EUROCONTROL

RADE-2T Experimental Report

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Abstract

The present report describes the conduct and the results of RADE-2T, an initial experiment that was conducted to assess the impact of displaying simplified ACAS Resolution Advisories (RAs) to the controller in a Terminal Control environment. The RADE-2T experiment took place from January 10 to January 19, 2006 and involved 4 controllers from 2 different European Approach Control units.

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 initial experiment were inconclusive with regard to the operational impact of RA downlink in a Terminal Control. The main reason is that the different RA causes (pilot error, controller error, or high-vertical rate before level off) were not equally distributed over the two RA downlink conditions. RAs that were due to controller or pilot error were much more frequent in the RA downlink than in the non-RA downlink conditions. As these types of RAs are associated with a lower level of situation awareness and a higher level of workload, there was a systematic bias against the RA downlink conditions. The study did reveal that an experimental test of RA downlink in a Terminal Control environment is very demanding, with respect to realising a sufficient number of RAs without compromising simulation realism.

Keywords

RA Downlink	ACAS	Simulation	RA
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Contact Person(s)	Tel	Unit
Stanislaw DROZDOWSKI	+32.2.729.3760	DAP/ATS

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EUROCONTROL Agency, Library Documentation and Archives (ALDA)
EUROCONTROL Headquarters (50.703)
96 Rue de la Fusée
B-1130 BRUSSELS

Tel: +32 (0)2 729 11 52
E-mail: publications@eurocontrol.int

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The following table identifies all management authorities who have successively approved the present issue of this document.

AUTHORITY	NAME AND SIGNATURE	DATE
Authors	Stanislaw Drozdowski, Doris Dehn, Bernd Lorenz, Jürgen Teutsch	10/05/2007
FARADS Project Manager	Stanislaw Drozdowski	29/05/2007

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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. RADE-2A assessed the operational impact of RA Downlink for Area Control. The present report describes the conduct and the results of a subsequent experiment, which is referred to as RADE-2T.

The general aim of the RADE-2T experiment was to analyse the impact of RA downlink on the controller's ability to separate traffic in an interactive control setting for a Terminal Control environment. In addition, controllers' attitudes on RA downlink, the proposed operational concept and the HMI were investigated. Testing RA downlink in a Terminal Control environment is particularly difficult because RA generation parameters require a closer aircraft proximity in lower airspace. Being aware of this problem, the decision was made to take advantage of the RADE-2A simulation infrastructure and to run the RADE-2T experiment as an initial study with a very restricted number of participants.

Three experimental variables were manipulated in the RADE-2T 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-2T experiment took place from January 10, 2006 to January 19, 2006. A total of four controllers from 2 different European Approach Control units participated in the RADE-2T simulation.

The experiment revealed that an experimental test of RA downlink in a Terminal Control environment is in fact very demanding, with respect to realising a sufficient number of RAs without compromising simulation realism. Although RAs were achieved in all simulation runs, this was in some cases on the expense of simulation realism. Half of the participants of RADE-2T had concerns regarding the realism of the traffic scenarios used in the simulation, which is a substantially higher share of participants that in RADE-2A.

The results of the experiment were inconclusive with regard to the operational impact of RA downlink in a Terminal Control environment. The main reason is that the RAs could not been realised in such a way that RA causes (pilot error, controller error, or high-vertical rate before level off) were balanced over the RA downlink conditions. RAs

that were due to controller/pilot error were much more frequent in the RA downlink condition than in the non-RA downlink condition. As these types of RAs are associated with a lower level of situation awareness and a higher level of workload, this means that there was a severe methodological flaw in the experiment.

Throughout the experiment, no contradictory clearances were issued to aircraft involved in an RA. There was one instruction to an RA aircraft in the RA downlink condition, though. This instruction had the same effect as the RA, but was even more rigorous. Follow-up conflicts (i.e. losses of separation between an RA aircraft and a third-party aircraft) occurred more often when RA downlink was provided than when it was not provided. Situational awareness as measured on the basis of the memory probe was the same regardless of whether RA downlink was present or not. For the subjective indicators of situation awareness as well as for workload, there was a negative effect of the RA downlink condition.

Nevertheless, because of the systematic bias against the RA downlink condition, the data pattern cannot be conclusively interpreted. In case no effect of RA downlink was observed, the bias may have masked an existing positive impact of RA downlink. In case a negative effect was observed, this effect cannot be exclusively attributed to the RA information. Rather, the higher number of RAs caused by pilot/controller error in the RA downlink condition alone could be sufficient to produce such an effect.

LIST OF ABBREVIATIONS & TERMS

ACAS	Airborne Collision Avoidance System *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
APP	Approach Control
ATC	Air Traffic Control
ATCo	Air Traffic Controller
ATIS	Automated Terminal Information Service
ATM	Air Traffic Management
AudioLAN	Innovative Internet Technology-based Voice Communication System
COC	Clear of Conflict *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
hPa	Hectopascal Unit of pressure
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
QNH	Atmospheric pressure at the mean sea level *Barometric altimeter setting which will cause the altimeter to read altitude above mean sea level.*
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
RWY	Runway
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
SID	Standard Instrument Departure
SME	Subject Matter Expert
STAR	Standard Instrument Arrival

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

TMA Terminal Control Area

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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 [22].

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 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-2T experiment – which is described in the present report – aimed to validate whether is it is possible to overcome this and other limitations by using a monitoring-and-control real-time simulation environment for Terminal Control. 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-2T experiment employed a specific HMI and an operational concept for RA downlink [10]]. This HMI as well as 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 and RADE-2A are documented in Ref. [12] and [8] respectively. The present document describes the experimental objectives, the conduct, and the results of the RADE-2T experiment. Note that the experimental plan for RADE-2T can be also found in Ref. [11].

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-2T 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-2T 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-2T.
- In Chapter 8, recommendations for future work are given.

2. Aims and Objectives of RADE-2 Experiments

2.1 General Aim

The general aim of the RADE-2 experiments 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 Ref. [11]). In this way, the RADE-2 experiments were 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.

Two environments were selected for this purpose: an Area Control environment, and a Terminal Control environment. The present study, RADE-2T, is an initial experiment to assess the impact of RA downlink in a Terminal Control environment.

Testing RA downlink in a Terminal Control environment is more difficult than in an Area Control experiment. This is mainly due to the fact that the RA generation parameters require significant aircraft proximity in the lower airspace, which is difficult to achieve in a simulation environment. The decision was made to take advantage of the RADE-2A simulation infrastructure and to perform an initial small scale experiment to assess the feasibility of an RA downlink experiment in the Terminal Control environment. This initial study should be carried out with a very restricted number of participants.

The simulation objectives, the experimental variables and the measurements used in RADE-2T were identical to those of RADE-2A.

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-2T 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 [12]. 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 [12]).

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.

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 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-2T 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-2T 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 should 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 a 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 the eight experimental conditions, a homogenous set of at least 8 different traffic samples was needed (see also [14] and [15]). The traffic samples are referred to as TMA_S1 to TMA_S8. Table 3-2 also shows the assignment of traffic samples to experimental conditions.

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

Table 3-2: Planned Assignment of Participants to Experiment Conditions

The table is to be read as follows: The condition referring to the lightly shaded cells in Table 3-2 (run 1-6, i.e. pair 1 and run 6) means that controller pair #1 was presented with traffic sample TMA_S2, received RA downlink, and encountered a timely pilot report. ATCo #2 worked as executive controller and ATCo #1 worked as planner.

Note that, with the limited number of participants, the experimental conditions could not be fully balanced with respect to the presentation order. As the experiment was meant as an initial (feasibility) study, this was not considered a problem.

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, four spare traffic samples were constructed for RADE-2T (TMA_S9 – TMA_S12).

4. MEASUREMENTS AND ANALYSIS SPECIFICATION

This chapter addresses the measurements collected during the RADE-2T experiments. The measurements fall into the following categories (see also [11]):

- Perceived realism of the simulation
- Controllers' (primary) task performance
- Workload
- Situational 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

In case of an RA that yields a deviation from the ATC clearance (see ICAO guidelines in Appendix J), the controller ceases to be responsible for separation of this aircraft and should not to interfere with the RA [24]. Thus, the controller should not issue any clearances to the aircraft involved in the RA. In order to assess the extent to which the controller complies with this, the number and type of clearances issued to RA aircraft was taken.

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-2T data analysis process (see Ref. [13]).

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-2T data analysis process (see Ref. [13]).

4.2.3 Losses of separation

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 number of separation losses was taken as a measurement for task performance.

Of particular interest is the controllers' efficacy to separate traffic <u>after</u> 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 <u>other aircraft</u> 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 <u>third-party aircraft</u> 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

Situational 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" (cf. Endsley, [18] and [21]). 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-2 experiments 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 situational 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.

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.

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 (cf. Ref. [2] and [21]).

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 predominantly 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-2 experiments, 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.

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-2T 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-2T 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 RADE-2 experiments, eDEP was configured to facilitate a small-scale simulation environment, and a TCAS server[2] 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-2T 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.

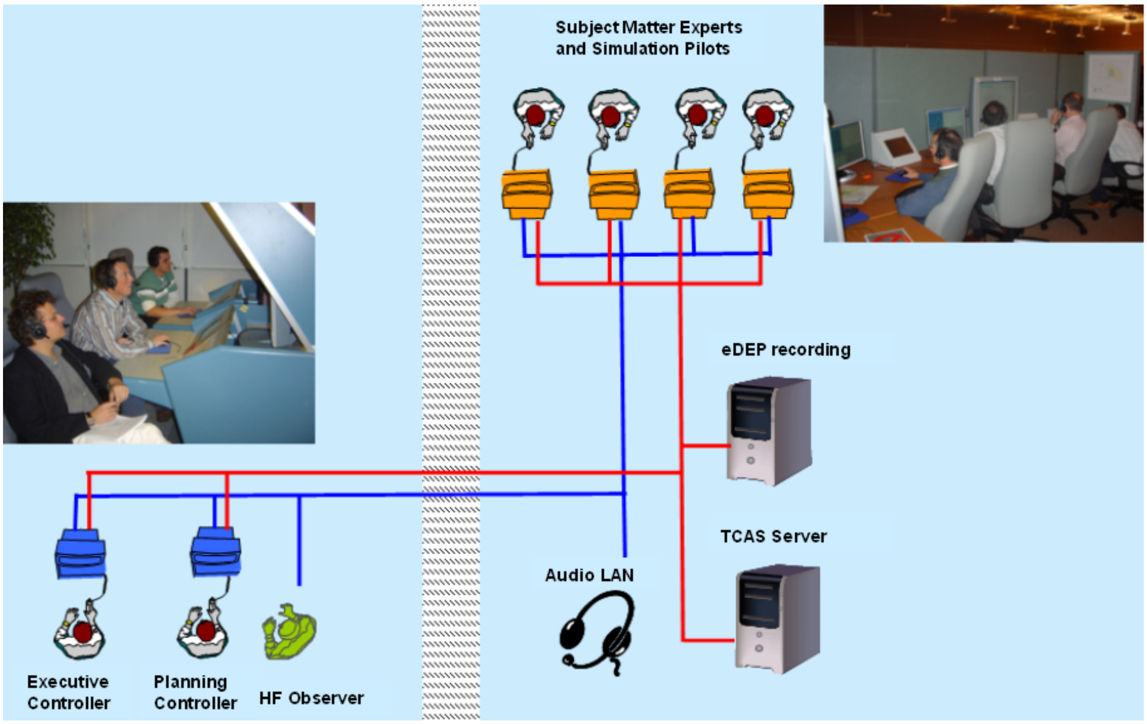

Figure 5-1: RADE-2 Configuration

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

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 RADE-2 experiments was based on the standard EATMP HMI. This HMI is described in the eDEP design document and the RADE-2P document (see Ref. [7] and [12]). In the following, only specific aspects of the TCAS and STCA alerts display are described.

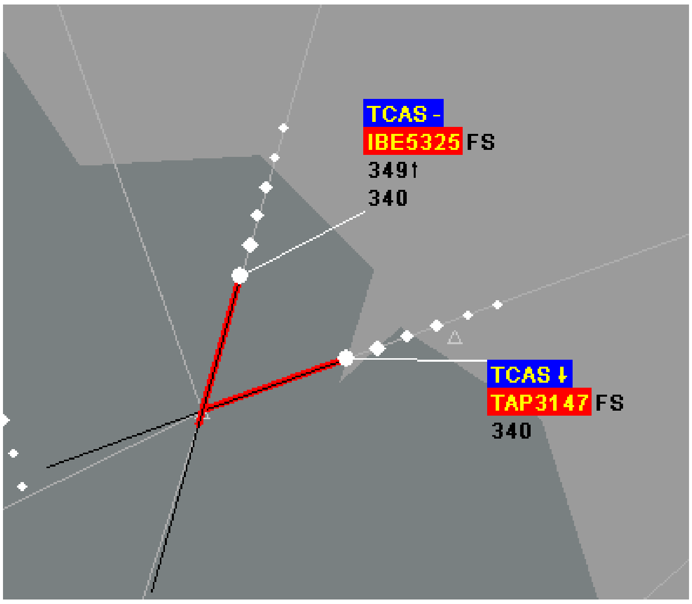

Figure 5-2: STCA and TCAS RA Display

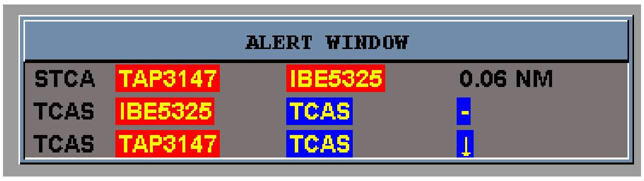

Figure 5-3: STCA and TCAS RA Indication in the Alert Window

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[3]), the intruder was shown with a red frame around the callsign (see Figure 5-5).

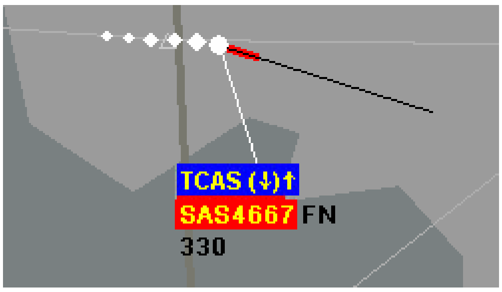

Figure 5-4: Reversal TCAS RA Display

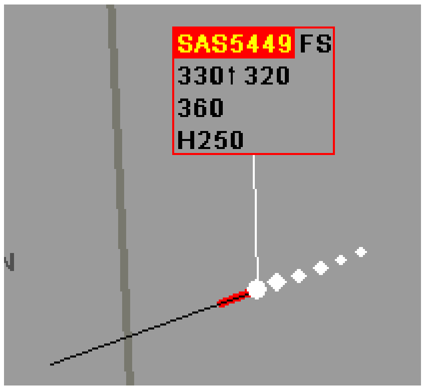

Figure 5-5: TCAS TA Display

RA information was also shown in the alert window. More information on the presentation of TCAS RAs can be found in the Appendix I and in the FARADS Operational Concept document [10][4].

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

[4] The figures above show the traffic situations recorded during the RADE-2A experiment. However, there was no difference in the way how TCAS and STCA HMI were presented to the controllers during RADE-2T.

5.1.3 Control Centre and Airspace

In RADE-2T, controllers were told that they were to work at the fictitious Brétigny Terminal Control Centre of Brétigny International Airport (BREG). They were on an afternoon shift in the Brétigny TMA sector (see Figure 5-6) which stretches from ground to FL 255 in the right part (east of NABOZ) and from FL 55 to 255 in the left part (around Brétigny Airport, west of NABOZ). The Brétigny APP sector is located beneath the left part of the TMA with transition level 50 (transition altitude 4000 ft.).

The TMA sector is laterally and vertically surrounded by sectors, which served as feed sectors in the experiment. The part of the feed sector above the TMA goes from FL 255 to 600. The feed sector was controlled by SMEs located in a separated room. Co-ordination with these sectors was done via a designated AudioLAN telephone connection or using System Supported Coordination (SYSCO).

Airport and Approach sector characteristics as well as main traffic flows were presented to controllers during the briefing session before the simulations (see also [15]). They are listed below:

- Airport and Approach sector (BREG)
  - RWY 08L for arrivals only
  - RWY 08R for departures only
  - Transition level 60, transition altitude 5000[5]
  - Departures climb to FL 70 on SID
  - Arrivals descend to co-ordinated level shown in the label
  - ATIS Weather Information for incoming traffic provided on flash cards
  - Assistance from a Director position was available on request (to vector incoming traffic from 4000 ft)[6]
  - Traffic to/from LFAT airport (north of BREG) transits sector.

[5] During the experiment, the QNH (aerodrome pressure) was constant at 1013 hPa.
[6] The Director position was foreseen as a workload alleviation position in requested by the Executive Controller. During the experiment, the Director position remained inactive at all times.

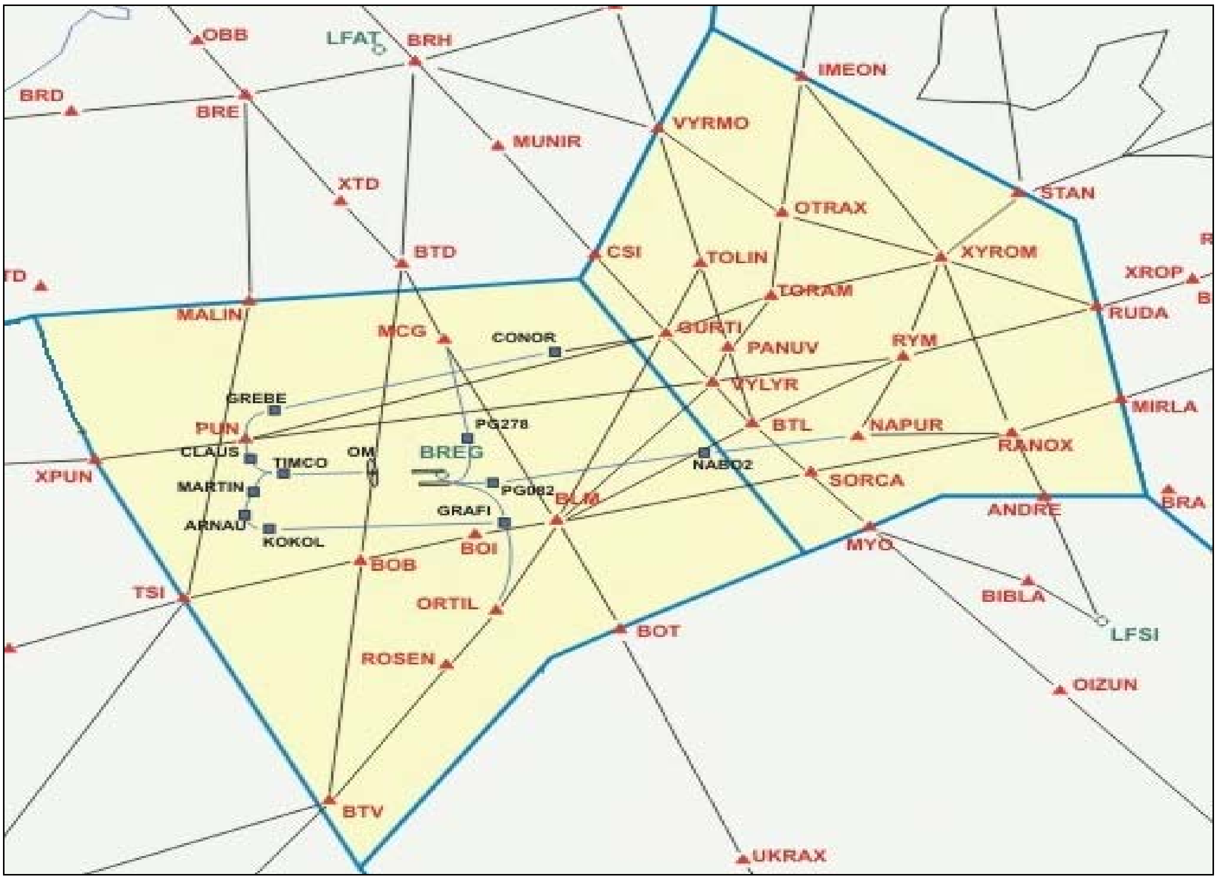

Figure 5-6: RADE-2T Simulated Airspace - Terminal Control of Brétigny Airport

- Main traffic flows
  - BREG arrivals from IMEON and RUDA merge at GURTI for STAR at CONNOR
  - BREG arrivals from BOT enter STAR at GRAFI
  - BREG departures leave SID at ORTIL for BTV
  - BREG departures leave SID at NAPUR for MIRLA
  - BREG departures leave SID at MCG for BTD
  - LFAT arrivals enter from MYO and RUDA and merge for STAR at VYRMO
  - LFAT arrivals enter from BTV and leave for STAR at BTD
  - LFAT departures enter from CSI and leave via BTV, MYO or RUDA.

5.2 RA Facilitation Method

One of the major challenges in the RADE-2 experiments was to facilitate RAs in a realistic way. In an interactive control setting, a participant acting as controller would take any possible actions to avoid an RA event. This problem is even more pronounced for RADE-2T than for RADE-2A, as the TCAS parameter settings require a closer proximity in lower airspace.

The method for achieving RA events was the same in RADE-2T as in RADE-2A and is described below.

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-2 experiments, 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-2 experiments, 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-2T 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 4 controllers participated in the RADE-2T 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). The most relevant responses are summed up below.

Two participants, of Austrian nationality, came from Vienna Approach Control Center. The other two participants, of Hungarian nationality, were from Budapest Approach Control Center.

The participants' age ranged between 37 and 51 years with an average of 45 (SD = 5.9). Experience as a licensed controller varied between 13 and 28 years with an average of 22 years (SD = 6.5). All controllers also worked as instructors, with instructing experience ranging between 8 and 20 years (M = 15.3, SD = 5.1).

Three out of the 4 participants 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 1 and 3 (M = 1.7, SD = 1.2).

All of the 3 participants who had witnessed an incident reported that in at least one of the incidents, RAs were generated. The number of witnessed RAs ranged between 1 and 2 with an average of 1.3 (SD = 0.6).

Of the 4 participants, one participant stated that s/he had experienced (a total of 15) cases in which the pilot reported an RA that was due to fast climbing or descending aircraft. Two controllers stated that they were each once informed by pilots about false RAs, that is, RAs that were triggered when no other traffic was in the vicinity of the aircraft.

5.4 Time Schedule

The RADE-2T experiment took place from January 10, 2006 to January 19, 2006. Two different controller teams took part in the experiments, each for four subsequent days.

The exact simulation dates are presented below (see Table 5-1).

RADE-2T	Group 1	10-Jan-2006 – 13-Jan-2006
	Group 2	16-Jan-2006 – 19-Jan-2006

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

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-2

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 from the RADE-2T experiment will be reported in the following order: After the results on the quality of the experimental 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 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 **Error! Reference source not found.**.

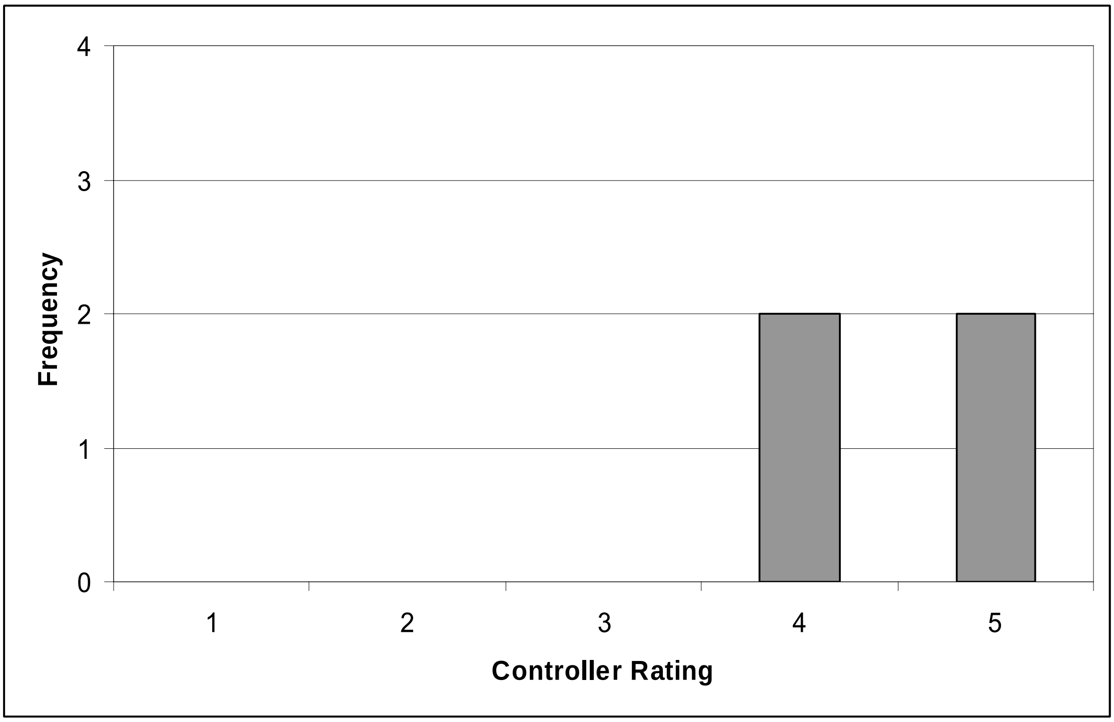

Figure 6-1: Training Sufficiency Ratings

6.1.2 Duration of exercises

Table 6-1 gives an overview of the total exercise time, as well as minimum, maximum, and mean exercise duration and standard deviation. Note that an exercise was terminated within 2 minutes after an RA was issued which caused the variation in exercise times.

Duration	RADE-2T	Group 1	Group 2
Total exercise	7:52:53	4:23:03	3:29:50
Minimum	0:09:15	0:09:15	0:11:11
Maximum	0:58:46	0:58:46	0:33:27
Mean	0:29:33	0:32:53	0:26:14
Standard deviation	0:14:10	0:18:50	0:07:06

Table 6-1: Duration of exercise during RADE-2T (hh:mm:ss)

6.1.3 Number and type of repeated exercises

A total of 16 runs (i.e., 8 runs for each of the 2 controller groups) were planned for RADE-2T. Half of the runs were done with, the other half without RA downlink. Out of the 16 runs, two were unsuccessful and had to be repeated. Both repeated runs occurred in Group 1.

	RA-Downlink	Pilot Report Timeliness	Traffic Sample	Successful Spare Traffic Sample	Reason
Run 1-2	No	Delayed	TMA S8	TMA S9	Loss of realism
Run 1-7	No	Timely	TMA S4	TMA S11	No RA generated

Table 6-2: Unsuccessful Runs in RADE-2T

Table 6-2 shows the unsuccessful runs that had to be repeated. Each entry shows the run number (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.

6.1.4 Generation of TCAS Resolution Advisories

Because there was one RA event in every successful run, there were a total of 16 RAs in the RADE-2T experiment. Figure 6-2 depicts the distribution of the 16 RAs across the three RA causes (pilot error, controller error and high vertical speed level off. In almost half (n = 7) of the runs, RAs were caused by a controller error. In five runs, RAs were caused by a pilot error, and in four runs, they were caused by a high vertical speed before level off. No combination of reasons was observed. This distribution of RA causes is different from the distribution obtained in RADE-2A [8], where high vertical speeds were by far the most frequent cause for an RA.

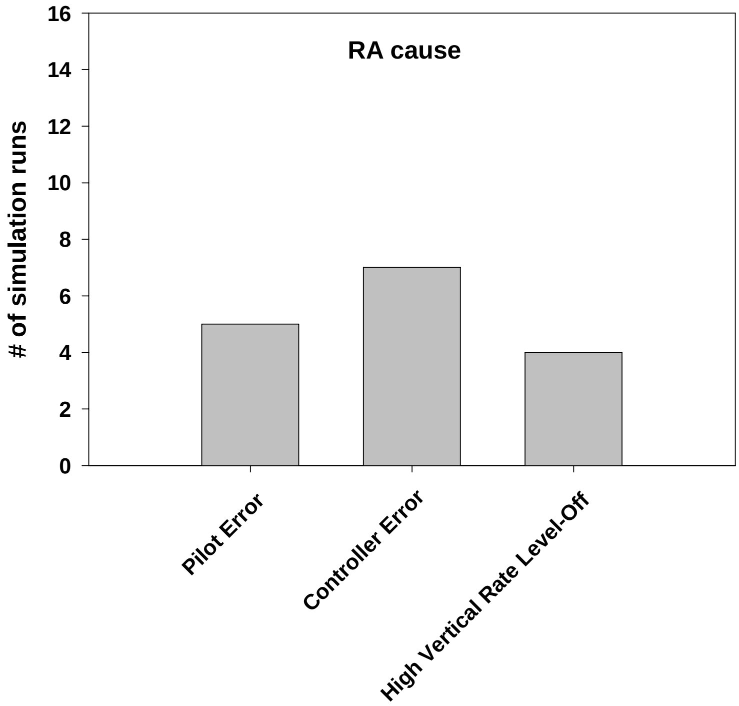

Figure 6-2: Distribution of RA Causes (RADE-2T)

Timely		RA Cause			Total
		Pilot Error	Controller Error	High Vertical speed	
RA Downlink	Downlink	3	5	0	8
	No Downlink	2	2	4	8
Total		5	7	4	16

Table 6-3: Distribution of RA Causes for Different Simulation Conditions (RADE-2T)

In
Table 6-3, the frequencies are cross-tabulated against the presence or absence of RA downlink. This reveals that all RAs that were due to high vertical speed before level off occurred when RA downlink was absent. Hence, in all runs with RA downlink, RAs were either caused by pilot or by controller error. This lack of balance in the RA causes over RA downlink conditions is confirmed by a chi²-test ($chi^2(3) = 10.97$; $p = 0.004$).

The confounding of RA causes and RA downlink conditions demarks a serious methodological flaw, and endangers the interpretation of all results. Because RAs caused by pilot or controller error are associated with higher workload and lower situation awareness than RAs caused by high vertical speeds, there is a fundamental bias against RA downlink in the study. Thus, even if RA downlink had positive effects, they are likely to be masked by the negative effect of the RA cause. This issue will be further addressed in Section 6.2.

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 questionnaire and 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. 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 16 responses for each aspect of simulation realism. The frequency distributions across the five rating categories obtained for the 16 simulation runs are shown in Figure 6-3 to Figure 6-5.

Mean ratings were 3.94 (SD = 1.29) for the traffic situation and 3.75 (SD = 1.24) for the RA event. There were only three runs in which ratings were below 3 for the overall traffic situation or the RA event. Pilot responses were rated as the most realistic aspect (M = 4.56; SD = 0.51): for all runs, ratings were ≥ 4.

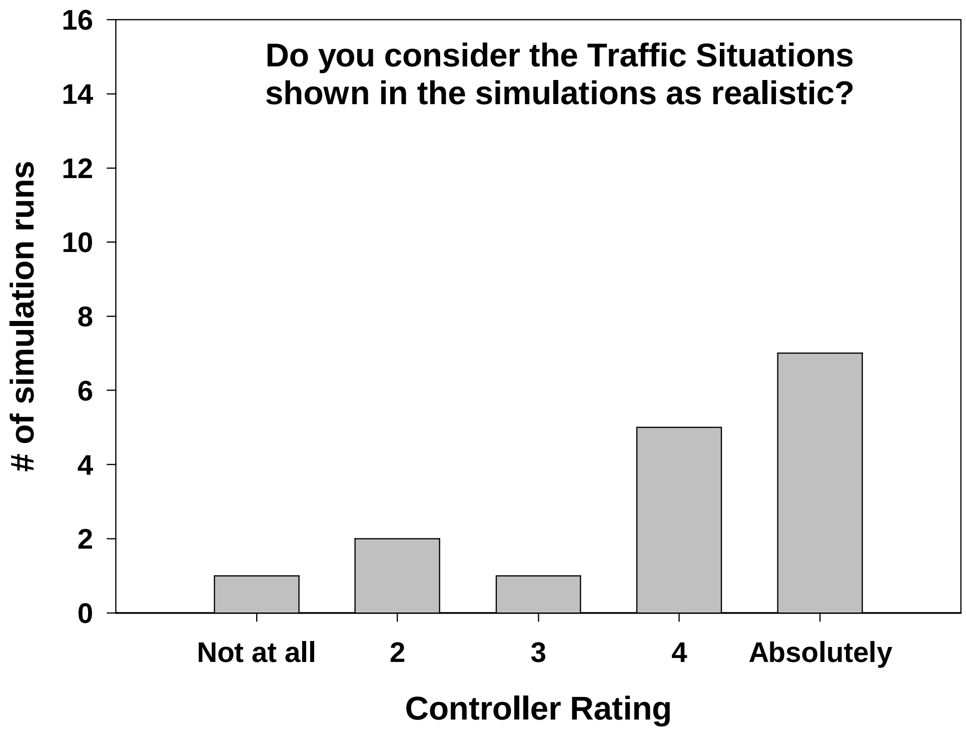

Figure 6-3: Realism of Traffic Situation (RADE-2T)

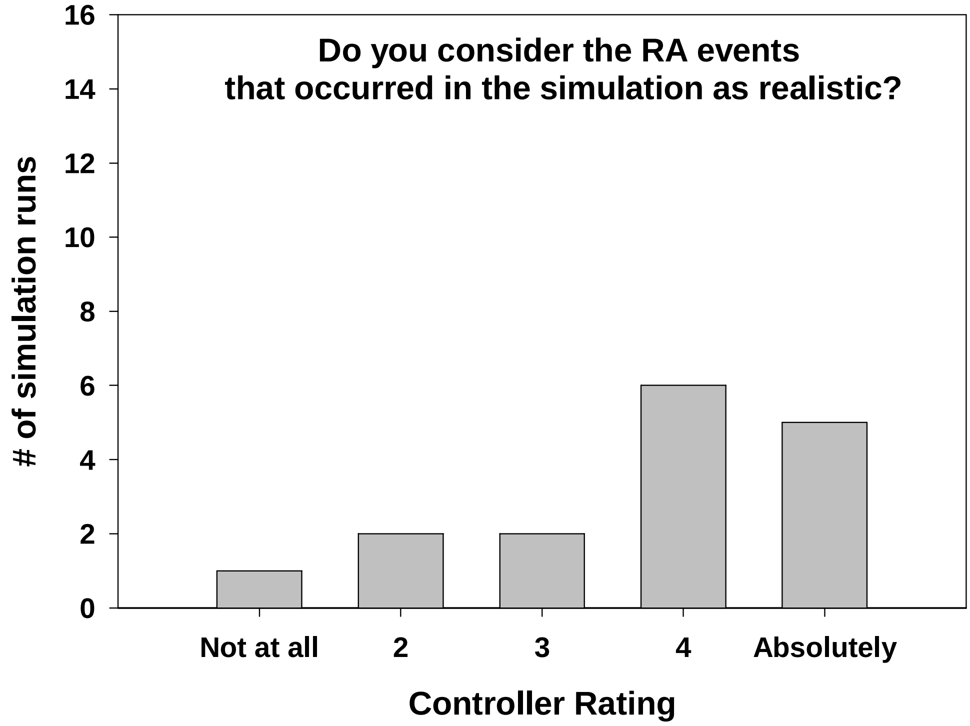

Figure 6-4: Realism of RA Event (RADE-2T)

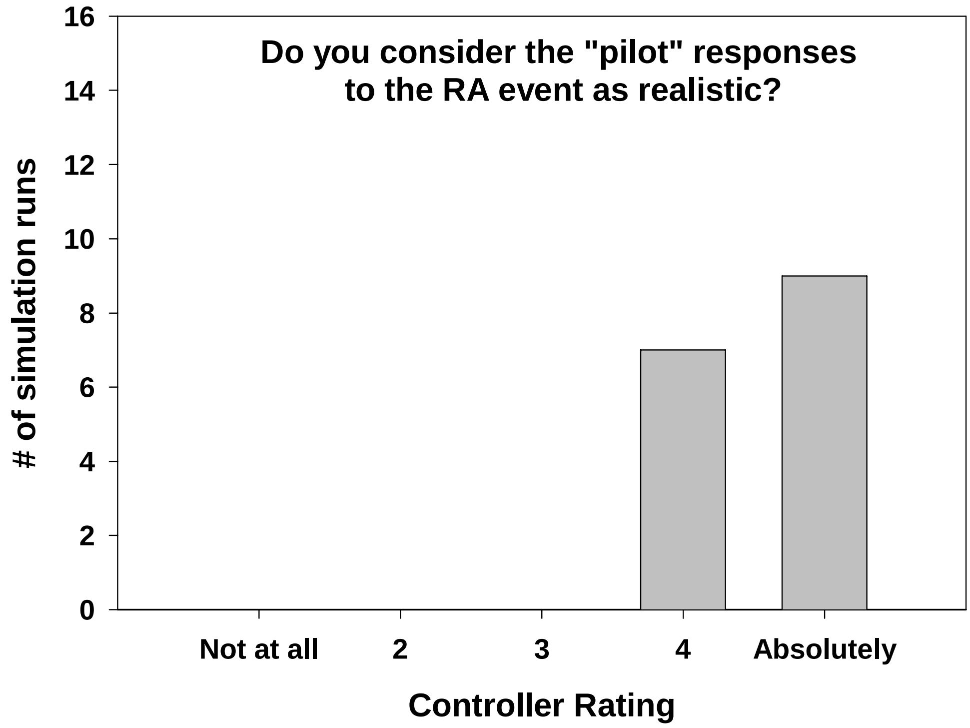

Figure 6-5: Realism of Pilot Responses (RADE-2T)

6.1.5.2 Post-experiment Questionnaire and De-briefing

After attending the whole 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 four participants filled in the post-experiment questionnaire individually, yielding a total of four 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 6-6. Ratings for the RA event and the pilot response are in line with the ratings collected after an individual exercise. However, ratings for the realism of the traffic situations collected at the end of the simulation are lower than the ones collected after a particular exercise (see Section 6.1.5.2). This is in line with the finding from RADE-2A [8], but more pronounced regarding the size of the difference. In RADE-2T, two out of the four participants did not consider the traffic situations as realistic (i.e. they gave a rating of “2”).

Item	Mean	Standard Deviation
Realism of traffic situations	2.8	1.0
Realism of RA event	3.8	1.3
Realism of pilot response to the RA	4.3	0.5

Table 6-4: Realism Ratings for different aspects of the simulation (RADE-2T)

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,
- pseudo-pilot performance (i.e. chosen climb and descend rates),
- scenarios more suitable for area control (with 90% of over-flyers).

A possible explanation for the difference between the ratings can be seen in the fact that during the post-exercise interviews, controllers were focussing to a larger extent on the RA event itself 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 negotiate with the adjacent units and military and had to cope with the peculiarities of the airspace.

To conclude, controller ratings of different aspects of the simulation realism were generally positive. One exception concerns the rating of the traffic scenarios obtained in the post-experimental questionnaires. Some of the factors mentioned as compromising the realism were inherent to the generation of an RA (such as high traffic load and pseudo-pilot performance). Nevertheless, there was one comment that raises some concerns on the adequacy of the traffic scenarios. Controllers had the impression that the traffic scenarios were not representative of approach control but included too many area control aspects.

6.2 Controller Task Performance

Indicators of controllers' primary task performance concern the handling of aircraft in the sector. Two types of controller behaviour were be 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.

6.2.1 Controller instructions to aircraft involved in the RA encounter

During the 16 simulation runs, one instruction was given to an aircraft involved in an RA encounter. This instruction was not contradictory to the RA, but was stricter than the RA (ATC stopped descent, while the RA called for a limitation in the descent rate). In this particular run, RA downlink information was displayed and the pilot response was delayed. Furthermore, the RA was caused by a controller error. The detailed description of the event can be found in Appendix K.

6.2.2 Provision of traffic information

Traffic information after an RA was given in 1 of the overall 16 runs. In this run, RA downlink information was present and the pilot report was delayed. However, due to the small number of observations, no statistical conclusions can be drawn.

Originally, the provision of traffic information was proposed as an indicator of the controller's ability to understand the traffic situation. However, the results of RADE-2A – as well as the low number of traffic information observed in RADE-2T – raise concerns about the validity of this interpretation.

6.2.3 Losses of Separation

A loss of separation after an RA occurred in an overall of N = 9 runs (56.3%). 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.

Losses of separation occurred only in runs in which the RA was caused by either a controller or a pilot error.

Table 6-5 breaks down the total number with regard to the two experimental conditions, which suggest that separation losses were more likely when RA downlink was present (N = 7 runs) than when it was absent (N = 2). Despite the fact that frequency tables with expected cell frequencies < 5 are not appropriate for statistical evaluation, a chi² test was computed, which confirmed a significant effect of RA downlink ($\text{chi}^2(df = 1) = 6.35$, $p = 0.01$).

		RA Downlink		
		Present	Absent	Total
Pilot report	Timely	3	2	6
	Delayed	4	0	3
	Total	7	2	9

Table 6-5: Separation losses after the RA as a function of conditions of RA downlink and pilot report timeliness (RADE-2T)

When interpreting these results, it needs to be taken into account that there is a bias against RA downlink in the data. In all eight runs with RA downlink, RAs were caused by either pilot or controller error. In contrast, only four RAs were caused by pilot or controller error without RA downlink. The other four RAs without RA downlink were caused by aircraft moving with high vertical speed before levelling-off. In the simulation, this type of RA never yielded a follow-up conflict.

6.3 Situation Awareness

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

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). Performance on the situation awareness memory probe was about the same for the two RA downlink conditions (RA downlink present vs. absent). The three-way ANOVA (RA Downlink x Pilot Report Timeliness x Controller Role) did not reveal any significant main or interaction effects.

		Measurement	RA Downlink		No RA Downlink	
			Mean	SD	Mean	SD
SA Memory Probe		Total Score	5.56	2.06	5.69	2.70
SASHA-Q		Global SA Rating	2.50	0.82	3.23	1.09
Workload	NASA-TLX	Unweighted Average	13.64	3.01	9.89	4.28
	Number of Untransferred Aircraft	RA - 3 min.	1.63	2.26	0.88	0.99
		RA	1.50	1.93	0.63	0.52
		COC	1.50	1.93	0.75	0.71
		COC + 2 min.	2.00	2.00	1.63	1.19

Table 6-6: RADE-2T descriptive statistics for situation awareness and workload measurements

Again, it has to be emphasized that RAs that are due to controller or pilot error are over-represented in the RA downlink runs. Those types of RAs have been found in RADE-2A to be associated with degraded SA memory probe performance. Thus, given no effect of RA downlink, the higher number of RAs caused by pilot/controller error in the RA downlink condition should have yielded a lower score on the SA memory probe. The effect of the RA type may have masked any positive effect of RA downlink on SA memory probe.

6.3.2 SASHA-Q Situation Awareness Self-Rating Scale

The global SA rating on the SASHA-Q questionnaire was higher without RA downlink than with RA downlink (see Table 6-6). The negative effect of RA downlink on the global SA score was confirmed by the results of an ANOVA ($F(1,3) = 54.00$, $p < .01$).

Half of the runs without RA downlink (but none with RA downlink) involved RAs caused by a high vertical rate before level-off. These types of RAs are usually associated with higher SA than RAs caused by pilot or controller error. For this reason, am additional analysis was carried out that excluded high-vertical rate RAs. If only runs with RAs caused by controller/pilot error are considered, the mean SA score without RA downlink decreases from 3.23 to 2.86. This compares with a mean SA score of 2.50 with RA downlink. Given the large standard deviation, it is very likely that this difference is due to random variation.

6.3.3 Situation Awareness On-line Probe

Situation Awareness on-line probes were successfully applied in 15 runs to the Executive Controller and in 16 runs to the Planning Controller. In three cases, the controller response was rated as suboptimal (that is, correct but delayed). All suboptimal responses were given in the “delayed pilot report” condition; two out of the three suboptimal responses were given in the “no RA downlink” condition. However, the number of observations is too small to allow for any statistical valid conclusions.

6.4 Workload

Controller workload was measured on the basis of subjective workload ratings (i.e., NASA-TLX) and the performance on a secondary task, that is, a task with lower priority.

6.4.1 Subjective Workload Ratings

The unweighted average NASA-TLX score (see Table 6-6) was subjected to a three-way ANOVA. This analysis revealed a significant main effect of RA downlink ($F(1,3) = 38.81$, $p < .01$) caused by higher workload ratings if controllers were provided with RA downlink information ($M = 13.65$, $SD = 3.01$) than if they were not provided with RA downlink information ($M = 9.89$, $SD = 4.28$). No further effects became significant (all $p > .30$). The negative effect of RA downlink is probably not due to the impact of RA information itself, but to the difference in RA types in the two RA downlink conditions.

6.4.2 Secondary Task Performance: Late transfers

The status of the number of untransferred aircraft was captured at four different time points in relation to the RA event: (1) three minutes before RA, (2) at RA, (3) at clear-of-conflict, and (4) two min after clear-of-conflict. Table 6-6 depicts the mean number of late transfers as a function of the four measurement times and the RA downlink condition. Numerically, the number of late transfers is higher if RA downlink is present than if it is not present. This effect, however, is not supported by the outcome of the respective statistical test ($F < 1$).

6.5 Controller Acceptance

Controller feedback on the 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. Answers could be given on a scale from 1 (not at all useful) to 5 (absolutely useful). The participants’ answers ranged from 3 to 5 with an average of 4.0 (median = 4, mode = 3, standard deviation = 1.2). Thus, controllers have either neutral or positive opinions on the utility of RA downlink.

Qualitative feedback was obtained by asking participants about the advantages and disadvantages as well as the potential and limitations of RA downlink. With respect to advantages, participants mentioned that RA downlink is useful in drawing the controllers’ attention to a conflict, so that they are better able to anticipate pilot reports from the conflicting aircraft. Furthermore, RA downlink can help the controller not to interfere with the RA aircraft. One controller group stated that RA downlink can act as a trigger for providing traffic information, however, it was also pointed out that traffic information should only be given if this actually helps the pilot. One participant group also experienced the RA display as a sort of re-assurance that the conflict situation is taken care of.

As regards the disadvantages of RA downlink, one controller group could not think of any disadvantages at all. The other group mentioned responsibility issues: it needs to be clear when the controller is not responsible for separation any more.

Both controller groups could not think of any situations in which RA downlink would not work well. Thus, they thought that RA downlink would work well under all circumstances. However, later in the de-briefing, participants mentioned a couple of factors that could limit the benefits of RA downlink. One factor mentioned were technical problems: it needs to be ensured that RA downlink works according to specification. Another factor was latency: one participant group controllers had the impression that in the simulation, the RA information was systematically presented too late so that “there was no time to do anything”[7].

To conclude, participants in the RADE-2T experiment see benefits in the implementation of RA downlink. In their opinion, there are no general issues that should prohibit the implementation of RA downlink.

6.5.2 The proposed Operational Concept for RA Downlink

Feedback on the operational concept for RA downlink 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.

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. On a scale from 1 (not at all) to 5 (absolutely), answers ranged between 4 and 5 with an average of 4.3 (median = 4, mode = 4, standard deviation = 0.5). 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. Answers ranged between 3 and 5 with an average of 4.0 (median = 4, mode = 3, standard deviation = 1.2). This indicates that the majority of controllers have neither a positive nor a negative view on this issue (as indicated by a mode of 3), on average though, controllers tend to favour this concept.

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. Participants' answers ranged between 3 and 5 with an average of 4.3 (median = 4.5, mode = 5, standard deviation = 1.0). Thus, controllers seem to support this concept. However, in the de-briefing that followed the questionnaire, one participant group stated that they would like to see strengthening RAs displayed as well.

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[7] As the controller should not issue any clearances or instructions to an RA aircraft, this comment has to be taken with some caution. Triggering controller action to ensure separation is a function provided by STCA.

Hence, the RADE-2T participants generally considered the proposed RA downlink concept as adequate, although they might want to see strengthening RAs as well.

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 3 and 5 with an average of 4.3 (median = 4.5, mode = 5, standard deviation = 1.0). This means that the majority of participants assessed the RA downlink HMI as very positive.

Nevertheless, in the de-briefing some points for improvements were mentioned. One controller group pointed out that RA displays should be dissimilar from the presentation of an STCA. This was well achieved for aircraft with RAs. However, the red frame around an ACAS-equipped intruder without an RA was perceived as too similar to an STCA and thus as confusing.

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 3 and 5 with an average of 4.0 (median = 4, mode = N/A, standard deviation = 1.0). The only negative remark made by one controller group was that they did not like the presentation of reversal RAs. Nevertheless, participants also stated that they were never confused about the actual movement of an aircraft after having been presented with the RA information on the screen.

In the post-experimental questionnaire, participants were also asked whether they had “ever been confused about the RA information presented in the simulations”. One out of the four participants stated that he had been confused about the RA information at least once during the simulation. This participant did not describe his confusion further.

The level of detail shown in the RA downlink HMI was considered as sufficient by the participants. When asked whether they would like to have more RA information presented on the screen (such as clear-of-conflict indications), none of the participants indicated the wish for more information. One group even though that the information might be a little bit too complex already.

In the RADE-2 experiments, the RA information is restricted to visual alerts. All of the four participants find these sufficient; none would recommend the use of an audible alert.

To summarise, the specific HMI proposed for RA downlink information was generally appreciated by the participants of the RADE-2T simulation. Minor issues concerned the presentation of an intruder without RA and the presentation of reversal RAs.

7. SUMMARY AND DISCUSSION

The results obtained in RADE-2T do not seem to point to a benefit of RA downlink and, at best, are neutral with respect to the impact of RA information.

Neither in the non RA downlink nor in the RA downlink condition, there were any contradictory clearances issued to an aircraft involved in an RA. In the RA downlink condition, though, there was one instruction to an RA aircraft. This instruction had the same effect, but was even more rigorous than the original RA. Follow-up conflicts (i.e. losses of separation between an RA aircraft and a third-party aircraft) occurred more often when RA downlink was provided than when it was not provided. Situational awareness as measured on the basis of the memory probe was the same regardless of whether RA downlink was present or not. For the subjective indicators of situation awareness as well as for workload, there was even a benefit for the non RA downlink condition.

The findings concerning controller performance, situation awareness and workload seem to be at least partially inconsistent with the controllers' feedback on RA downlink. Participants saw benefits but no general disadvantages of the concept of RA downlink, and – with some minor exceptions – considered the proposed operational concept and HMI as adequate.

The negative results on the operational impact of RA downlink are very likely due to an imbalance of RA causes between the two RA downlink conditions. RAs in runs with RA downlink were exclusively caused by either controller or pilot error. RAs in runs without RA downlink, in contrast, were in half of the cases due to high-vertical rate before level-off. The latter type of RAs is often considered as "nuisance" by controllers, as they occur in situations in which the controller is fully aware and in control of the traffic situation. In line with this, situation awareness has been found to be higher and workload has been found to be lower for RAs that are caused by a high-vertical rate before level-off than with pilot/controller error RAs. Thus, there is a substantial bias against the RA downlink condition in the data.

Additionally, the small sample size of N = 4 renders the generalisation of the results rather problematic. There is a considerable amount of noise (i.e. random variations) in the data, as shown by large standard deviations. With small sample sizes, the influence of noise is stronger and, if numerical values are compared, can give the wrong impression of a systematic difference.

Because of the restrictions mentioned above, the results obtained for RADE-2T cannot be taken as evidence for or against operational benefits of RA downlink in a terminal control scenario. However, the study did reveal that an experimental test of RA downlink in a Terminal Control environment is even more demanding than in an Area Control environment. Half of the participants of RADE-2T had concerns regarding the realism of the traffic scenarios used in the simulation, which is a substantially higher number than in the RADE-2A experiment.

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9. LIST OF FIGURES AND TABLES

9.1 List of Figures

9.2 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 ☐ No RA-Downlink	Scenario no.:	☐ Executive Controller ☐ 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 ❑ No RA-Downlink	Scenario no.:	❑ Executive Controller ❑ 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?

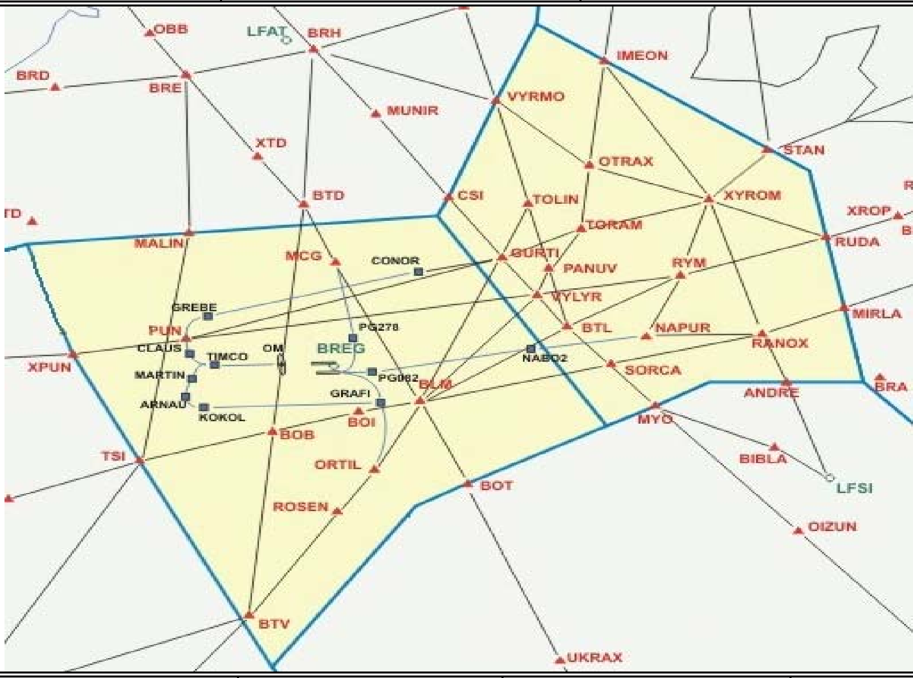
Poor ☐ Quite poor ☐ Okay ☐ Quite good ☐ Very good ☐

Comments:

Appendix D Human Factors Expert Observer Notebook

HF Observer Notebook RADE-2T

Participant-ID:	Observer:	Date:
❑ RA-Downlink ❑ No RA-Downlink	Pilot report quality: ❑ Timely ❑ Delayed	Scenario no.: Run no.: Start Time: End Time: Weather Sample:



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)   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

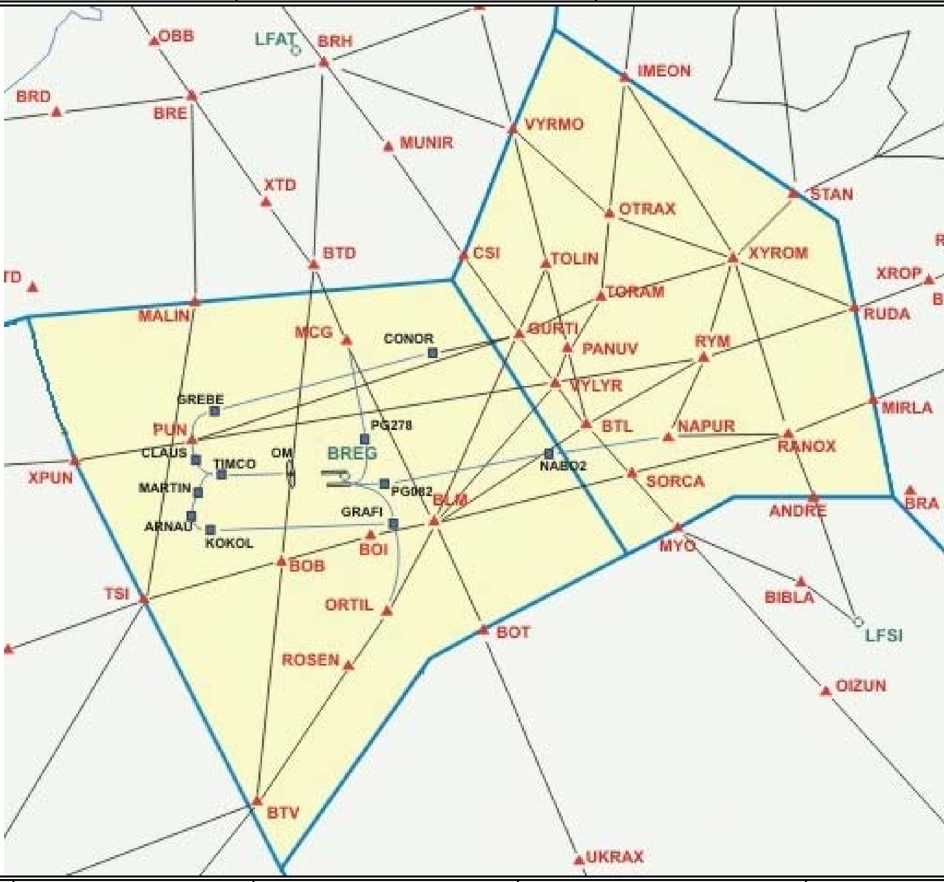
The second set of information should be marked in the record table below the map.

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-2T

Participant-ID:	SME:	Date:
❑ RA-Downlink ❑ No RA-Downlink	Pilot report quality: ❑ Timely ❑ Delayed	Scenario no.: Run no.: Start Time: End Time: Weather Sample:



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 ☐
Comments:

After-RA-event question asked – Planning Controller:

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

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 ☐ Replay with RA-Downlink ☐ Replay without RA-Downlink	Scenario no.: 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 RA Downlink Operational Concept Used for RADE-2

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 J).

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 Climb, crossing climb Increase climb… Maintain vertical speed, maintain * Maintain vertical speed, crossing maintain *	[callsign] TCAS CLIMB	TCAS ↑
Descend, descend Descend, crossing descend Increase descend… Maintain vertical speed, maintain * 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-1: RA Downlink Symbols

Appendix J ICAO Regulations on the Subject of TCAS and RAs

As of 1 September 2006.

Appendix J.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 J.2 ICAO Doc 4444

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) **Controller:** (acknowledgement)
t	… after ACAS “Clear of Conflict” is annunciated	**Aircrew:** RETURNING TO (assigned clearance) **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) **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 **Controller:** (acknowledgement) (or alternative instructions)
z	… when unable to comply with a clearance because of an ACAS resolution advisory	**Aircrew:** UNABLE, TCAS RESOLUTION ADVISORY; **Controller:** (acknowledgement)

Table A-2: 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 J.3 ICAO Doc 7030

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 J.4 ICAO Doc 8168

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 K Description of Events with Contradicting Clearances

Appendix K.1 Group 2/Traffic Sample M6 – Conflict between BAW1232 and RJA4719.

The following RA occurred during Traffic Sample M6 in Group 2 (RA Downlink present, delayed pilot report). The RA was caused by controller error (incorrect descent clearance to RJA4719).

BAW1232 was flying level eastbound at FL170, while RJA4719, on the northwest track, was cleared to descend from FL210 to FL100. The controller did not update the cleared level field in the label (so it was still indicating 210). The exit level field was correctly updated.

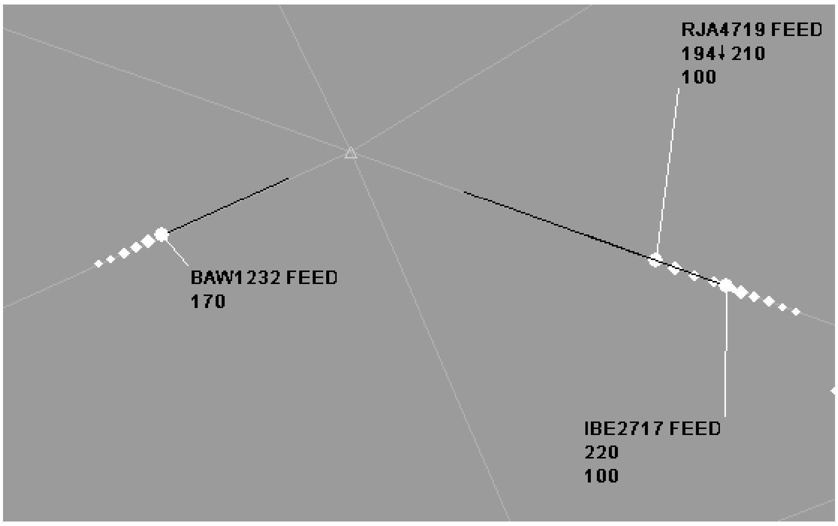


Figure K-1: Radar picture approximately 90 seconds prior to the conflict.

An STCA alert was generated 25 seconds prior to the RA. The predicted lateral separation was below 0.5 NM.

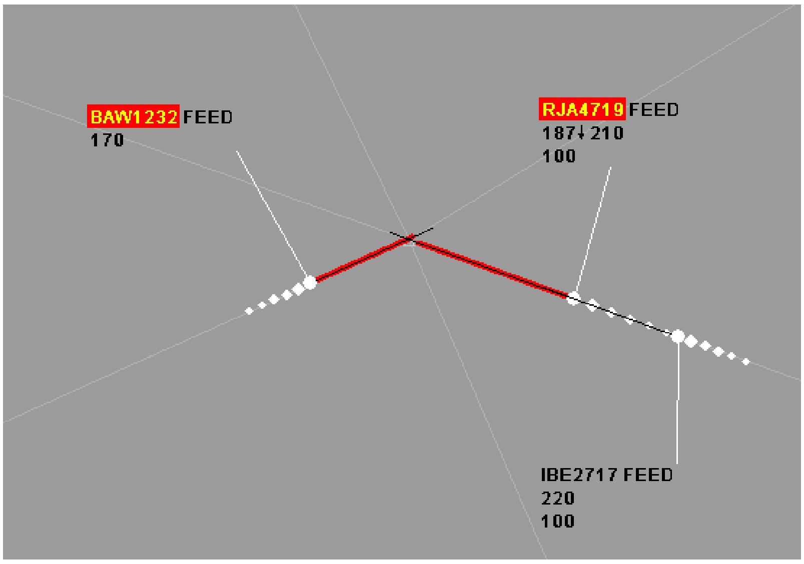


Figure K-2: Radar picture at the time when an STCA alert was displayed.

While the RJA4719 was passing FL182 and 27 seconds after the STCA had been displayed, the controller instructed them to stop descend at FL180 (due to BAW1232 below). This instruction coincided with the RA generation on board of the RJA4719 ("limit descend 500 feet/min.")[8]. No RA was issued for the intruder (BAW1232).

When instructed to stop the descend, the pilot responded: "Do you want us to stop descend, we have a TCAS RA?". That transmission coincided with the display of TCAS RA on the controller screen (Figure K-3). The controller repeated his instruction for the pilot to level off at FL180.

At this time the RJA4719 had descended some 200 feet below FL180 and the pilot climbed back to FL180.

The post-run analyses were conducted using the InCAS tool (see Section 5.1.1 and Figure K-4), R/T and radar picture recordings as well as an interview with the controller. It has been observed that:

- the controller issued the clearance to the RJA4719 after he had been informed about the RA by both pilot report and RA downlink
- controller instruction was not in the opposite sense to the RA
- RA downlink was displayed on the CWP with a delay of 7 seconds.

During the interview the controller stated that he had been distracted by another developing conflict.

[8] It should be noted that there is no specific ICAO phraseology prescribed to report this type of RA.

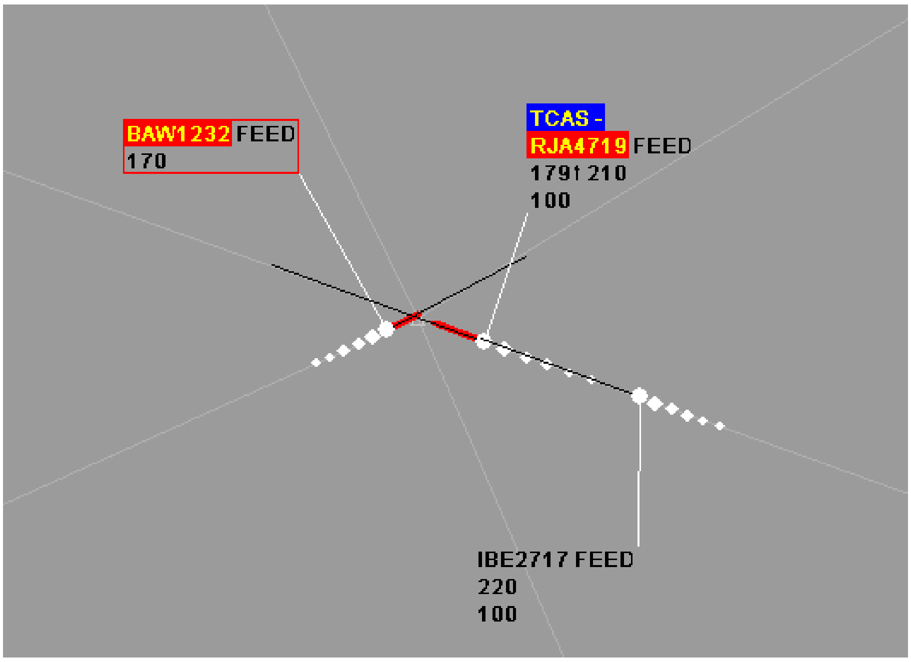


Figure K-3: Radar picture at the time when the RA was displayed.

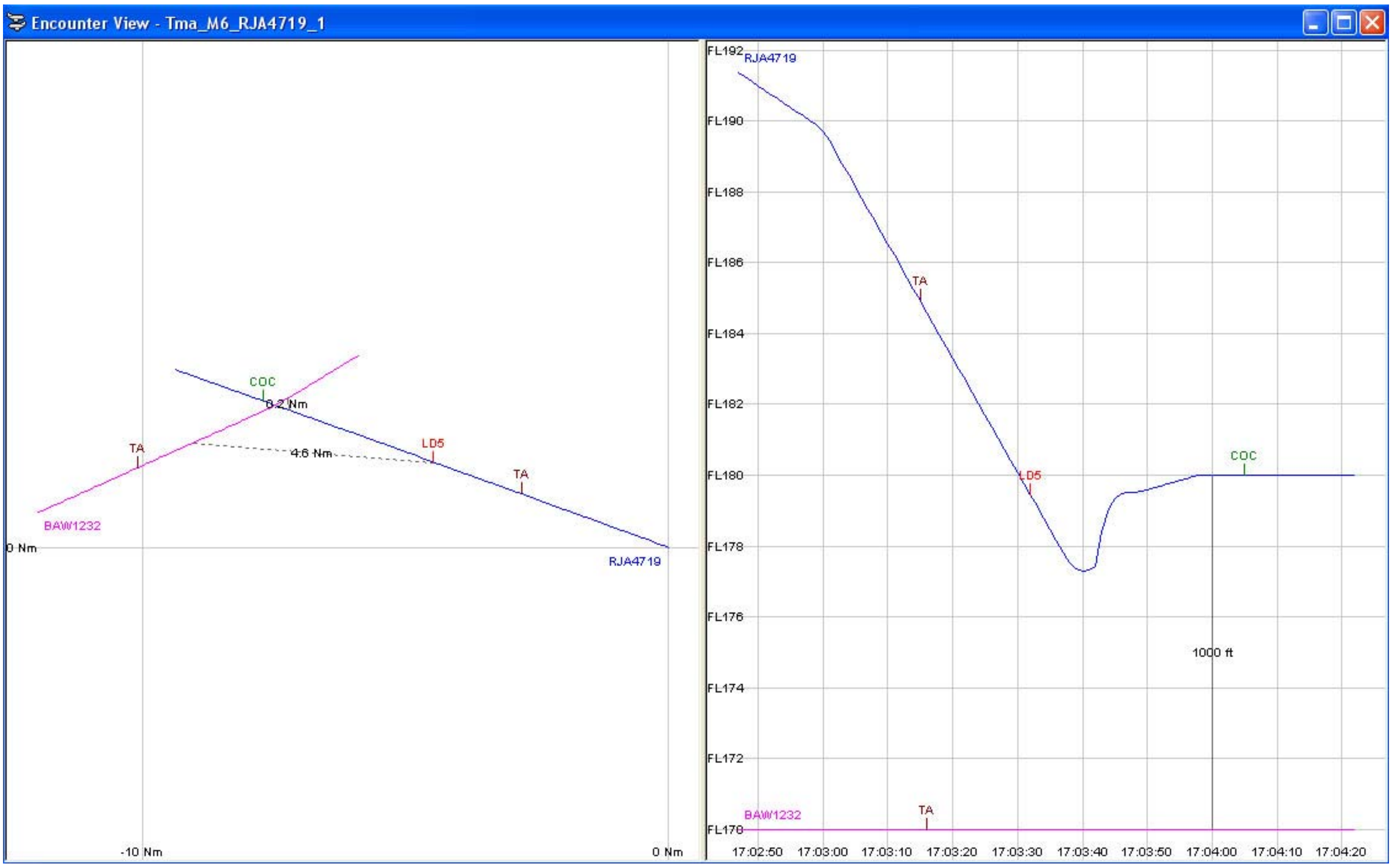


Figure K-4: InCAS Analysis of Run with Procedure Violation Conflict between BAW1232 and RJA4719