircraft (with TA only)
- Situations involving RAs caused by high vertical speed level off
- Problems in interpreting reversal RAs
- Triggering of RAs without clear separation infringements, for instance, caused by aircraft in a turn (mentioned twice).

Note that not all of the reasons mentioned above relate to the HMI for RA downlink (e.g., the comment on triggering of RAs). Furthermore, in order to sensibly interpret the responses to this item, it would be necessary to know how often the pilot report of an RA caused confusion. In the post-experimental questionnaire, though, no questions on the comparison between the RA downlink and the non-RA downlink condition was asked. For a comparison between the two conditions in terms of understanding of the traffic situation see Chapter 6.3.

One item in the post-experimental questionnaire specifically addressed the display of RA directions. Controllers were asked to assess the chosen way of displaying the RA direction on a scale from 1 (poor) to 5 (very good). Answers ranged between 1 and 5 with an average of 3.3 (SD = 1.6). Two controllers indicated that they found the symbol for an "adjust vertical speed" RA confusing. This type of RA is displayed by a horizontal bar, which was said to evoke the association with a level flight. This comment was also made by two participant groups in the de-briefing. Nevertheless, only 2 out of 12 participants indicated that they "have ever been confused about the actual movement of an aircraft after receiving the RA downlink information". Thus, there is only limited evidence that the RA symbology introduced confusion with respect to aircraft manoeuvres.

The level of detail shown in the RA downlink HMI was considered as sufficient by most participants. When asked whether they would like to have more RA information presented on the screen (such as clear-of-conflict indications), only four out of 12 controllers wished for more information. This is in line with the results from the de-briefing.

In the RADE-2A experiment, the RA information was restricted to visual alerts. All of the participants found this sufficient; none would recommend the use of an audible alert.

Other comments on the HMI for RA downlink diverged between controllers and were, in several cases, contradictory. Furthermore, a number of comments relating to topics such as colours, or blinking of alerts seemed to reflect personal taste rather than operational necessities. For this reason, these comments are not reported in detail.

To summarise, the specific HMI proposed for RA downlink information was generally appreciated. Nevertheless, two issues were mentioned that require further attention. One refers to screen clutter due to additional information; the other refers to a lack of intuitiveness with respect to certain RA symbols (in particular, the symbol for "adjust vertical speed").

# 7. SUMMARY AND DISCUSSION

## 7.1 Adequacy of the Experimental Approach

One of the major challenges in the RADE-2A experiment was to assess the impact of RA downlink in a real-time simulation covering an area control sector. This challenge was achieved 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.

Below, the results from the RADE-2A simulation will be summarised and discussed with respect to the three main experimental objectives.

## 7.2 General Impact of RA Downlink

| **Objective 1:** |
|---|
| Evaluate benefits of RA downlink for controller performance, situation awareness, and workload. |

Controller performance was measured in terms of number of clearances to the conflict aircraft, the number of separation losses in the sector, and – with some reservations – the frequency of traffic information to aircraft affected by the RA.

### 7.2.1 Controller Clearances to Aircraft Involved in the RA Event

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 (see Appendix L). These clearances occurred in runs without RA downlink, and with RAs that were due to pilot or controller error. Note that one of the contradictory clearances was given after the controller had been informed about the RA by the pilot. Although the number of events is too small to base firm conclusions on, an analysis of both events raises doubts of whether they could have happened in the same way with RA downlink. Thus, there is some evidence that RA downlink in fact has benefits in terms of decreasing the probability of contradictory clearances to an aircraft involved in an RA encounter.

### 7.2.2 Separation Losses in the Sector

The number of separation losses occurring after the RA event was taken as a further indicator of controller task performance. There were two hypotheses associated with the number of separation losses: If RA downlink improves the controller's ability to plan the post-traffic situation, then the number of follow-up conflicts should be lower with RA downlink. If, on the other hand, RA downlink induces cognitive tunnelling in the controller, then the number of conflicts involving aircraft unrelated to the RA event should be higher. However, no effect with respect to the impact of RA downlink information on the controller ability to separate traffic was found. There were no losses of separation involving aircraft unrelated to the RA event, and the number of separation losses occurring as a result of RA manoeuvres was equally distributed with and without RA downlink. It cannot be excluded, though, that the absence of an effect is due to the low sensitivity of the indicator: losses of separation are usually so infrequent, that they do not easily reflect subtle changes in the ATC environment.

### 7.2.3 Provision of Traffic Information

Controllers issued traffic information more frequently if RA downlink was absent than if it was present. Traffic information was almost exclusively issued to aircraft directly involved in the RA encounter, rather than to third-party aircraft.

Originally, the provision of traffic information, although not a mandatory task, was assumed to be an indicator of good controller performance: If the controller provides correct traffic information, this reflects an understanding of the RA situation (if traffic information is provided to one of the aircraft involved in the RA) or the anticipation of the post-RA situation (if traffic information is provided to third-party aircraft).

During the course of the experiment and in discussion with controller and pilots, it became evident that the provision of traffic information is not without problems. This holds especially if the traffic information is given to aircraft involved in the RA. First, the RA event causes a high level of workload in the cockpit. Any additional radio communication may even increase the pilot workload and may interfere with the pilot's primary task of following the RA. Second, there is a non-negligible chance of the controller to provide incorrect traffic information, which may introduce confusion in the cockpit.

In contrast, the potential advantages of providing traffic information to conflict aircraft are rather limited. Provision of traffic information can support the pilot in the visual acquisition of the intruder; however, in crowded airspace visual acquisition of the potential intruder can be even misleading. Moreover, there is evidence in the literature that with improved shared situation awareness, the need for explicit team communication may decrease: Efficient teams have been found to reduce verbal communications when shared displays are available (see [1]). To a certain extent, the provision of RA information to both the pilot and the controller can be considered a shared display. The reduced number of traffic information with RA downlink could thus point to better shared awareness of the pilot and controller, decreasing the need for an information exchange between them.

The above arguments only hold for traffic information that is provided to aircraft involved in the RA event. Provision of traffic information to third party aircraft could still be considered as beneficial for the pilot and, thus, as "good" controller behaviour. However, the number of traffic information issued to third-party aircraft was negligible throughout the RADE-2A study (i.e. one occurrence). Thus, it is arguable whether the finding less traffic information with RA downlink should be interpreted as a decrease in controller performance.

### 7.2.4 Situation Awareness and Workload

With respect to controllers' situation awareness and workload, significant results were only found if the type of RA event (i.e., the cause of the RA) was considered in the data analysis. For this reason, the effect of RA downlink on situation awareness and workload will be discussed below with reference to the effect of different operational scenarios.

### 7.2.5 "Cognitive Tunnelling"

One of the concerns associated with the display of RA information is the potential for the controller to allocate too much attention to the RA event, on the expense of other traffic in the sector. This phenomenon is labelled "cognitive tunnelling".

Cognitive tunnelling was assessed on the basis of controller responses to pilot requests unrelated to the RA event. There was no difference in the controllers' ability to respond to requests between the two RA downlink conditions (absent vs. present). This lack of an effect could be due to a ceiling effect (i.e., a too high level of performance on the task, which can mask an effect). However, as the numerical differences in the data point to an advantage of RA downlink, it can be reasonably concluded that there is no evidence for cognitive tunnelling as a consequence of RA downlink.

The number of delayed or missed transfers (primarily intended as an indicator of controller workload) can also be taken as an indicator of cognitive tunnelling. Cognitive narrowing typically occurs to the disadvantage of low-priority tasks but in favour of information processing of high priority tasks when the latter need to be protected against increased workload, fatigue, or the adverse impact of environmental stress [16]. However, the pattern of results related to late transfers is inconclusive and suggests a different impact of RA downlink depending on the RA cause (see 7.3).

Finally, the number of separation losses in the sector did not provide any evidence for cognitive tunnelling as a consequence of RA downlink. If there was cognitive tunnelling, it did at least not impair controller's ability to separate traffic in the experiment.

## 7.3 Impact of RA Downlink Depending on the Operational Scenario

| **Objective 2:** |
|---|
| Evaluate benefits of RA downlink for different operational scenarios (i.e., timeliness of pilot report, and RA cause). |

### 7.3.1 Two Classes of RA Causes

Data analyses generally revealed the importance to differentiate between two categories of operational scenarios, which reflect different causes for an RA. In slightly more than half of the simulation runs (n = 25), RAs occurred as a result of an aircraft either descending or climbing at a high vertical speed before levelling off, with an aircraft on an adjacent flight level. In the other simulation runs (n = 23), RAs were caused by a pilot error (e.g. busting a flight level), a controller error (e.g., failure to notice a conflict, incorrect clearance), or a combination of both.

RA events that were triggered by a high vertical speed before level off were found to be less challenging for the controller than RA events that were due to a pilot or controller error. For high vertical speed RA events, participants showed better situation awareness than for pilot/controller error RA events, both with respect to controllers' self-ratings and with respect to performance in a memory test. Furthermore, controllers experienced a lower level of workload in runs in which RAs were caused by high vertical speed before level off. This was reflected in lower self-ratings of workload as well as in better performance on a secondary task. Regarding the latter, the number of delayed aircraft transfers to the downstream sector was lower for high vertical speed RA events than for pilot/controller RA events.

If the data analysis takes into account the type of RA event, a couple of effects were found:

1. For RAs that are due to pilot or controller error, controllers re-constructed the conflict geometry of an RA event better and recalled more RA-related information if RA downlink was present. In contrast, there was no effect of RA downlink on the re-construction of the RA event, if it was due to a pilot or controller error.

2. For RAs that are due to a high vertical speed before level-off, RA downlink decreases the number of delayed or missed aircraft transfers in the time period immediately after the RA. For RAs that are due to controller or pilot error in contrast, there was limited (i.e., not statistically corroborated) evidence that RA downlink increases the likelihood of a late transfer.

Below, the main findings on the effect of RA downlink depending on the RA cause are summarised.

### 7.3.2 RA Cause and Situation Awareness

It was found that RA downlink improved the recollection of the conflict situation and other RA-related information if the RA event was caused by a pilot or controller error. This finding clearly supports one of the intended benefits of RA downlink, which is to increase the controller's understanding of the conflict situation as well as of the development of the situation in the near future (i.e., the direction vertical movement as prescribed by the RA).

Note that in RADE-1 the same situation awareness memory test was used; however, in contrast to RADE-2A, no benefit for RA downlink was found. A likely explanation for this discrepancy can be seen in the fact that, in RADE-2A, the occurrence of an RA that is due to a pilot/controller error is associated with a (partial) degradation of the controllers' situation awareness. In RADE-1, in contrast, participants only observed replays of RA events. Thus, it can be assumed that the benefits of RA downlink (in terms of a better understanding of the traffic situation) only manifest themselves in case situation awareness is partially degraded. This assumption is also in line with the finding that situation awareness benefits of RA downlink were only observed for RAs that were caused by pilot or controller error.

Situation awareness was also measured in terms of controller self-ratings. For these self-ratings, no effect of RA downlink on situation awareness was found. The only effect observed refers to the cause of an RA: Controllers rated their understanding of the traffic situation higher, if an RA was caused by a high vertical speed before level off than if it was caused by a pilot or controller error.

### 7.3.3 RA Cause and Workload

Workload was measured in terms of controller self-ratings (NASA-TLX) and performance on a secondary task (timeliness of aircraft transfers). With respect to workload self-ratings, there was a highly significant effect of the RA cause on experienced workload: workload was higher if RAs were caused by pilot or controller error than if they were caused by high vertical speeds before levelling of. As opposed to this, there was no difference in the experienced workload between the two RA downlink conditions. Even if the RA cause was taken into account, no effect of RA downlink on experienced workload was found.

There was, however, an effect of RA downlink on the number of delayed or missed aircraft transfers. This effect depended on the cause of an RA. For RAs that are caused by high vertical speeds before levelling off, the number of late transfers is lower if RA downlink is present than if it is absent. For RAs that are due to pilot or controller error, though, the number of late transfers was numerically (though not significantly) higher if RA downlink was present. This pattern of results does not allow for a conclusive interpretation with respect to the effect of RA downlink on the controller workload.

### 7.3.4 Timeliness of the Pilot Report

Another operationally relevant variable that was assumed to modify the effect of RA downlink is the timeliness of the pilot report. However, for none of the investigated indicators (pertaining to task performance, situation awareness or workload), there was a significant interaction of pilot report timeliness with the RA downlink condition. Such an interaction would have pointed to the fact that the advantages or disadvantages of RA downlink depend on whether the pilot reports are timely or delayed. The present study did not find any evidence for this relationship in the quantitative data, but only in the qualitative data (i.e. controller feedback).

## 7.4 Controller Acceptance of RA Downlink

| Objective 3: |
|---|
| Evaluate controller acceptance of the RA downlink and the operational concept. |

The vast majority of participants saw clear advantages of RA downlink. These were, in particular, an increased situation awareness due to additional information 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. RAs that are due to high vertical speed level offs 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. According to the existing ICAO regulation (see Appendix K), the controller's responsibility to provide separation ceases if 'an aircraft departs from the current ATC clearance in compliance with an RA' [23]. This regulation can cause ambiguity in the transfer of responsibility if the controller is unaware of an aircraft departing from the clearance in compliance with an RA (e.g. in case of a delayed or missing pilot report). The role of RA downlink in disambiguating the transfer of responsibility was controversially assessed by the participating controllers. Participants were concerned that this ambiguity is not entirely solved with the introduction of RA downlink. If the pilot does not follow the RA, the controller is still responsible for the aircraft. RA downlink, however, might mislead the controller to assume that he or she is not responsible any more. Furthermore, RA downlink would facilitate the detection of discrepancies between an RA and the pilot behaviour. Some controllers feared that they would be held responsible in the situations when the pilot does not follow the RA, the controller is aware of the RA through the downlink and takes no action to remind the pilot to follow the RA.

With respect to the proposed operational concept, controllers appreciated the fact that the pilot still has to report the RA to ATC. However, opinions diverged as to what event (RA downlink vs. pilot report) should trigger the shift of responsibility. Some controllers consider the pilot report as the adequate event for such a shift, whereas others would like to have the shift of responsibility at RA downlink.

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 additional information may clutter the screen; the other refers to problems in understanding certain RA symbols.

# 8. RECOMMENDATIONS FOR FUTURE WORK

The RADE-2A experiment can be considered a successful step in the thorough analysis of RA downlink and its impact on controller behaviour. The experiment succeeded in creating RA events in an interactive environment, without comprising the realism of the traffic situations. However, like any experiment that aims at deriving conclusions from a limited set of laboratory exercises to real operation, RADE-2A has certain limitations.

Firstly, in real operation, RAs are a fairly rare event. The actual frequency of RA events depends on airspace characteristics and traffic density; however even if some variation in the frequency is accounted for, handling RA events cannot be considered a nominal controller task. In contrast, participants in the RADE-2A simulation were exposed to one RA event per simulation run. The fact that RAs in the simulation were much more frequent and predictable than in real operation is likely to have an influence on controller behaviour. There is no reason to assume that the core results on RA benefits (i.e., less contradictory clearances to aircraft involved in an RA, and better understanding of the RA situation for RAs caused by pilot or controller error) are artefacts of the experimental situation. However, there are aspects that might be influenced by the frequency of an RA event. For instance, whether or not an HMI for RA information is experienced as easy or hard to interpret will depend on the frequency with which controllers are exposed to an RA (and thus, to the RA display).

Secondly, in the experiment, the numbers of RAs that yielded or did not yield a deviation form the ATC clearance (i.e. RAs that were due to high vertical speed before level-off vs. RAs that were due to pilot or controller error) were equally distributed. However, there is experimental evidence that the effect of RA downlink depends on the type of RA. Furthermore, RAs that do not yield a deviation form the clearance are often perceived as “nuisance alerts” by controllers. Thus, in order to assess the overall effect of RA downlink on controller performance, knowledge on the relative proportion of “nuisance” and “genuine” RAs in real operations are needed.

Finally, the RADE-2A experiment did not take into account false alarms or missed alarms. A false alarm can be defined as an RA displayed on the ground in the absence of an RA on the flight deck. A missed alarm refers to the situation of an RA on the flight deck which is not displayed on the ground. Both situations were not studied in RADE-2A. Nevertheless, false alarms and missed alarms potentially have a detrimental influence on the controller’s trust in RA downlink or even on the controller’s ability to separate traffic.

In order to address the above limitations, the following recommendations are made:

1. EUROCONTROL should implement a comprehensive RA monitoring to gain reliable figures on the frequency of RAs in various airspaces. This monitoring should also include the type of RAs issued in the cockpit, the pilot’s reporting behaviour, as well as the controller reaction to the RA.

2. An in-depth study on the likelihood of false alarms and misses in RA downlink should be carried out. This study should take into account the technical implementation of RA downlink as well as any other factor that might influence the rate of missed or false alerts.

There are two other strands of research that deserve more considerations. In the RADE-2A experiment, a conservative approach to the choice of an operational procedure for RA downlink was taken. The suggested operational procedure followed the current ICAO procedures as closely as possible (with respect to the shift of responsibility between air and ground and the requirement for the pilot to report all RAs). However, as the ICAO regulations are currently undergoing revisions, there might be a need to revise the proposed operational procedures for RA downlink.

3. Following the revision of ICAO procedures related to TCAS and RAs, the impact of the revisions on the proposed operational procedures for RA downlink should be analysed. If necessary, the operational procedures should be modified to accommodate changes in the ICAO regulations.

Finally, the RADE-2A experiment identified some issues related to the display of information. Some of the symbols used for certain types of RAs lacked intuitiveness, and there was a potential for screen clutter. Furthermore, the displays of STCAs and RAs were not optimally integrated.

4. The HMI for the display of RA downlink should be revisited. This revision should take into account the results of RA monitoring in order to find the appropriate RA display for the expected level of exposure. The lower the likelihood of exposure, the more “intuitive” the RA display should be. STCA and RA displays should be integrated in order to avoid confusion of whether or not the controller is expected to act on a conflict.

The above order of recommendations also reflects the priorities for future work. RA monitoring and an investigation into technical failures associated to RA downlink are, at this point, more essential than a re-development of the HMI display.

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# 10. LIST OF FIGURES AND TABLES

## 10.1 List of Figures

## 10.2 List of Tables

## Appendix A Pre-Experimental Questionnaire

| Participant-ID: | Date: | Time: |
|---|---|---|

# Pre-experiment Questionnaire

Note: All data collected during this simulation will be treated with the ***strictest confidentiality***. Only members of the experimental team will have access to the questionnaires; data analysis and report will be done in such a way that responses cannot be traced back to any particular person.

### ABOUT YOURSELF

1 – What is your age? ____________________

2 – What is your nationality? ____________________

### ABOUT YOUR EXPERIENCE AS AN AIR TRAFFIC CONTROLLER

3 – In which ACC do you work? ______________________________________________

4 – What other ratings do you hold or have held? _________________________________

5 – How long are you licensed as a controller (in years)? __________________________

6 – How long are you licensed as an area controller (in years)? ____________________

7 – Do you have experience as an instructor (including On-The-Job Training)?

- ❑ Yes, for _______ years
- ❑ No

8 – Have you ever witnessed any incidents where a serious violation of separation minima has occurred or could have occurred? (This can either concern traffic under your responsibility or under responsibility of adjacent sectors/your colleagues)

- ❑ Yes; please indicate how many ___________
- ❑ No

If you responded “yes”, please proceed with Question 9. If you responded “no”, please proceed with Question 13.

9 – In case you have witnessed (an) incident(s): were there any Resolution Advisories (RAs) generated in these situations?

- ❑ Yes; in _______ out of ________ case(s)
- ❑ No
- ❑ I don't know

10 – In case you responded "yes" to the previous question, how did you come to know about these RAs?

- ❑ Pilot reporting it on R/T
- ❑ Through an investigation
- ❑ Don't remember

11 – In the incidents witnessed by you, did RAs help to resolve the conflict situation?

Not at all ☐ ☐ ☐ ☐ ☐ Absolutely

12 – In case your experiences with RAs differ (that is, in one incident it might have helped, in another, it might not), please specify.

13 – Have you ever been informed by the pilot about RAs that were nuisance alerts (e.g., due to fast climbing or fast descending aircraft)?

- ❑ Yes; please indicate how many __________
- ❑ No

14 – Have you ever been informed by the pilot about RAs that were false alerts (i.e., there was no other traffic in the vicinity)?

- ❑ Yes; please indicate how many __________
- ❑ No

**Thank you very much!**

## Appendix B Post-exercise Questionnaire (SA Memory Test)

**Post-exercise Questionnaire**

| Participant-ID: | Date: | Run-no.: |
|---|---|---|
| ☐ RA-Downlink<br>☐ No RA-Downlink | Scenario no.: | ☐ Executive Controller<br>☐ Planning Controller |

In your opinion, what was/were the reason/s for the RA-incident in the previous scenario? (Multiple answers possible)

☐ ATC error
☐ Pilot error
☐ TCAS error (that is, an alert without any conflicting aircraft in the vicinity)
☐ Fast climbing/fast descending aircraft
☐ Don't know
☐ Other, namely ______________________________

Please describe the situation by filling in the table below.

| | 1 | | | 2 | | | 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| Aircraft involved in the situation (Callsigns)? | | | | | | | | | |
| Cleared Level? | | | | | | | | | |
| Climb/level/descend prior to RA/incident? (please mark) | ↑ | → | ↓ | ↑ | → | ↓ | ↑ | → | ↓ |
| Approximate Heading? | | | | | | | | | |
| Did pilot report RA? (if both reported indicate who did it first who second) | | | | | | | | | |
| Type of RA issued to aircraft? | | | | | | | | | |
| Did aircraft follow RA? | | | | | | | | | |
| Did RA reverse its sense? | | | | | | | | | |
| Did pilot manoeuvre yield any new conflicts? If so, describe. | | | | | | | | | |

## Appendix C SASHA-Q Questionnaire

### Situation Awareness Questionnaire

| Participant-ID: | Date: | Run-no.: |
|---|---|---|
| ❑ RA-Downlink<br>❑ No RA-Downlink | Scenario no.: | ❑ Executive Controller<br>❑ Planning Controller |

Q1: - Did you have the feeling that you were ahead of the traffic and able to predict the evolution of the traffic?

Not at all ☐ ☐ ☐ ☐ ☐ Absolutely

Comments:

Q2: - Did you have the feeling that you were able to plan and organise your work as you wanted?

Not at all ☐ ☐ ☐ ☐ ☐ Absolutely

Comments:

Q3: - Have you been surprised by an a/c call that you were not expecting?

Not at all ☐ ☐ ☐ ☐ ☐ Absolutely

Comments:

Q4: - Did you have the feeling of starting to focus too much on a single problem and/or area of the sector?

Not at all ☐ ☐ ☐ ☐ ☐ Absolutely

Comments

Q5: - Did you forget to transfer any aircraft?

Not at all ☐ ☐ ☐ ☐ ☐ Absolutely

Comments

Q6: - Did you have any difficulty finding an item of (static) information?

Not at all ☐ ☐ ☐ ☐ ☐ Absolutely

Comments:

(* to be answered only if RA information was displayed on the screen, if not proceed to Q12)

*Q7: - Did the RA information help you to have a better understanding of the situation?

Not at all ☐ ☐ ☐ ☐ ☐ Absolutely

Comments

| |
|---|
| |

*Q8: - Did you feel distracted by the RA information (from attending other relevant aspects of the traffic situation)?

Not at all ☐ ☐ ☐ ☐ ☐ Absolutely

Comments:

| |
|---|
| |

*Q9: - Did the RA information help you to focus on the safety-relevant aspects of the traffic situation?

Not at all ☐ ☐ ☐ ☐ ☐ Absolutely

Comments:

| |
|---|
| |

*Q10: - Did the RA information influence your plans for separating aircraft (both the aircraft involved in the RA encounter and the surrounding traffic under your control)?

Not at all ☐ ☐ ☐ ☐ ☐ Absolutely

Comments:

*Q11: - Did you have any difficulty in interpreting the sense of the RA?

Not at all ☐ ☐ ☐ ☐ ☐ Absolutely

Comments:

Q12: - Finally, how would you rate your overall situation awareness during this exercise?

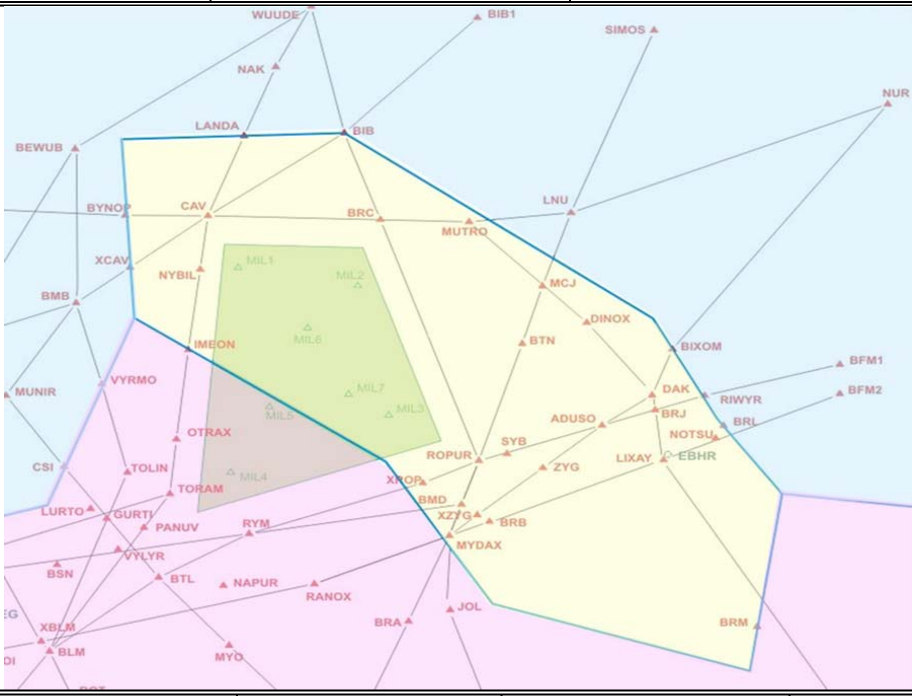
Poor ☐ Quite poor ☐ Okay ☐ Quite good ☐ Very good ☐

Comments:

# Appendix D Human Factors Expert Observer Notebook

## HF Observer Notebook RADE-2A

| Participant-ID: | Observer: | Date: |
|---|---|---|
| ❑ RA-Downlink<br>❑ No RA-Downlink | Pilot report quality:<br>❑ Timely<br>❑ Delayed | Scenario no.:<br>Run no.:<br>Start Time:<br>End Time: |




| Time | Traffic info | RA sense reversal | Procedure violation | Follow-up conflicts |
|---|---|---|---|---|
| | ☐ Yes ☐ No | ☐ Yes ☐ No | ☐ Yes ☐ No | ☐ Yes ☐ No |

Reason:

pilot error ☐ ATC error ☐ TCAS error ☐ Fast climbing/descending A/C ☐

Other:

Remarks:

**Observation recording principles**

The information recorded by the HF experts serves two principal purposes:

1. Collection of information that enables the scoring of the RA-related SA-memory items of the post-exercise questionnaire.

For that purpose, it is important to take note of:

- The A/Cs involved
- Their cleared level
- Their climb/level/descend prior to RA incident
- Their approximate heading
- Type of RA issued to A/Cs
- Did RA reverse its sense?
- Did all A/C involved follow the RA?

2. Collection of other dependent measures.

- Missed transfers of A/Cs to adjacent sectors
- Was traffic information given?
- RA operational procedure violations
- Follow-up conflicts


The first set of information should be recorded with the help of the sector map. An example of how to code an RA event at the position where it occurred is given above.

- Orientation of A/C symbols (use arrows) should depict their heading
- Note RA sense (arrows) and time above call sign
- Note cleared level and climb/level/descend status below call sign
- Note transfer misses as illustrated

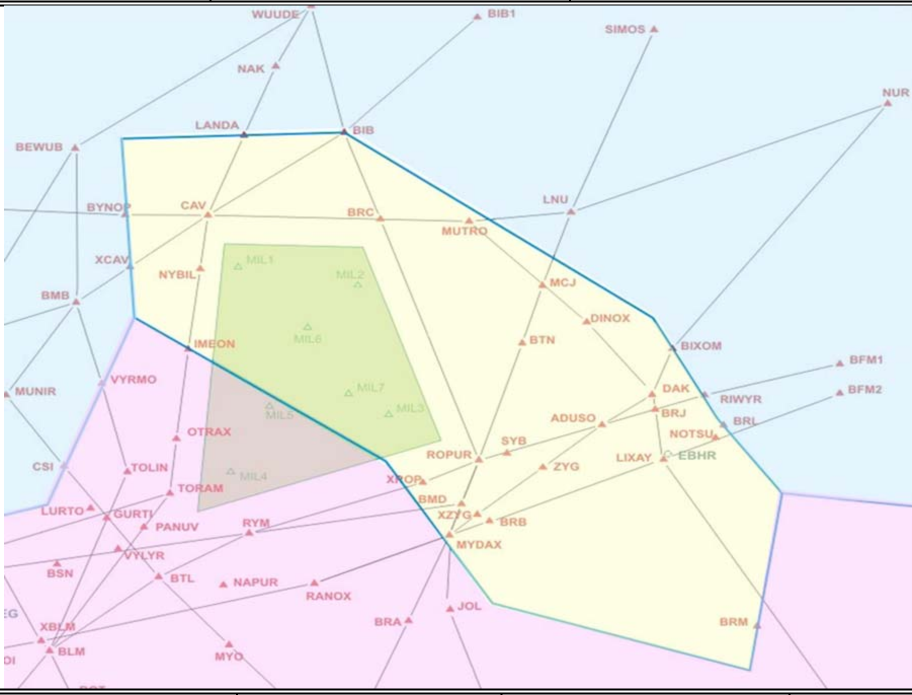
The second set of information should be marked in the record table below the map.

The reverse page can be used for further remarks on events, controller action, questions, or anything else worth noting. Time, A/C involved, and sector position should be recorded with the help of the map. If clutter becomes a problem an extra sheet can be used.

## Appendix E Subject Matter Expert Notebook

### SME Notebook RADE-2A

| Participant-ID: | SME: | Date: |
|---|---|---|
| ❑ RA-Downlink<br>❑ No RA-Downlink | Pilot report quality:<br>❑ Timely<br>❑ Delayed | Scenario no.:<br>Run no.:<br>Start Time:<br>End Time: |




| Time | Traffic info | RA sense reversal | Procedure violation | Follow-up conflicts |
|---|---|---|---|---|
| | ☐ Yes ☐ No | ☐ Yes ☐ No | ☐ Yes ☐ No | ☐ Yes ☐ No |

***Reason***: ☐ pilot error ☐ ATC error ☐ TCAS error ☐ Fast climbing/descending A/C

Other:

***Did all A/C follow the RA?*** ☐ Yes ☐ No (if Not, indicate which one and note deviation)

***RA elicitation (spontaneous/Facilitation method, etc.)***:

***After-RA-event question asked – Executive Controller***:

***ATCO answer****:*
timely/correct ☐ timely/incorrect ☐ delayed/correct ☐ delayed/incorrect ☐ No response ☐

***After-RA-event question asked – Planning Controller***:

***ATCO answer****:*
timely/correct ☐ timely/incorrect ☐ delayed/correct ☐ delayed/incorrect ☐ No response ☐

**Observation recording principles**

The information recorded by the SME experts serves two principal purposes:

1. Collection of information that enables the scoring of the RA-related SA-memory items of the post-exercise questionnaire (this will be checked and resolved for consistency with the HF expert recordings)

For that purpose, it is important to take note of:

- The A/Cs involved
- Their cleared level
- Their climb/level/descend prior to RA incident
- Their approximate heading
- Type of RA issued to A/Cs
- Did RA reverse its sense?
- Did all A/C involved follow the RA?

2. Assessment of controller performance/situation awareness after the RA event (i.e. after clear-of-conflict)

- Follow-up conflicts
- Controller response to the SA-probe question/pilot request after the RA event


The first set of information should be recorded with the help of the sector map. An example of how to code an RA event at the position where it occurred is given above.

- Orientation of A/C symbols (use arrows) should depict their heading
- Note RA sense (arrows) and time above call sign
- Note cleared level and climb/level/descend status below call sign

The second set of information should be marked in the record table below the map.

The reverse page can be used for remarks on events, controller action, questions, or anything else worth noting. Time, A/C involved, and sector position should be recorded with the help of the map. If clutter becomes a problem an extra sheet can be used.

## Appendix F Basic Set of Questions for a Replay-Supported Interview

| Participant-ID: | Date: |
| --- | --- |
| ☐ Scenario with RA-Downlink<br>☐ Replay with RA-Downlink<br>☐ Replay without RA-Downlink | Scenario no.:<br>Run-no.: |

**Facilitating questions**

1 – When did you first notice the situation that created the RA event?

☐ Prior to STCA
☐ After the STCA
☐ Did not notice/do not remember STCA
☐ No STCA

2 – When did you realise that an RA had been issued?

☐ Prior to pilot report
☐ After pilot report
☐ At display of RA on CWP (RA downlink)

3 – Please, describe how you dealt with the conflict?

4 – What circumstances, if any, prevented you from optimally dealing with the conflict?

5 (Ask if scenario had no RA-Downlink) – Observing the replay with RA downlink, in what way would this have changed your work? Think in terms of pros and cons with respect to dealing with the conflict and other aspects of the traffic that needed your attention!

| |
|---|
| |

6 (Ask if scenario had RA-Downlink) – Observing the replay without RA downlink, in what way would this have changed your work? Think in terms of pros and cons with respect to dealing with the conflict and other aspects of the traffic that needed your attention!

| |
|---|
| |

7 Do you consider the traffic situations shown in the simulation as realistic?

Not at all ☐ ☐ ☐ ☐ ☐ Absolutely

Please indicate why:

| |
|---|
| |

8 – Do you consider the RA events that occurred in the simulation as realistic?

Not at all ☐ ☐ ☐ ☐ ☐ Absolutely

Please indicate why:

9 – Do you consider the "pilot" responses to RA events as realistic?

Not at all ☐ ☐ ☐ ☐ ☐ Absolutely

Please indicate why:

## Appendix G Post-experiment Questionnaire

| Participant-ID: | Date: |
|---|---|

**GENERAL ATTITUDE ON TCAS**

After attending the experiment, we would like you to give us your opinion on the potential advantages and disadvantages of RA downlink again.

1 – How would you assess your knowledge of TCAS II?

Poor ☐ ☐ ☐ ☐ ☐ Very good

2 – How familiar are you with the idea of RA downlink?

Not at all ☐ ☐ ☐ ☐ ☐ Absolutely

3 – How useful do you think is the display of RAs to the controller?

Not at all ☐ ☐ ☐ ☐ ☐ Absolutely

4 - What are – in your opinion – the operational advantages of displaying RAs to the controller?

| |
|---|
| |

5 - What are – in your opinion – the operational disadvantages of displaying RAs to the controller?

| |
|---|
| |

## HUMAN-MACHINE INTERFACE

The questions below refer to the way in which the RA information was provided to you, that is, the Human-Machine Interface.

6 – What is your evaluation of the RA downlink HMI?

Poor ☐ ☐ ☐ ☐ ☐ Very good

In case of negative evaluation, please explain.

7 – What is your evaluation of the indication of the RA sense (direction)?

Poor ☐ ☐ ☐ ☐ ☐ Very good

In case of negative evaluation, please explain.

8 – Have you ever been confused about the RA information?

Yes ☐
No ☐

If yes, please explain

9 – Have you ever been confused the actual movement of the aircraft after seeing RA on the screen?

Yes ☐
No ☐

If yes, please explain

10 – Do you recommend additional audible alerts?

Yes ☐
No ☐

If yes, please explain:

11 – Do you think the display should indicate more information on the content of the RA (for example clear-of-conflict notification)?

Yes ☐
No ☐

If yes, please explain:

**PROCEDURES RELATED TO RA DOWNLINK**

The following statements describe the controller's task during an RA encounter according to current procedures. Please rate to what extent the RA downlink concept implemented in the simulation experiment help to accomplish this task.

12 – The controller shall cease to issue clearances to the generating aircraft. The RA downlink concept helps to accomplish this task.

Not at all ☐ ☐ ☐ ☐ ☐ Absolutely

13 – The controller may provide traffic information. The RA downlink concept helps to accomplish this task.

Not at all ☐ ☐ ☐ ☐ ☐ Absolutely

14 – In the current operational concept, the pilot is still required to report an RA. Do you consider this an adequate procedure?

Not at all ☐ ☐ ☐ ☐ ☐ Absolutely

15 – In the current operational concept, the transfer of responsibility only takes place at pilot report (not at RA downlink). Do you consider this an adequate procedure?

Not at all ☐ ☐ ☐ ☐ ☐ Absolutely

16 – In the current operational concept, only initial RAs and reversals were displayed. Do you consider this an adequate procedure?

Not at all ☐ ☐ ☐ ☐ ☐ Absolutely

Please provide comments on operational concept.

**ON THE SIMULATION**

In this section, we want your feedback on the content and the organisation of the experiment.

17 – Do you consider the traffic situations shown in the simulation as realistic?

Not at all ☐ ☐ ☐ ☐ ☐ Absolutely

Please indicate what aspects (events, behaviours, etc.) you consider unrealistic: .

18 – Do you consider the RA events that occurred in the simulation as realistic?

Not at all ☐ ☐ ☐ ☐ ☐ Absolutely

Please comment

19 – Do you consider the “pilot” responses to RA events as realistic?

Not at all ☐ ☐ ☐ ☐ ☐ Absolutely

Please comment

20 – Did you feel sufficiently trained before progressing to the measured exercises?

Poor ☐ ☐ ☐ ☐ ☐ Very good

What could be improved?

21 – How do you assess the organisation of the simulation, in terms of the travel and the accommodation?

Poor ☐ ☐ ☐ ☐ ☐ Very good

What could have been improved?

22 – How do you assess the organisation of the simulation, in terms of the daily schedule you had?

Poor ☐ ☐ ☐ ☐ ☐ Very good

What could have been improved?

23 – Are there any aspects of the simulation you particularly liked?

24 – Are there any aspects of the simulation you particularly disliked?

25 – Are there any other comments on the simulation you would like to make?

## Appendix H NASA TLX

| | | |
|---|---|---|
| **Participant-ID:** | **Date:** | **Trial:** |
| **Role:** | **Condition:** | |

# NASA TLX RATING SHEET

**INSTRUCTIONS**: On each scale, place a mark that represents the magnitude of that factor in the task you just performed.

LOW HIGH

**MENTAL DEMAND**

LOW HIGH

**PHYSICAL DEMAND**

LOW HIGH

**TEMPORAL DEMAND**

PERFECT FAILURE

**PERFORMANCE**

LOW HIGH

**EFFORT**

LOW HIGH

**FRUSTRATION**

| RATING SCALE DEFINITIONS | | |
|---|---|---|
| Title | Endpoints | Descriptions |
| MENTAL DEMAND | Low/High | How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving? |
| PHYSICAL DEMAND | Low/High | How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious? |
| TEMPORAL DEMAND | Low/High | How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic? |
| EFFORT | Low/High | How hard did you have to work (mentally and physically) to accomplish your level of performance? |
| PERFORMANCE | Good/Poor | How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals? |
| FRUSTRATION LEVEL | Low/High | How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task? |

# Appendix I Descriptive Statistics of SASHA-Q Items

| "How would you rate your overall situation awareness during this exercise?" | | | |
|---|---|---|---|
| Experimental Conditions | Mean | Standard Deviation | N |
| RA Downlink / Executive / Delayed Pilot Report | 3.5833 | .9003 | 12 |
| RA Downlink / Executive / Timely Pilot Report | 3.5000 | 1.0871 | 12 |
| RA Downlink / Planner / Delayed Pilot Report | 3.8150 | .7159 | 12 |
| RA Downlink / Planner / Timely Pilot Report | 3.7967 | .9389 | 12 |
| No RA Downlink / Executive / Delayed Pilot Report | 3.6667 | .8876 | 12 |
| No RA Downlink / Executive / Timely Pilot Report | 3.2500 | .9653 | 12 |
| No RA Downlink / Planner / Delayed Pilot Report | 3.3333 | 1.3027 | 12 |
| No RA Downlink / Planner / Timely Pilot Report | 3.7317 | .4456 | 12 |

**Table A-1: Descriptive Statistics of SASHA-Q Item #12**

| "Did you have the feeling that you were ahead of the traffic and able to predict the evolution of the traffic?" | | | |
|---|---|---|---|
| Experimental Conditions | Mean | Standard Deviation | N |
| RA Downlink / Executive / Delayed Pilot Report | 4.0833 | .6686 | 12 |
| RA Downlink / Executive / Timely Pilot Report | 3.4167 | 1.5643 | 12 |
| RA Downlink / Planner / Delayed Pilot Report | 3.9167 | .7930 | 12 |
| RA Downlink / Planner / Timely Pilot Report | 3.9167 | .9003 | 12 |
| No RA Downlink / Executive / Delayed Pilot Report | 4.0833 | .9003 | 12 |
| No RA Downlink / Executive / Timely Pilot Report | 3.6667 | 1.3027 | 12 |
| No RA Downlink / Planner / Delayed Pilot Report | 3.7500 | 1.2881 | 12 |
| No RA Downlink / Planner / Timely Pilot Report | 4.0000 | 1.1282 | 12 |

**Table A-2: Descriptive Statistics of SASHA-Q Item #1**

| "Did you have the feeling that you were able to plan and organise your work as you wanted?" | | | |
|---|---|---|---|
| Experimental Conditions | Mean | Standard Deviation | N |
| RA Downlink / Executive / Delayed Pilot Report | 3.9167 | .6686 | 12 |
| RA Downlink / Executive / Timely Pilot Report | 3.5833 | 1.3790 | 12 |
| RA Downlink / Planner / Delayed Pilot Report | 4.0000 | .6030 | 12 |
| RA Downlink / Planner / Timely Pilot Report | 3.6667 | 1.2309 | 12 |
| No RA Downlink / Executive / Delayed Pilot Report | 3.9167 | .7930 | 12 |
| No RA Downlink / Executive / Timely Pilot Report | 3.6667 | 1.0731 | 12 |
| No RA Downlink / Planner / Delayed Pilot Report | 3.9167 | 1.1645 | 12 |
| No RA Downlink / Planner / Timely Pilot Report | 4.0833 | .9003 | 12 |

**Table A-3: Descriptive Statistics of SASHA-Q Item #2**

| "Have you been surprised by an a/c call that you were not expecting" | | | |
|---|---|---|---|
| Experimental Conditions | Mean | Standard Deviation | N |
| RA Downlink / Executive / Delayed Pilot Report | 3.0833 | 1.5643 | 12 |
| RA Downlink / Executive / Timely Pilot Report | 2.2500 | 1.2154 | 12 |
| RA Downlink / Planner / Delayed Pilot Report | 3.2500 | 1.4848 | 12 |
| RA Downlink / Planner / Timely Pilot Report | 2.0000 | .9535 | 12 |
| No RA Downlink / Executive / Delayed Pilot Report | 2.1667 | 1.3371 | 12 |
| No RA Downlink / Executive / Timely Pilot Report | 2.9167 | 1.4434 | 12 |
| No RA Downlink / Planner / Delayed Pilot Report | 2.1667 | 1.2673 | 12 |
| No RA Downlink / Planner / Timely Pilot Report | 2.6667 | 1.4355 | 12 |

**Table A-4: Descriptive Statistics of SASHA-Q Item #3**

| "Did you have the feeling of starting to focus too much on a single problem and/or area of the sector?" | | | |
|---|---|---|---|
| Experimental Conditions | Mean | Standard Deviation | N |
| RA Downlink / Executive / Delayed Pilot Report | 2.1667 | 1.1146 | 12 |
| RA Downlink / Executive / Timely Pilot Report | 2.4167 | 1.3114 | 12 |
| RA Downlink / Planner / Delayed Pilot Report | 2.3333 | 1.1547 | 12 |
| RA Downlink / Planner / Timely Pilot Report | 2.0833 | .7930 | 12 |
| No RA Downlink / Executive / Delayed Pilot Report | 2.5000 | 1.0000 | 12 |
| No RA Downlink / Executive / Timely Pilot Report | 2.6667 | 1.1547 | 12 |
| No RA Downlink / Planner / Delayed Pilot Report | 2.5000 | 1.3143 | 12 |
| No RA Downlink / Planner / Timely Pilot Report | 2.7500 | 1.3568 | 12 |

**Table A-5: Descriptive Statistics of SASHA-Q Item #4**

| "Did you forget to transfer any aircraft?" | | | |
|---|---|---|---|
| Experimental Conditions | Mean | Standard Deviation | N |
| RA Downlink / Executive / Delayed Pilot Report | 2.3333 | 1.3027 | 12 |
| RA Downlink / Executive / Timely Pilot Report | 3.0417 | 1.6301 | 12 |
| RA Downlink / Planner / Delayed Pilot Report | 2.6771 | 1.4386 | 12 |
| RA Downlink / Planner / Timely Pilot Report | 2.1458 | 1.2712 | 12 |
| No RA Downlink / Executive / Delayed Pilot Report | 2.7500 | 1.3568 | 12 |
| No RA Downlink / Executive / Timely Pilot Report | 3.1667 | 1.4668 | 12 |
| No RA Downlink / Planner / Delayed Pilot Report | 2.8750 | 1.3463 | 12 |
| No RA Downlink / Planner / Timely Pilot Report | 2.4062 | 1.2353 | 12 |

**Table A-6: Descriptive Statistics of SASHA-Q Item #5**

| "Did you have any difficulty finding an item of (static) information?" | | | |
|---|---|---|---|
| Experimental Conditions | Mean | Standard Deviation | N |
| RA Downlink / Executive / Delayed Pilot Report | 2.2500 | 1.3568 | 12 |
| RA Downlink / Executive / Timely Pilot Report | 2.0000 | .9535 | 12 |
| RA Downlink / Planner / Delayed Pilot Report | 1.9167 | 1.1645 | 12 |
| RA Downlink / Planner / Timely Pilot Report | 2.1667 | 1.1146 | 12 |
| No RA Downlink / Executive / Delayed Pilot Report | 1.9167 | 1.0836 | 12 |
| No RA Downlink / Executive / Timely Pilot Report | 2.0833 | 1.1645 | 12 |
| No RA Downlink / Planner / Delayed Pilot Report | 2.0000 | 1.1282 | 12 |
| No RA Downlink / Planner / Timely Pilot Report | 2.0833 | 1.0836 | 12 |

**Table A-7: Descriptive Statistics of SASHA-Q Item #6**

## Appendix J RA Downlink Operational Concept Used for RADE-2A

Whenever an RA is generated, the aircraft's transponder provides information about the RA, which could be downlinked to ATC for display on Controller Working Positions (CWP). The following information will be displayed on CWP:

- An indication of all initial RAs (preventative and corrective) including the identity of the aircraft generating the RA and the intruder aircraft;
- Weakening RAs will not be indicated,
- All follow-up strengthening RAs will be indicated,
- All follow-up reversal RAs will be indicated,
- The climb/descend, increase climb/increase descend, crossing climb/descend, reversal climb/reversal descend RA information will be displayed in a graphical form representing the vertical movement ,
- For all other RAs, information is presented in a graphical form indicating that a vertical speed limit RA has been issue,
- There is no indication of 'Clear of Conflict'.

The controller shall cease issuing clearances and instructions once the pilot has reported that he/she is following an RA (as per current ICAO regulations – see Appendix K).

| Cockpit Audible Alert | ICAO Phraseology to Report RA | CWP RA |
|---|---|---|
| Adjust vertical speed, adjust | No specific phraseology prescribed | TCAS – |
| Monitor vertical speed | No specific phraseology prescribed | TCAS |
| Climb, climb<br>Climb, crossing climb<br>Increase climb…<br>Maintain vertical speed, maintain *<br>Maintain vertical speed, crossing maintain * | [callsign] TCAS CLIMB | TCAS ↑ |
| Descend, descend<br>Descend, crossing descend<br>Increase descend…<br>Maintain vertical speed, maintain *<br>Maintain vertical speed, crossing maintain * | [callsign] TCAS DESCENT | TCAS ↓ |
| Climb, climb now… | [callsign] TCAS CLIMB | TCAS (↓) ↑ |
| Descend, descend now… | [callsign] TCAS DESCENT | TCAS (↑) ↓ |
| Clear of conflict | [callsign] TCAS CLIMB (*or* DESCENT) COMPLETED (*assigned clearance*) RESUMED | [none] |

**Table A-8: RA Downlink Symbols**

# Appendix K ICAO Regulations on TCAS and RAs

As of 1 September 2006.

## Appendix K.1 ICAO Annex 10

### Definitions

***Airborne collision avoidance system (ACAS).*** An aircraft system based on secondary surveillance radar (SSR) transponder signals which operates independently of ground-based equipment to provide advice to the pilot on potential conflicting aircraft that are equipped with SSR transponders.

*Note.— SSR transponders referred to above are those operating in Mode C or Mode S.*

***Resolution advisory (RA)*** – an indication given to the flight crew recommending:

a) a manoeuvre intended to provide separation from all threats; or
b) a manoeuvre restriction intended to maintain existing separation.

***Corrective RA.*** A resolution advisory that advises the pilot to deviate from the current flight path.

***Preventive RA.*** A resolution advisory that advises the pilot to avoid certain deviations from the current flight path but does not require any change in the current flight path.

### 3.5.8.10.3 Contrary pilot response

Manoeuvres opposite to the sense of an RA may result in a reduction in vertical separation with the threat aircraft and therefore must be avoided. This is particularly true in the case of an ACAS-ACAS coordinated encounter.

## Appendix K.2 ICAO Doc 4444 (as of 1 September 2006)

The following table summarises the phraseology presented in ICAO Doc 4444 12.3.1.2.

| Para. | Circumstances | Phraseologies |
|---|---|---|
| r | … after modifying vertical speed to comply with an ACAS resolution | **Aircrew:** TCAS CLIMB (or DESCENT)<br>**Controller:** (acknowledgement) |
| t | … after ACAS "Clear of Conflict" is annunciated | **Aircrew:** RETURNING TO (assigned clearance)<br>**Controller:** (acknowledgement) (or alternative instructions) |

| Para. | Circumstances | Phraseologies |
|---|---|---|
| v | … after the response to an ACAS resolution advisory is completed | **Aircrew:** TCAS CLIMB (or DESCENT), RETURNING TO (assigned clearance)<br>**Controller:** (acknowledgement) (or alternative instructions) |
| x | … after returning to clearance after responding to an ACAS resolution advisory | **Aircrew:** TCAS CLIMB (or DESCENT), COMPLETED (assigned clearance) RESUMED<br>**Controller:** (acknowledgement) (or alternative instructions) |
| z | … when unable to comply with a clearance because of an ACAS resolution advisory | **Aircrew:** UNABLE, TCAS RESOLUTION ADVISORY;<br>**Controller:** (acknowledgement) |

**Table A-9: RA Reporting Phraseology**

### 15.6.3 Procedures in regard to aircraft equipped with airborne collision avoidance systems (ACAS)

15.6.3.1 The procedures to be applied for the provision of air traffic services to aircraft equipped with ACAS shall be identical to those applicable to non-ACAS equipped aircraft. In particular, the prevention of collisions, the establishment of appropriate separation and the information which might be provided in relation to conflicting traffic and to possible avoiding action shall conform with the normal ATS procedures and shall exclude consideration of aircraft capabilities dependent on ACAS equipment.

15.6.3.2 When a pilot reports a manoeuvre induced by an ACAS resolution advisory (RA), the controller shall not attempt to modify the aircraft flight path until the pilot reports returning to the terms of the current air traffic control instruction or clearance but shall provide traffic information as appropriate.

15.6.3.3 Once an aircraft departs from its clearance in compliance with a resolution advisory, the controller ceases to be responsible for providing separation between that aircraft and any other aircraft affected as a direct consequence of the manoeuvre induced by the resolution advisory. The controller shall resume responsibility for providing separation for all the affected aircraft when:

a) the controller acknowledges a report from the flight crew that the aircraft has resumed the current clearance; or

b) the controller acknowledges a report from the flight crew that the aircraft is resuming the current clearance and issues an alternative clearance which is acknowledged by the flight crew.

15.6.3.4 ACAS can have a significant effect on ATC. Therefore, the performance of ACAS in the ATC environment should be monitored.

15.6.3.5 Following an RA event, or other significant ACAS event, pilots and controllers should complete an air traffic incident report.

Note 1.— The ACAS capability of an aircraft may not be known to air traffic controllers.

Note 2.— Operating procedures for use of ACAS are contained in PANS-OPS (Doc 8168), Volume I, Part VIII, Chapter 3.

Note 3.— The phraseology to be used by controllers and pilots is contained in Chapter 12, 12.3.1.2.

## Appendix K.3 ICAO Doc 7030 (as of 1 September 2006)

### 20.1 Carriage and operation of ACAS II

20.1.1 ACAS II shall be carried and operated in the EUR region (including FIR Canarias) by all aircraft that meet the following criteria:

a) With effect from 1 January 2000, all civil fixed-wing turbine engined aircraft having a maximum take-off mass exceeding 15 000 kg or maximum approved passenger seating configuration of more than 30.

b) With effect from 1 January 2005, all civil fixed-wing turbine engined aircraft having a maximum takeoff mass exceeding 5 700 kg or a maximum approved passenger seating configuration of more than 19.

20.1.2 From 1 July 2001, ACAS II equipment which operates in accordance with the relevant provisions of Annex 10, Volume IV, shall be carried and operated by all turbine-engined aeroplanes of a maximum certificated take-off mass in excess of 15 000 kg or authorized to carry more than 30 passengers operating within the Amman, Beirut, Cairo, Damascus and Tel Aviv FIRs except when operating wholly within an FIR for which the State responsible has notified in its AIP or by NOTAM that these requirements do not apply.

## Appendix K.4 ICAO Doc 8168 (as of 1 September 2006)

### Part VIII. Chapter 3 OPERATION OF ACAS EQUIPMENT

3.1 GENERAL

3.1.1 Airborne collision avoidance system (ACAS) indications shall be used by pilots in the avoidance of potential collisions, the enhancement of situational awareness, and the active search for, and visual acquisition of, conflicting traffic.

3.1.2 Nothing in the procedures specified in 3.2 hereunder shall prevent pilots-in-command from exercising their best judgement and full authority in the choice of the best course of action to resolve a traffic conflict or avert a potential collision.

Note 1.— The ability of ACAS to fulfil its role of assisting pilots in the avoidance of potential collisions is dependent on the correct and timely response by pilots to ACAS indications. Operational experience has shown that the correct response by pilots is dependent on the effectiveness of initial and recurrent training in ACAS procedures.

Note 2.— ACAS II Training Guidelines for Pilots are provided in Attachment A to Part VIII.

## 3.2 USE OF ACAS INDICATIONS

The indications generated by ACAS shall be used by pilots in conformity with the following safety considerations:

a) pilots shall not manoeuvre their aircraft in response to traffic advisories (TAs) only;

Note 1.— TAs are intended to alert pilots to the possibility of a resolution advisory (RA), to enhance situational awareness, and to assist in visual acquisition of conflicting traffic. However, visually acquired traffic may not be the same traffic causing a TA. Visual perception of an encounter may be misleading, particularly at night.

Note 2.— The above restriction in the use of TAs is due to the limited bearing accuracy and to the difficulty in interpreting altitude rate from displayed traffic information.

b) on receipt of a TA, pilots shall use all available information to prepare for appropriate action if an RA occurs;

c) in the event of an RA, pilots shall:

1) respond immediately by following the RA as indicated, unless doing so would jeopardize the safety of the aeroplane;

Note 1.— Stall warning, wind shear, and ground proximity warning system alerts have precedence over ACAS.

Note 2.— Visually acquired traffic may not be the same traffic causing an RA. Visual perception of an encounter may be misleading, particularly at night.

2) follow the RA even if there is a conflict between the RA and an air traffic control (ATC) instruction to manoeuvre;

3) not manoeuvre in the opposite sense to an RA;

Note.— In the case of an ACAS-ACAS coordinated encounter, the RAs complement each other in order to reduce the potential for collision.

Manoeuvres, or lack of manoeuvres, that result in vertical speeds opposite to the sense of an RA could result in a collision with the threat aircraft.

4) as soon as possible, as permitted by aircrew workload, notify the appropriate ATC unit of the RA, including the direction of any deviation from the current air traffic control instruction or clearance;

Note.— Unless informed by the pilot, ATC does not know when ACAS issues RAs. It is possible for ATC to issue instructions that are unknowingly contrary to ACAS RA indications. Therefore, it is important that ATC be notified when an ATC instruction or clearance is not being followed because it conflicts with an RA.

5) promptly comply with any modified RAs;

6) limit the alterations of the flight path to the minimum extent necessary to comply with the RAs;

7) promptly return to the terms of the ATC instruction or clearance when the conflict is resolved; and

8) notify ATC when returning to the current clearance.

Note.— Procedures in regard to ACAS-equipped aircraft and the phraseology to be used for the notification of manoeuvres in response to an RA are contained in the PANS ATM (Doc 4444), Chapters 15 and 12, respectively.

# Appendix L Description of Events with Contradicting Clearances

## Appendix L.1 Group 1/Traffic Sample S9 – Conflict between DLH6124 and EZY7353

The following RA occurred during Traffic Sample S9 in Group 1 (no RA Downlink, timely pilot report). The RA was caused by pilot error (level bust).

DLH6124 was flying eastbound at FL290, while EZY7353, almost on the opposite track was in the climb to FL280. The predicted lateral separation was below 0.5 NM. An STCA alert was generated just before EZY7353 levelled off at FL280 (see Figure A-10-1).

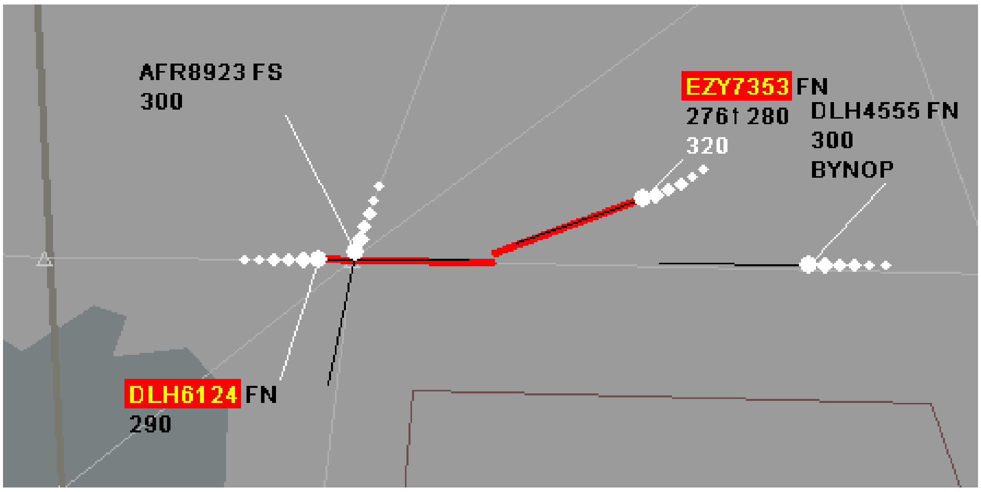



**Figure A-10-1: Radar picture: STCA generated between DLH6124 and EZY7353**

EZY7353 busted their cleared level and continued the climb (see Figure A-10-2). The STCA alert was continuously displayed but the predicted lateral separation increased to 1.8 NM (as EZY7353 was completing a right turn).

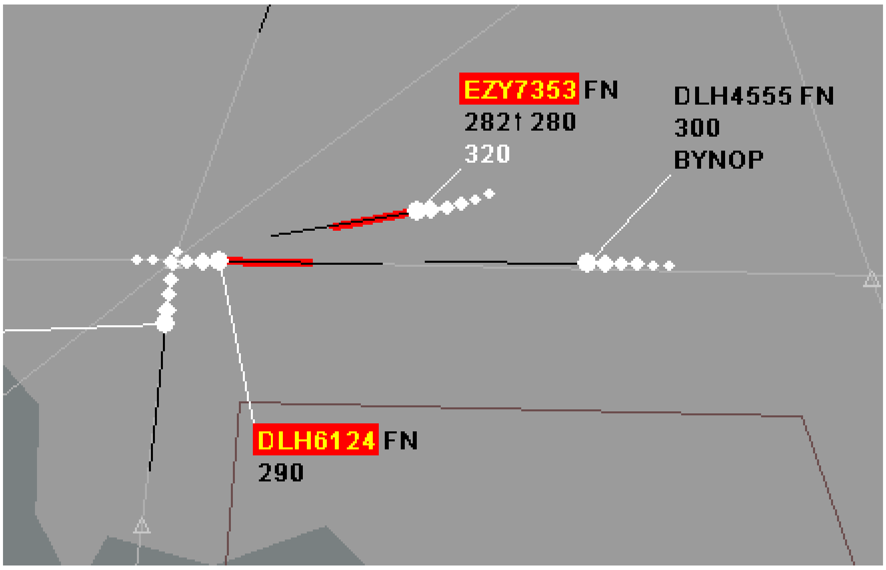



**Figure A-10-2: Radar picture: EZY7353 level bust**

When the aircraft were approximately 8 NM apart, RAs were issued – "climb" for DLH6124 and "descend" for EZY7353 (see Figure A-10-3). The climb RA put DLH6124 on the collision course with opposite direction DLH4555 level at FL300.

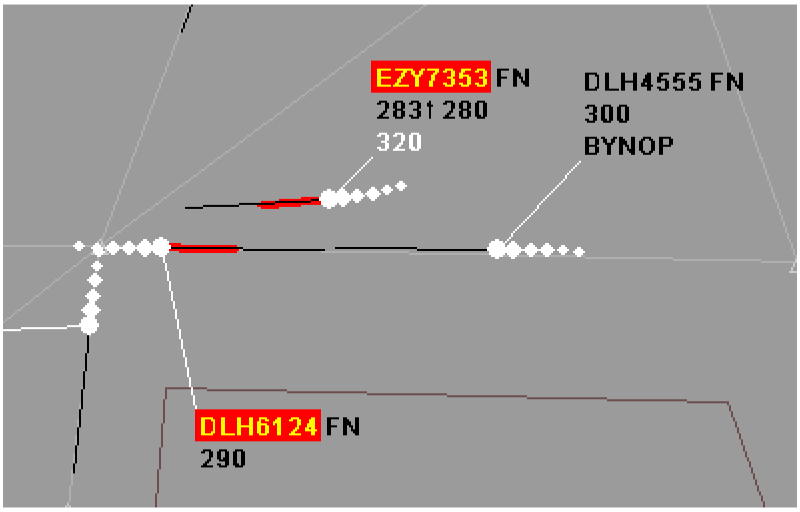



**Figure A-10-3: Radar picture: RAs generated onboard of EZY7353 and DLH6124**

The EZY7353 pilot reported the RA with a delay of 5 seconds. The controller responded with traffic information.

As soon as the frequency was not busy, 17 seconds after the RA, the DLH6124 pilot also reported the RA. The controller responded with traffic information concerning the opposite direction DLH4555 (at this time some 5 miles ahead) and instructed the pilot to descend to FL 290 (see Figure A-10-4). At this time, EZY7353 that caused the RA, was already behind DLH6124.

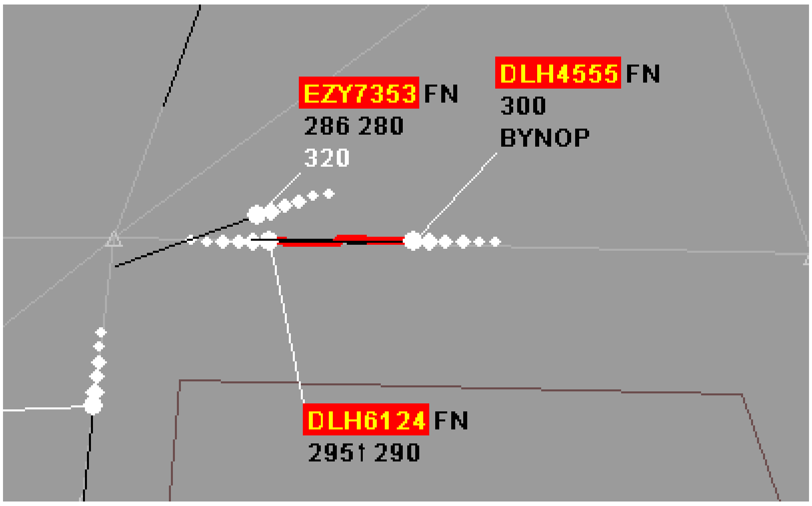



**Figure A-10-4: Radar picture: DLH6124 descent clearance issued to DLH6124**

The post-run analyses were conducted using the InCAS tool (see Section 5.1.1 and Figure A-10-5), R/T and radar picture recordings. The analyses determined that when the controller was issuing the instruction to DLH6124 to descend, the TCAS had already generated an RA for DLH6124 against DLH4555. The RA initially was a composite RA (taking into account EZY7353 as well). The RA instructed the pilot to monitor vertical speed. That later (when the EZY7353 was no longer a factor) was strengthened to descend. DLH4555 also received an RA (initially "climb", followed by "do not descend").

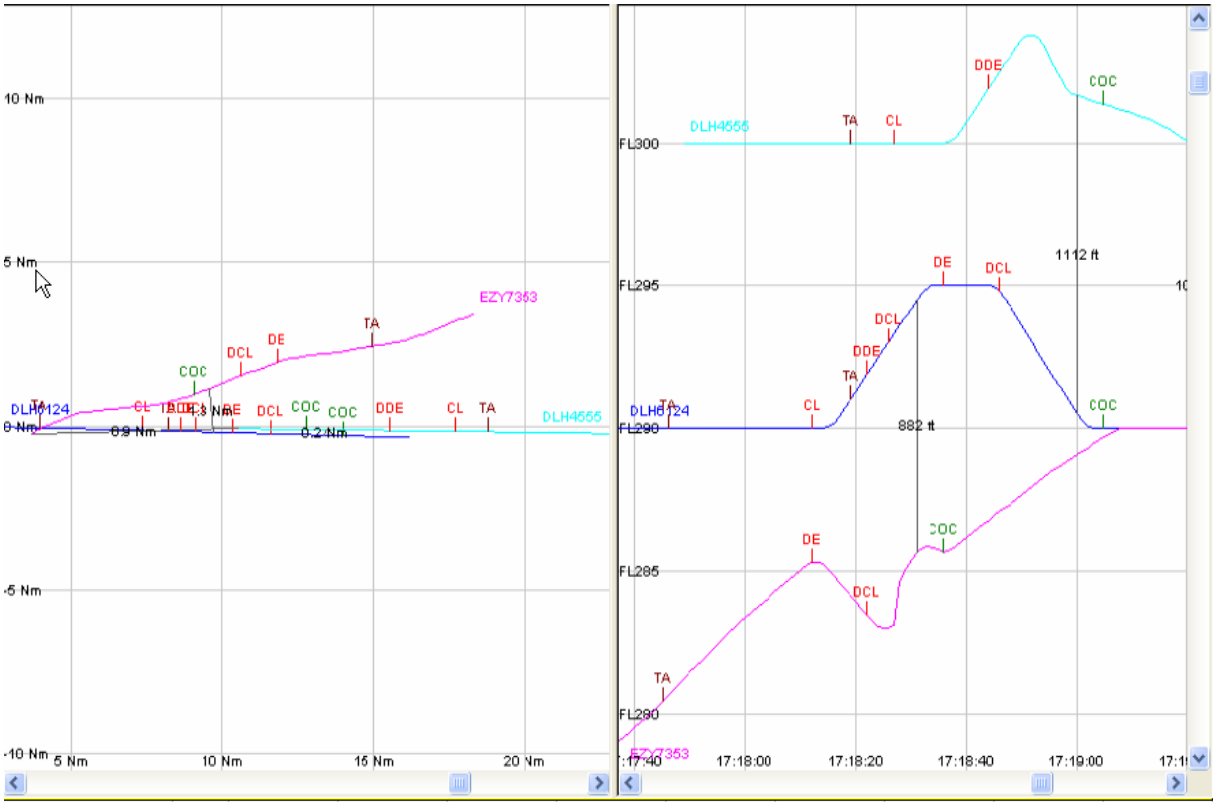



**Figure A-10-5: DLH6124 - EZY7353 conflict – InCAS Analysis**

### Appendix L.2 Group 3/Traffic Sample S10 – Conflict between RYR339 and EIN435.

The following RA occurred during Traffic Sample S10 in Group 3 (no RA Downlink, delayed pilot report). The RA was caused by RYR339 high vertical speed level off.

RYR339 and EIN435 were crossing each other at BRC waypoint. RYR339 was climbing to FL310, while EIN435 was level at FL320. The predicted lateral separation was below 0.5 NM. The controller reminded RYR339 to maintain FL310 on reaching due to crossing traffic above (see Figure A-10-6).

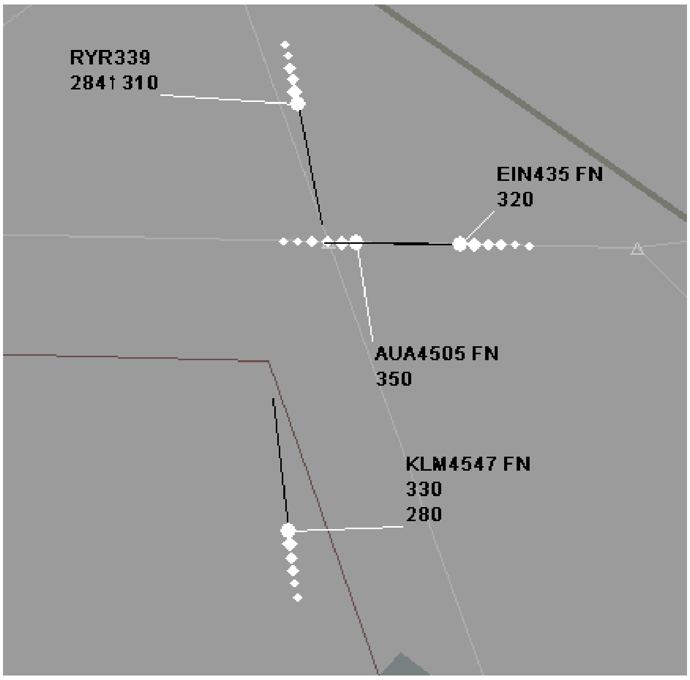



**Figure A-10-6: Radar picture: 30 seconds prior to the RA between RYR339 and EIN435**

When RYR339 was passing through FL302, their vertical speed caused a “Limit Climb 2000 feet/min” RA (cockpit aural alert: “Adjust vertical speed, adjust”). Few seconds later a “Climb” RA was triggered for EIN435. The controller gave traffic information to RYR339 while they were levelling off at FL310 (see Figure A-10-7).

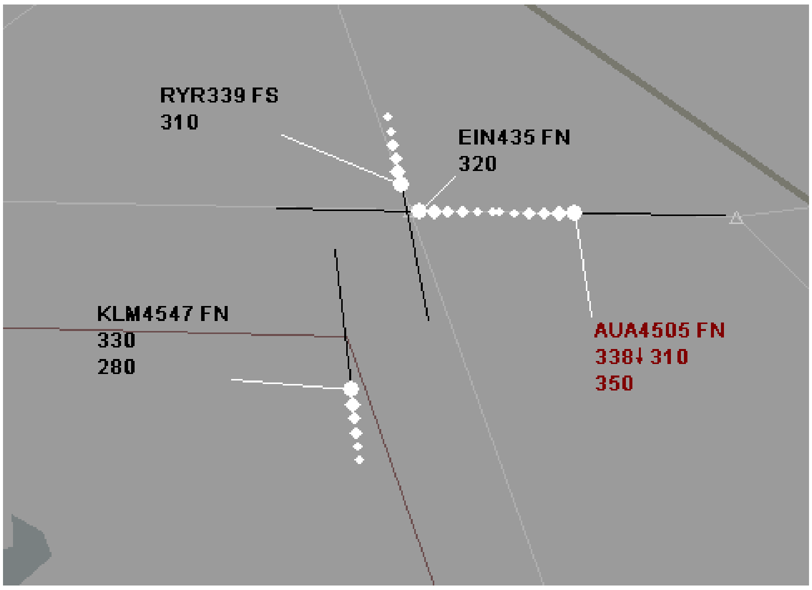



**Figure A-10-7: Radar picture: traffic information issued to RYR339**

The response to the “Climb’ RA put EIN435 on the collision course with a third aircraft (KLM4547) crossing from left to right, at FL330 (predicted lateral separation 3.5 NM). Some ten seconds later, seeing that EIN435 is ascending and the STCA warning, the controller not knowing about the RA, instructed EIN435 to maintain FL320 (see Figure A-10-8).

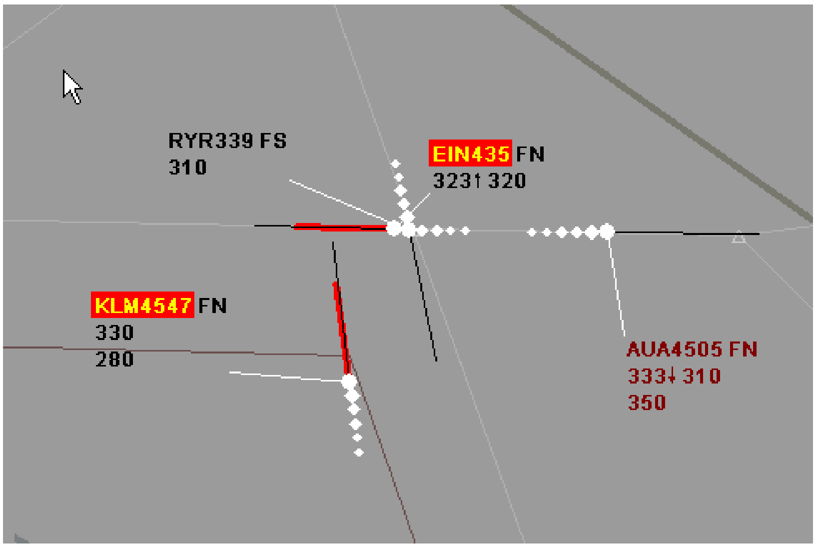



**Figure A-10-8: Radar picture: EIN435 instructed to maintain their level**

This instruction was contradicting the climb RA. EIN435 reported RA with a delay of 23 seconds. Only much later, with a delay of 55 seconds, RYR339 reported their RA to adjust vertical speed and also reported that it was resuming its original clearance at FL310.

The InCAS tool (see Section 5.1.1 and Figure A-10-9) was used to analyse the exact chain of events in both horizontal and vertical views. Furthermore, radar picture and R/T recordings were available for detailed analysis of the sequence of events.

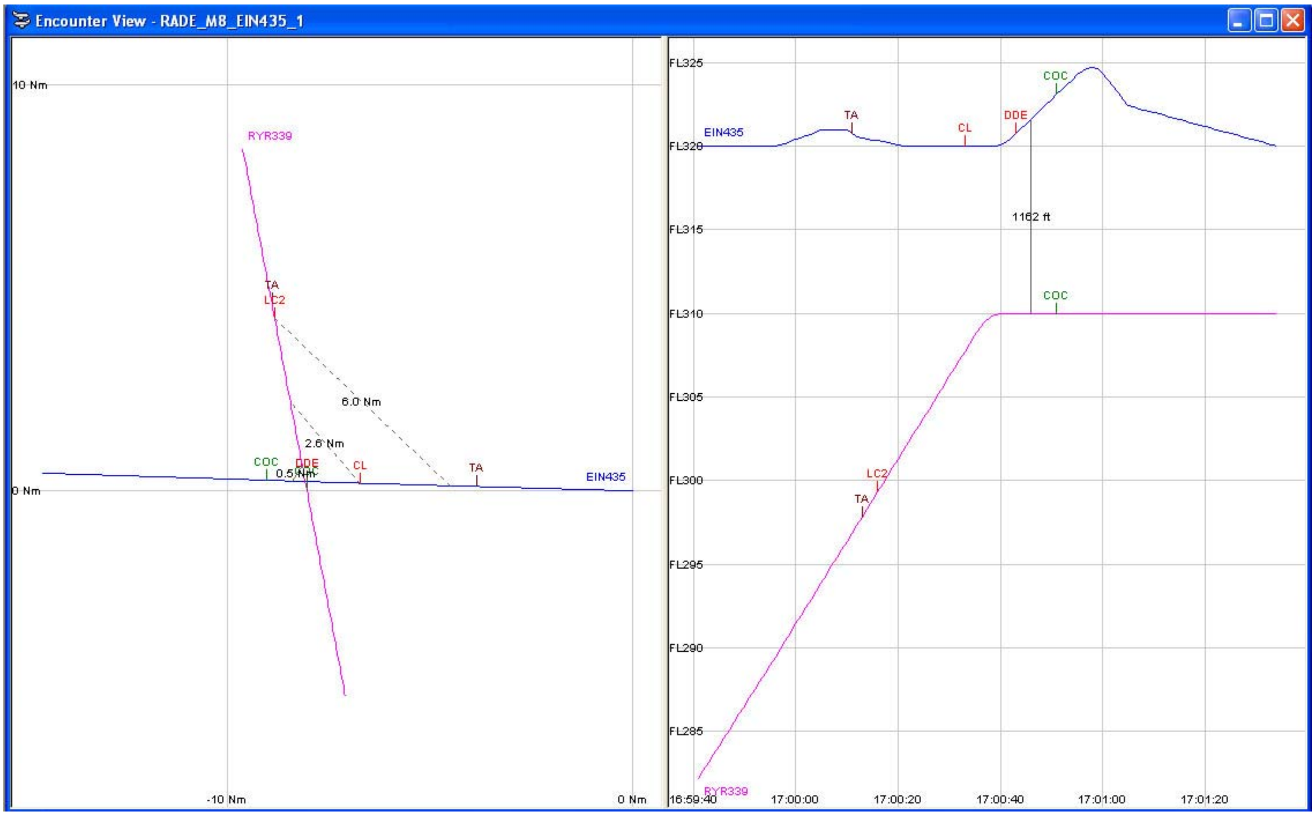


**Figure A-10-9: RYR339 - EIN435 conflict - InCAS Analysis**