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ACAS RA Downlink

Cognitive Task Analysis

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Abstract

This report documents the Cognitive Task Analysis for the proposed ACAS RA Downlink. It is produced in conjunction with the Human Reliability Assessment and the Safety Case

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ABBREVIATIONS

ACAS	Airborne Collision Avoidance System
ACTA	Applied Cognitive Task Analysis
CIT	Critical Incident Technique
CoC	Clear of Conflict
CPA	Closest Point of Approach
CTA	Cognitive Task Analysis
CWP	Controller Working Position
FARADS	Feasibility of an ACAS RA Downlink Study
FHA	Functional Hazard Analysis
HMI	Human Machine Interface
HRA	Human Reliability Assessment
HTA	Hierarchical Task Analysis
ICAO	International Civil Aviation Organisation
OC1	Operational Concept 1 (i.e. current day)
OC7	Operational Concept 7 (with RAD)
PVD	Plan View Display
RA	Resolution Advisory
RAD	Resolution Advisory Downlink
RT	Radio Telephony
STCA	Short Term Conflict Alert
TA	Traffic Advisory
TCAS	Traffic Collision and Avoidance System
VS	Vertical Speed

EXECUTIVE SUMMARY

The Feasibility of an ACAS RA Downlink Study (FARADS) is currently investigating the potential downlink of Resolution Advisory (RA) information to ATC. This would mean that all RAs generated for the flight crew would, following a transmission delay, be apparent to ATC. As part of FARADS, a Cognitive Task Analysis (CTA) was conducted of five RA scenarios (each with and without RA Downlink (RAD)). The aim was to identify the cognitive elements underlying performance in the RA scenarios, and to identify potential error mechanisms. A functional task description was developed in a previous Functional Hazard Analysis (FHA), and this served as the basis for the CTA. Data collection for the CTA was conducted during one half-day session (and follow-up teleconference) between one researcher and a licensed air traffic controller. The controller was sent a packet of introductory material ahead of time on the RAD operational concept. Data collection began with a follow-up briefing on this material.

The first step in the CTA was a card sorting exercise, in which potential tasks and sub-tasks were laid out in logical order. Second, a standard Hierarchical Task Analysis (HTA) was conducted to decompose the tasks as much as possible. Third, each of the five scenarios[1] (x 2 variants each– each with and without RAD) were stepped through in logical order. During this exercise, the controller was encouraged to think aloud about what information was required, from where the information came, the mental and physical steps involved, potential sources of error, etc. A series of prompt questions, and a list of potential cognitive elements, was used to guide discussion. An audio recording was made of the CTA session, and was later transcribed for analysis.

On the basis of notes, sketches, and transcribed discussion, a full task analysis was conducted for the two nominal RA scenarios (i.e. with and without RAD). Except where decomposition revealed relevant differences between the RAD and non-RAD cases, task description was kept as high as possible for the sake of clarity. The impact of both non-nominal events, and other "contextual factors," was then examined with respect to their differential impact on the RAD and non-RAD scenarios.

One chief conclusion from the CTA was that RAD can benefit both the speed and accuracy of locating aircraft onscreen, by transforming the current-day task of locating aircraft (e.g. remembering call sign, scanning screen, identifying aircraft calling) to a largely perceptual one. This can benefit performance throughout the RA encounter. However a few caveats are in order:

- RAD might prime ATC to hear what they expect to hear, and as a result mishear the subsequent pilot report;
- Despite the fact that a pilot report is necessary for ATC to cede authority, it seems that ATC will provisionally transfer authority on the basis of an RAD, and seek to gather confirmatory evidence of an RA;
- In the absence of such evidence, an ambiguous control situation can emerge either at the beginning or end of an RA encounter;
- The timing of RAD can prompt ATC to query at the same time as pilot reports are to be expected, and can increase the chance of a "stepped-on´ transmission from encounter aircraft;
- There will be false/nuisance RAs. It is difficult to analytically determine the influence of trust in ATC's willingness to (perhaps mistakenly) believe RAD in the absence of other evidence (e.g. manoeuvre, report); and
- The potential costs of RAD in terms of attention-tunnelling, and the risk of neglecting other traffic, must be clarified.

[1] The fifth scenario was analysed after the initial data collection

This CTA should be seen as part of a larger analysis effort. The next steps in this effort are to elaborate (via Human Reliability Assessment or *HRA*) specific error mechanisms, to quantify the probabilities of each, and to assess the criticality of identified error paths. The output of the CTA thus fed directly into the HRA and, given the tight coupling between the two, they should ideally be read together.

1. BACKGROUND

Airborne Collision Avoidance System (ACAS) is a 'last-resort' method of preventing mid-air collisions or near collisions between aircraft[2]. ACAS produces vertical collision avoidance advice in Resolution Advisory (RA) messages and displays these to the flight crew roughly 15 to 35 seconds before Closest Point of Approach (CPA). The Feasibility of an ACAS RA Downlink Study (FARADS) is currently investigating the potential utility of downlinking such RA information, and displaying it (with a slight transmission delay) to ATC.

1.1 The Current Day RA Environment

When an RA is activated the flight crew should respond by adhering to the RA to avoid potential collision. The pilot is required to inform ATC of any deviation from the cleared flight path in order that the controller is aware of the RA and the transfer of responsibility, though this information may be delayed, incoherent or not transmitted due to the increased workload and pressure of avoiding the possible collision. If not informed of the deviation from flight path ATC might believe they remain responsible for separation and continue to issue instructions.

The end of the RA is announced to the aircrew by an aural ‘Clear of Conflict’ message. Once a corrective RA has ended, responsibility for separation returns to ATC only when the controller has acknowledged a report from the flight crew that the aircraft is resuming the current clearance or the controller acknowledges the report but issues an alternative clearance which is acknowledged by the flight crew.

Currently ATC relies implicitly on the flight crew to inform them of any deviation from clearance due to an RA and when the aircraft is clear of conflict. If this information is delayed or not received, the controller would be unaware and may therefore attempt to resolve the conflict by issuing instructions to the incident aircraft, with the risk that the pilot may choose to follow the controller rather than TCAS and hence increase the risk of collision.

1.2 The RA Downlink (RAD) Concept

Whenever an RA is generated in the cockpit, the aircraft’s transponder provides detailed information about the nature of the RA, which could be downlinked to ground ATC for display on Controller Working Positions (CWPs). In the proposed operational concept, the following information will be displayed on the controller’s HMI:

- An indication of all initial RAs (preventative and corrective[3]) including the identity of the aircraft generating the RA and the intruder aircraft;
- All follow-up weakening RAs will not be indicated;
- All follow-up strengthening RAs will be indicated;

[2] Traffic Collision Avoidance System (TCAS) is a brand name for a commercially-available ACAS system, and the terms ACAS and TCAS are used interchangeably in this report.

[3] The RA concept distinguishes between **Corrective** RAs (which require a deviation from cleared flight path) and the less-common **Preventive** RAs (which do not); CTA considered the impact of Preventive RAs, as an additional contextual factor.

- 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;
- There is no positive indication of 'Clear of Conflict' (rather the RAD is extinguished).

As part of FARADS, a Cognitive Task Analysis (CTA) was conducted to help compare the potential for human error under current RA operations and potential future RAD operations.

1.3 Cognitive Task Analysis (CTA)

Task analysis refers to a family of techniques used to describe and analyse operator performance within a human-machine system [1]. In all, it seems that at least three dozen major task analysis techniques have been used over the years [2;3]. All task analysis techniques aim to decompose complex system tasks, to elaborate a description of the system, and to identify information and action flows within the system [4]. Task analysis has many potential applications, including system design, system evaluation, training design and evaluation, interface design, job design, personnel selection, and system reliability analysis. It is this last application that is most relevant to the FARADS project.

Cognitive Task Analysis (CTA) is a relatively recent outgrowth of general task analysis methods. *CTA* refers to a group of techniques used to capture and represent the cognitive elements underlying performance of a given task. CTA recognises that, increasingly, automation in complex systems is changing the nature of work, and shifting emphasis from physical tasks (such as pushing buttons or pulling levers) to more cognitive tasks (e.g. monitoring, interpreting, analysing, planning, diagnosing, deciding, etc). As a result of this shift, much of current-day "work," from air traffic control rooms, to nuclear power plants, is not directly observable. CTA was therefore developed to extend task analysis methods to the mental skills and processes (e.g. critical decisions) underlying observable behaviour. CTA has been applied in various domains, from flight deck operations [5], to ATC [6], to military command and control [7], nuclear power plant operation [8] and process control [9]. Although there is some disagreement in the field, CTA is often used to decompose **both** the cognitive and behavioural aspects of task performance. CTA is particularly useful when the task involves elements of the following [10;11]:

- Complexity;
- Uncertainty;
- Decision making;
- Dynamic interactions; and
- Teamwork

CTA typically involves the following three steps: (1) Describing the task using traditional task analysis; (2) Identifying the cognitive elements, or critical decision points; and (3) Describing the decisions with respect to potential error mechanisms. A fairly recent state-of-the-art review [2] identified six general types of outputs from task analysis, as summarised in the following table.

Technique	Output
Timelines	Task sequence and times
Flow process charts	Task types and sequence
Operational sequence diagrams	Task sequence and times
Critical task analysis	Task sequence, times, tolerances
Decision tables	Key decision and criteria

Table 1. Task analysis general outputs

2. METHOD

The initial plan for the project was that Functional Hazard Analysis (FHA) would drive the CTA (by providing the basis for a functional task description). CTA would in turn specify potential human errors, and thereby drive a Human Reliability Assessment (HRA) that sought to identify the probabilities of specific errors, by identifying such factors as controller reaction times, types of detection failures, interpretation errors, and potential controller workload issues. As shown in figure 1, there was a good deal of overlap between the CTA and HRA processes, especially as concerns identifying error mechanisms and error scenarios.

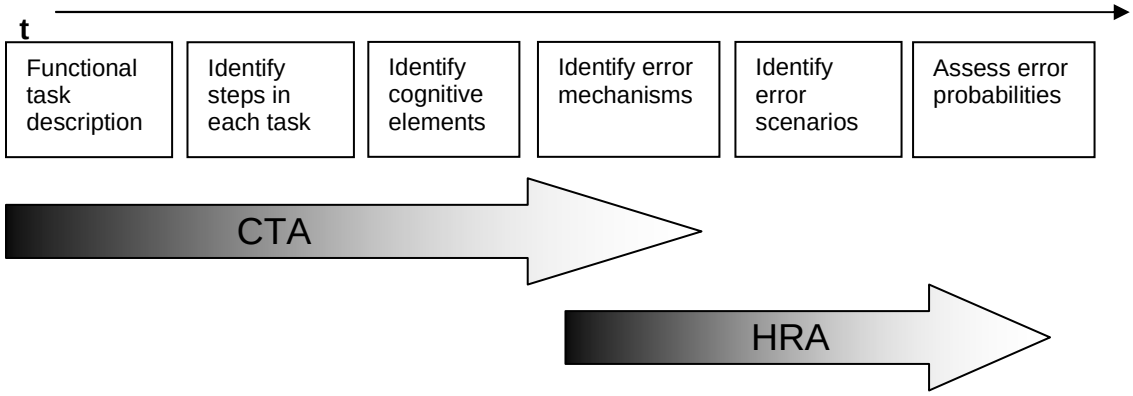


Figure 1. An overview of the CTA and HRA analyses.

The method for the CTA was a hybrid, combining elements of the Applied Cognitive Task Analysis (ACTA) technique [12;13], with modifications for the system development phase. That is, ACTA typically relies on the Critical Incident Technique [14], which uses open-ended questions to elicit information on particularly challenging past incidents. CIT depends on past experience, and seems less applicable to new systems or operational concepts, however.

As laid out in the following sections, the general approach for the CTA was to define a functional task description, identify the steps involved in each task, and to systematically evaluate each task with respect to the associated cognitive elements, and potential error mechanisms.

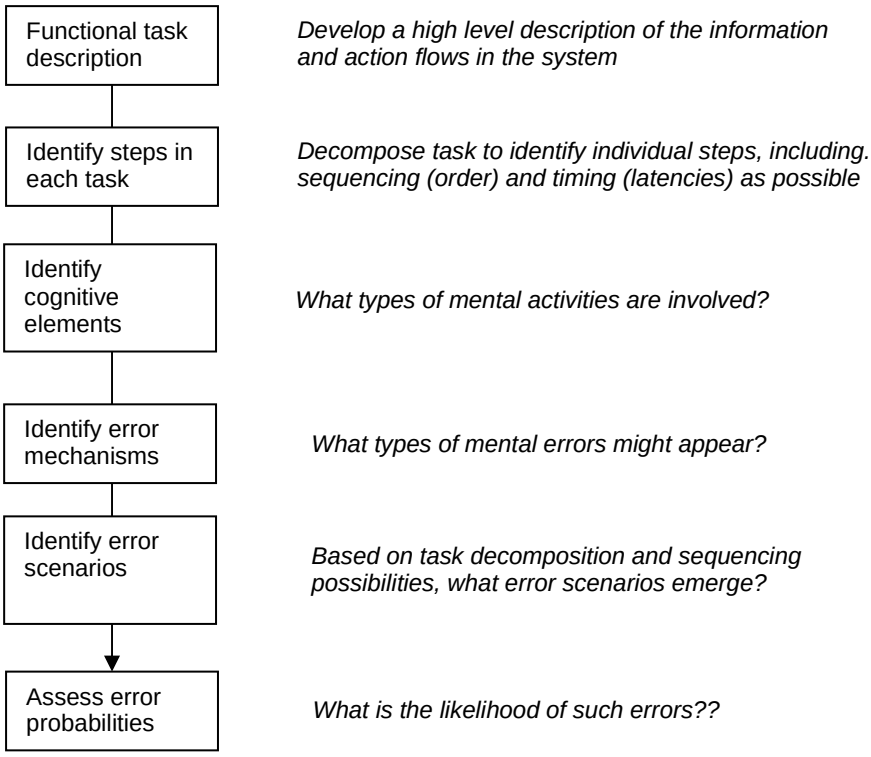


Figure 2. Specific questions to address during the combined CTA and HRA analysis.

Notice how this approach differs from typical functional hazard assessment. Using the CTA approach, hazard scenarios are identified not from a functional description of the system, but built up from an identification of the underlying cognitive mechanisms and errors than can emerge. This is a potentially powerful technique that can uncover error paths not otherwise easily identifiable. The quality of CTA results, however, is very dependent on the quality of elicited expertise, which experts often have difficulty verbalising, either because their knowledge is tacit or automatic, or because they simplify their knowledge for non-experts [15]. Before we could begin this process, however, we first needed a working description of the RA task itself.

2.1. The RA scenarios

Based on the FHA output, five interesting RA scenarios were selected. The five scenarios were all based on typical two-aircraft en-route encounters, in which an RA is presented to both air and ground, and disregarded such contextual factors as mixed equipage (i.e. where an intruder is not TCAS equipped), multiple aircraft encounters, etc.

Each of five scenarios was presented as two different variants, one for the current day RA operations (*Operational Concept 1*, or OC1) and one for the RAD operations (OC7) as defined in [16]. Together, this yielded the following ten RA scenario variants:

Scenario	**Variant**	
	OC1 No downlink	*OC7 RA downlink*
1: Nominal RA: The pilot reports correctly and in a timely fashion, and follows the RA correctly	**1**	**1R**

Scenario	Variant	
	OC1 No downlink	*OC7 RA downlink*
2: No report: No pilot report, but he correctly follows RA	**2**	**2R**
3: Incorrect report: Incorrect pilot report, but he correctly follows RA	**3**	**3R**
4: No report, no manoeuvre	**4**	**4R**
5. Correct report, no manoeuvre: Pilot reports correctly, but does not manoeuvre	**5**	**5R**

Table 2: The ten scenario variants

A full CTA was made for scenarios 1 and 1R (i.e. the nominal OC1 and OC7 scenarios), and the impact of non-nominal and certain other contextual factors was assessed in terms of their impact on the nominal scenarios.

For purposes of the full CTA, the following assumptions were made:

- The RA encounter (with or without RAD) was defined as the period from RA onset to Clear of Clearance;
- Technical performance of the RAD and TCAS systems (e.g. potential for system false/nuisance alerts or misses) was defined as nominal;
- Aircrew functions were unchanged from today (Manoeuvre aircraft in accordance with RA; report RA; return to cleared flight level once clear of conflict; and report clear of conflict);
- RAs were corrective (preventive RAs were also considered as "other contextual factors, as described later);
- Both aircraft were assumed to be TCAS equipped and operating in en-route airspace;
- Weakening, strengthening and reversal RAs were disregarded;
- One controller was assumed to be communicating with both aircraft; and
- The controller HMI was as defined for the RADE-2 operational concept.

2.2. Data collection session

The CTA itself consisted of a half-day session (and follow-up teleconference) between one researcher and one licensed air traffic controller. Familiarisation materials were provided in advance of the meeting, and the CTA session began with a briefing on the RA Downlink operational concept including phraseology, HMI symbology, etc.

Audio recordings were made of the session, and were later transcribed. On the basis of the transcription and resulting task analysis, a teleconference was held at a later date to explore some finer points.

2.2.1. Functional task description

A rough task description was first derived directly from the Operational Concepts, as defined in [16], and as built up through the FHA workshop. During the CTA session, this diagram was

presented and discussed. On the basis of a card-sorting exercise (in which the main tasks were laid out in sequence as appropriate), a final version was agreed. This functional task description (see figure 3) was intentionally high level, and was intended as a starting point to the CTA discussion. This was really just a broad overview of the nominal RA task, irrespective of whether RAD was present or not. What was next required was a decomposition of the task into constituent elements, to describe the subtasks, the sequence of activities, role responsibility, information requirements, information flows (inputs, outputs), and decision points.

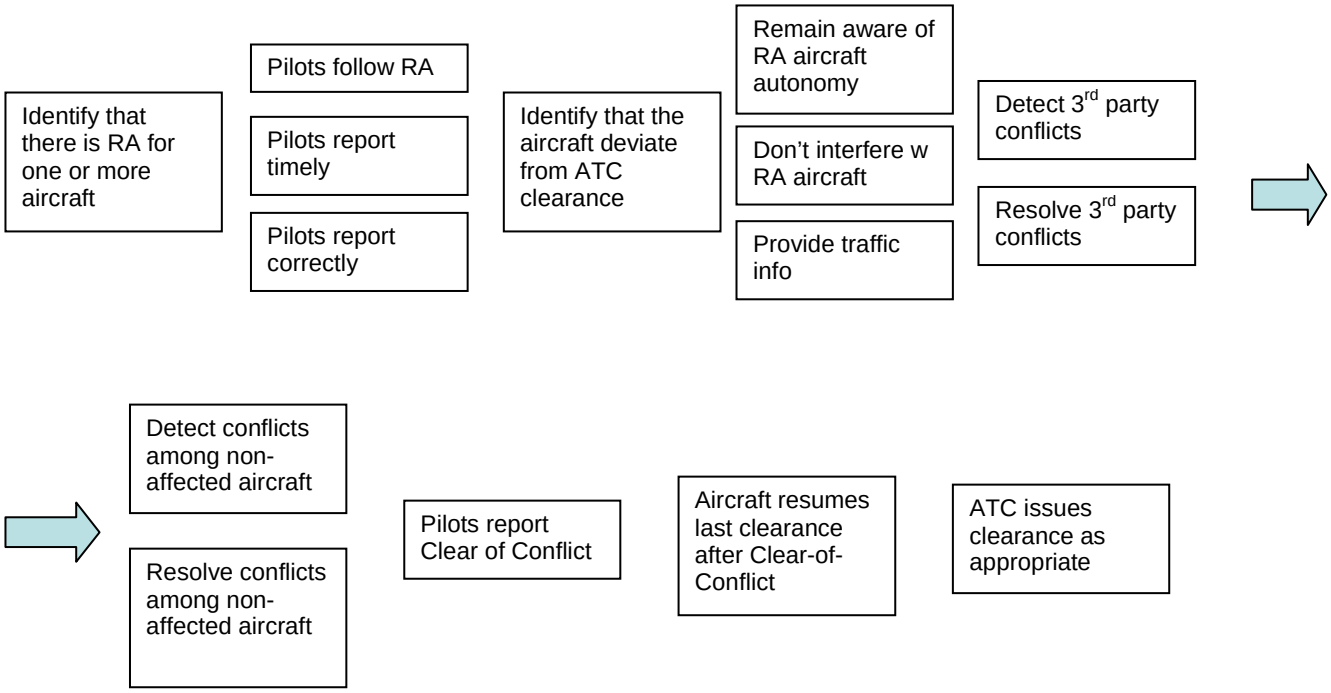


Figure 3. Final functional task description for the CTA.

2.2.3 The CTA

On the basis of the functional task description, tasks were then decomposed by typical hierarchical task analysis (HTA), in which complex tasks are systematically broken down into constituent elements (sub tasks). The expert was prompted to break each given task down into 3-6 subtasks, as recommended in [13].

Mental walkthrough

On the basis of the task diagram, and identified elements, the expert was asked to step through the scenarios one-by-one in logical order, to think aloud about the precise steps required, the kinds of information needed, and decisions needed at each point [17]. During this exercise, the researcher relied on a checklist of prompt questions focusing on, for instance:

- Who was responsible;
- What, if any, decision was required at the moment;
- What information was required;

- Whether long term knowledge was required;
- What information was exchanged;
- Sequence dependencies in the information flow (e.g. “if he doesn’t give me that information now, I need this information then…”)
- Situation assessments (“here’s what is happening…”)
- Plans for possible contingencies (“now if he doesn’t do this, I’ll do that…”); and
- Potential errors at each step.

In addition to the nominal scenarios (i.e. scenarios 1 and 1R), the expert also walked through performance of the other scenarios.

Sketching out the CTA

On the basis of notes, sketches, and transcribed discussion, a formal CTA diagram was later made of the two nominal scenarios, one with (scenario 1R) and one without (scenario 1) RAD. Essentially, these represent the nominal OC1 and OC7 scenarios.

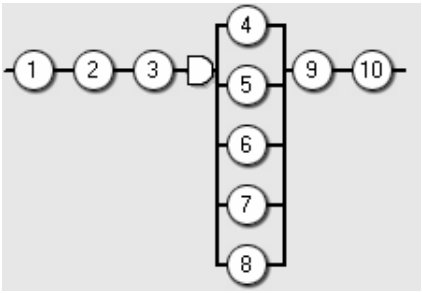
The TaskArchitect® software package was used to capture the task analysis, including the subtask structure and conditional logic (in TaskArchitect®’s so-called “plans” which capture whether subtasks are completed sequentially, in parallel, conditionally, etc)[18]. Task decomposition had quickly led to the conclusion that, across the sequence of activities, the following three general phases are common to any RA encounter:

Phase 1: Pre-autonomous
Phase 2: Autonomous aircraft
Phase 3: Post autonomous

From this perspective, the task of the controller involves determining exactly when the encounter has begun, ceding authority, carrying out limited specific duties during the encounter, determining when the encounter has ended, and resuming authority.

3. RESULTS

The CTA focused on the period between when an RA is activated, until when ATC ultimately resumes authority. As shown figure 4, a total of ten high level tasks fell out of the CTA. In the process of normal scanning and control, the steps of verifying an RA encounter, verifying a deviation and ceding authority to the aircraft are carried out sequentially. Once authority is transferred to the aircraft, the controller then proceeds to carry out the remaining five tasks in parallel – monitoring for third party conflicts, providing traffic advisories, etc, all the while watching for signs (either via report or a return to clearance) that the RA encounter is complete.



1 Verify RA encounter
2 Verify deviation
3 Cede authority to encounter aircraft
4 Monitor RA encounter for compliance
5 Identify potential third party conflicts
6 Prevent third party conflicts
7 Provide traffic info to encounter aircraft
8 Provide traffic info to third party aircraft
9 Determine end of RA encounter
10 Resume ATC authority

Figure 4. CTA-identified highest level tasks, for the nominal RA scenarios

The following task breakdowns focus on those tasks that are most subject to change as a result of RAD, namely those near the beginning and the end of the RA encounter. For the sake of completeness, task breakouts are provided for all ten tasks. The following sections will now focus separately on each of these tasks for the nominal OC1 and OC7 scenarios, and:

- compare differences between the non-RAD (OC1) and RAD (OC7) scenarios;
- assess the impact of non-nominal scenarios (which primarily affect tasks 1 - 3);
- assess the impact of other contextual factors; and
- identify potential errors.
-

Full CTA diagrams are shown in Annexes C (for the nominal scenario 1) and D (for the nominal RAD scenario 1R).

3.1. Nominal task 1: Verify RA encounter

Under nominal conditions, tasks 1-3 are in fact tightly coupled and performed in quick succession. Task 1 consists of detecting and verifying an RA. Under OC1, the report combines both of these tasks (into task 1.1). Under OC7, RAD detection (task 1.1) provides an early alert to the RA that can both focus attention toward the RA encounter and help speed verification (task 1.2) by heightening anticipation. RAD detection under OC7 (task 1.1) precedes the report, and thus does not add a concurrent demand to tasks 1.2.1 / 1.2.2. The next task (under both OC1 and OC7) is the receipt of report and verification of the RA encounter. Receiving the report is no different under OC1 or OC7, though RAD-driven anticipation suggests that acknowledging the report would likely be as fast or faster under OC7 (1.2.1.3) than under OC1 (1.1.1.3).

The next step, comparison of the aircraft trajectories (task 1.1.2 under OC1, task 1.2.2 under OC7), is where OC1 and OC7 most differ, and is shown in the following CTA extracts. This task basically involves locating the aircraft and comparing the trajectories (via the flight data block) for the aircraft. Specifically, the task of locating the encounter aircraft (OC1-1.1.2.2 OC7-1.2.2.1.2 / 1.2.2.2.2) is the most relevant difference between OC1 and OC7. Under OC7, the RAD signal(s) facilitate detection of the encounter pair (more so if multiple RADs are present). Under OC1, ATC must recall the appropriate call sign (1.1.2.1), scan the screen for that call sign (1.1.2.2.1), and verify the presence of the calling aircraft within a proximate pair (1.1.2.2.1, 1.1.2.2.2).

OC1 Plan: do only 1	**OC7 (RAD) Plan: do in sequence 1-2**
	1.1 Detect RA
	1.1.1 If ONE RAD
	1.1.1.1 Detect the RAD (from visual "pop out")
	1.1.1.2 Presume RA encounter
	1.1.2 If TWO RADs
	1.1.2.1 Detect either RAD (from visual "pop out")
	1.1.2.2 Presume RA encounter
1.1 Verify RA	1.2 Verify RA
1.1.1 Receive REPORT	1.2.1 Receive REPORT
1.1.1.1 Receive RA report via RT	1.2.1.1 Receive RA report via RT
	1.2.1.1.1 Query aircraft if no report
1.1.1.2 Remember call sign	1.2.1.2 Remember call sign
1.1.1.3 Acknowledge RA report via RT	1.2.1.3 Acknowledge RA report via RT
1.1..2 Compare aircraft trajectories	1.2.2 Compare aircraft trajectories
1.1.2.1 Recall call sign	1.2.2.1 If ONE RAD
1.1.2.2 Locate aircraft 1	1.2.2.1.1 Locate aircraft 1
1.1.2.2.1 Scan PVD for proximate pairs	1.2.2.1.2 Locate potential intruder (from proximate traffic)
1.1.2.2.2 Verify presence of call sign within the pair	1.2.2.1.3 Interpret aircraft 1 data block (altitude, VS)
1.1.2.3 Locate potential intruder (from proximate traffic)	1.2.2.1.4 Interpret aircraft 2 data block (altitude, VS)
1.1.2.4 Remember location of encounter aircraft pair	1.2.2.1.5 Compare trajectories
1.1.2.5 Interpret aircraft 1 data block (altitude, VS)	1.2.2.2 If TWO RADs
1.1.2.6 Interpret aircraft 2 data block (altitude, VS)	1.2.2.2.1 Locate aircraft 1
1.1.2.7 Compare trajectories	1.2.2.2.2 Locate potential intruder (from RAD "pop out")
	1.2.2.2.3 Interpret aircraft 1 data block (altitude, VS)
	1.2.2.2.4 Interpret aircraft 2 data block (altitude, VS)
	1.2.2.2.5 Compare trajectories
1.1.2.8 Verify RA encounter	1.2.2.3 Verify RA encounter

Task 1: Verify RA encounter

Annexes A and B present summary tables of likely errors in the two nominal scenarios for OC1 and OC7, respectively.

3.2. Nominal task 2: Verify deviation

OC1 Plan: do in sequence 1-3; do all in any order 4-5; do in sequence 6-7	**OC7 (RAD) Plan: do in sequence 1-3; do all in any order 4-5; do in sequence 6-7**
2.1 Locate encounter aircraft 2.1.1 Recall call sign of aircraft calling 2.1.2 Search screen 2.1.3 Locate aircraft calling	2.1 Locate encounter aircraft pair 2.1.1 Detect either encounter aircraft
2.2 Scan screen for proximate traffic	2.2 Scan screen for proximate traffic
2.3 Locate intruder	2.3 Locate intruder
2.4 Interpret aircraft 1 data block (altitude, VS)	2.4 Interpret aircraft 1 data block (altitude, VS)
2.5 Interpret aircraft 2 data block (altitude, VS)	2.5 Interpret aircraft 2 data block (altitude, VS)
2.6 Compare trajectories	2.6 Compare trajectories
2.7 Verify coordinated manoeuvre	2.7 Verify coordinated manoeuvre

Task 2: Verify deviation

Once an RA encounter has been verified (OC1-1.1.2.8, OC7-1.2.2.3), task 2 involves verifying that aircraft are in fact deviating from their clearance, and coordinating their evasive manoeuvres (2.6). Based on controller input, the CTA breaks this out as part of a separate verification process (task 2). At this point ATC has (on the basis of a pilot report) ceded authority to the aircraft. However, a controller will seek to verify (on the basis of the aircraft trajectories) that encounter aircraft are accomplishing a coordinated evasive manoeuvre. As part of this process, RAD offers speed and accuracy benefits in locating the aircraft (task 2.1). Under OC1, ATC must recall the call sign of aircraft calling (2.1.1), search for and locate the aircraft (2.1.2-2.1.3), then search for and identify the intruder (2.2-2.3)[4]. This risks long search time, and also the possibility of identifying the wrong aircraft calling (call sign misheard) or intruder (incorrect proximate traffic identified).

The same potential speed and accuracy benefits of RAD are seen in the later task of locating the intruder (2.3).

Annexes A and B present summary tables of likely errors in the two nominal scenarios for OC1 and OC7, respectively.

3.3. Nominal task 3: Cede authority to encounter aircraft

Task 3 is in fact a decision based on tasks 1-2 and, disregarding the provisional nature of the authority transfer under OC7 (as referenced earlier), there are no significant differences expected between OC1 and OC7 in task 3.

[4] In fact, the controller will probably only search once for the aircraft pair during tasks 1-2, but the search task is presented redundantly for clarity (and to allow for the possibility that two searches would take place).

OC1 Plan: do only 1	OC7 (RAD) Plan: do only 1
Cede authority to encounter aircraft	Cede authority to encounter aircraft

Task 3: Cede authority to encounter aircraft

3.4. Nominal task 4: Monitor RA encounter for compliance

OC1 Plan: do all in any order 1-2; 3	OC7 (RAD) Plan: do all in any order 1-2; 3
4.1 Determine aircraft 1 following RA 4.1.1 Locate aircraft 1 4.1.1.1 Recall call sign of aircraft calling 4.1.1.2 Search screen 4.1.1.3 Locate aircraft 1 4.1.2 Recall aircraft 1 reported manoeuvre 4.1.3 Interpret aircraft 1 data block VS (+/-) 4.1.4 Remember aircraft 1 VS (+/-) 4.1.5 Compare aircraft 1 reported manoeuvre and VS (+/-) 4.1.6 Verify aircraft 1 following RA 4.2 Determine aircraft 2 following RA 4.2.1 Locate aircraft 2 4.2.1.1 Recall call sign of aircraft calling 4.2.1.2 Search screen 4.2.1.3 Locate aircraft 2 4.2.2 Recall aircraft 2 reported manoeuvre 4.2.3 Interpret aircraft 2 data block VS (+/-) 4.2.4 Remember aircraft 2 VS (+/-) 4.2.5 Compare aircraft 2 reported manoeuvre and VS (+/-) 4.2.6 Verify aircraft 2 following RA 4.3 Verify reciprocal RA manoeuvres 4.3.1 Recall aircraft 1 VS (+/-) 4.3.2 Recall aircraft 2 VS (+/-) 4.3.3 Compare RA commands aircraft 1 vs. aircraft 2 4.3.4 Verify reciprocal manoeuvres	4.1 Determine aircraft 1 following RA 4.1.1 Locate aircraft 1 4.1.1.1 Detect RAD 4.1.2 Interpret RA symbology aircraft 1 (CLIMB/DESCEND) 4.1.3 Remember aircraft 1 commanded RA 4.1.4 Interpret aircraft 1 data block VS (+/-) 4.1.5 Remember aircraft 1 VS (+/-) 4.1.6 Recall aircraft 1 RA command (CLIMB/DESCEND) 4.1.7 Compare aircraft 1 RA command and VS (+/-) 4.1.8 Verify aircraft 1 following RA 4.2 Determine aircraft 2 following RA 4.2.1 Locate aircraft 2 4.2.1.1 Detect RAD 4.2.2 Interpret RA symbology aircraft 2 (CLIMB/DESCEND) 4.2.3 Remember aircraft 2 commanded RA 4.2.4 Interpret aircraft 2 data block VS (+/-) 4.2.5 Remember aircraft 2 VS (+/-) 4.2.6 Recall aircraft 2 RA command (CLIMB/DESCEND) 4.2.7 Compare aircraft 2 RA command and VS (+/-) 4.2.8 Verify aircraft 2 following RA 4.3 Verify reciprocal RA manoeuvres 4.3.1 Recall aircraft 1 RA command (CLIMB/DESCEND) 4.3.2 Recall aircraft 2 RA command (CLIMB/DESCEND) 4.3.3 Compare RA commands aircraft 1 vs. aircraft 2 4.3.4 Verify reciprocal manoeuvres

Task 4: Monitor RA encounter for compliance

Task 4 refers to the ongoing and iterative monitoring that ATC will likely perform, to continually verify that encounter aircraft are manoeuvring in such as way as to avoid one another. The first task in monitoring for compliance is locating the encounter aircraft (tasks 4.1.1 and 4.2.1). The task is qualitatively different under OC1 and OC7. Under OC1, this task requires recalling the call sign (4.1.1.1 and 4.2.1.1), searching the screen (4.1.1.2 and 4.2.1.2) and positively locating the aircraft (4.1.1.3 and 4.2.1.3). Under OC7, RAD pop-out makes locating the calling aircraft much faster. Although search time under OC1 can be shortened if ATC adopts a strategy of searching for proximate pairs to limit the search area, OC7 will still provide benefits in detection time. Further, the additional subtasks required under OC1 carry at least three potential additional types of error in this task:

- ATC might mis-recall call sign, especially if similar call signs are present;
- Search for proximate aircraft pairs might initially lead to locating incorrect aircraft;
- Visual search time might lead to missing other critical traffic.

Next, ATC must verify a reciprocal RA manoeuvre (task 4.3). Under OC1 ATC must interpret (4.2.3, 4.3.3), remember (4.2.4, 4.3.4) and recall (4.3.1,4.3.2) vertical speeds for the two encounter aircraft, and compare them (4.3.3) before reciprocal manoeuvre can be verified (4.3.4). Although the same tasks must be performed under OC7, the controller has an aid in this process – the RAD. Having verified that the aircraft are manoeuvring in compliance with RA (OC1-4.1.6/4.2.6; OC7-4.1.8/4.2.8), the ongoing tasks of comparing RA commands (4.3.3) and verifying reciprocal manoeuvre (4.3.4) are faster and less error prone. However, the controller expert identified as part of this process one new potential source of error: that ATC will mistake the RA command symbology for actual flight trajectory (in task OC7-4.1.2, OC7-4.2.2), and therefore base subsequent comparison (OC7-4.1.7; OC7-4.2.7) and verification (OC7-4.1.8; OC7-4.2.8) on incorrect data. However, the likelihood of this (given the proposed HMI) would seem to be low.

Annexes A and B present summary tables of likely errors in the two nominal scenarios for OC1 and OC7, respectively.

3.5. Nominal task 5: Identify potential third party conflicts

OC1 Plan: do in sequence 1-3	OC7 (RAD) Plan: do all in any sequence 1-3
5.1 Identify trajectory of encounter aircraft 5.1.1 Locate aircraft 5.1.1.1 Recall call sign of aircraft calling 5.1.1.2 Search screen 5.1.1.3 Locate aircraft 1 5.1.2 Interpret aircraft data block (altitude, VS (+/-)) 5.1.3 Interpret aircraft heading 5.1.4 Remember aircraft trajectory 5.2 Identify proximate threats to encounter aircraft 5.2.1 Scan screen 5.2.2 Identify potential proximate threat 5.2.3 Interpret potential threat aircraft data block (altitude, VS (+/-)) 5.2.4 Interpret potential threat aircraft heading 5.2.5 Remember potential threat aircraft trajectory 5.2.6 Recall encounter aircraft trajectory 5.2.7 Compare trajectories of encounter aircraft and potential threat aircraft 5.2.8 Verify conflict 5.2.9 Remember call signs of third party conflict aircraft	5.1 Identify trajectory of encounter aircraft 5.1.1 Locate aircraft 5.1.1.1 Detect RAD 5.1.2 Interpret aircraft data block (altitude, VS (+/-)) 5.1.3 Interpret aircraft heading 5.1.4 Remember aircraft trajectory 5.2 Identify proximate threats to encounter aircraft 5.2.1 Scan screen 5.2.2 Identify potential proximate threat 5.2.3 Interpret potential threat aircraft data block (altitude, VS (+/-)) 5.2.4 Interpret potential threat aircraft heading 5.2.5 Remember potential threat aircraft trajectory 5.2.6 Recall encounter aircraft trajectory 5.2.7 Compare trajectories of encounter aircraft and potential threat aircraft 5.2.8 Verify conflict 5.2.9 Remember call signs of third party conflict aircraft

Task 5: Identify potential third party conflicts

The essential steps in this task are to locate the encounter aircraft (5.1.2,5.3.2)[5],identify (5.2.2,5.4.2) and verify (5.2.8,5.4.8) third party threats to the encounter aircraft. Whereas RAD makes no difference in the identification and verification of threats, it does benefit the onscreen location of encounter aircraft, as stated earlier. Since this task must be performed iteratively (continuously scanning for conflicts), the speed benefit of RAD would accrue for each successive search. Notice that in task 5 the RAD is used only to locate the aircraft –

[5] For clarity, this is broken out as a separate task here though, as in task 2, ATC has already located the aircraft and likely need not repeat the task here.

there is no need to interpret the RAD symbology as in task 4. Thus the risk of misinterpreting RAD symbology – to the extent that it exists – is absent in task 5.

Here, "third party conflicts" are defined as conflicts between encounter and non-encounter aircraft. The possibility of conflict exists also between two (or more) non-encounter aircraft, but scanning for these constitutes part of ATC's normal responsibility, and would not be expected to differ on the basis of RAD (apart from the risk of cognitive tunnelling). Because an RA encounter might force non-encounter aircraft to blunder toward one another, this possibility is considered as a contextual factor, below.

Some maintain that controllers are prone to error in issuing relative bearing clearances (in fact, this expert was told during ab initio training to purchase an analogue watch, for reasons of keeping clear the meaning of clock headings). Whereas this risk would appear under either OC1 or OC7, there is speculation that RAD might encourage controllers to issue more traffic advisories and hence present more opportunities for error.

Annexes A and B present summary tables of likely errors in the two nominal scenarios for OC1 and OC7, respectively.

3.6. Nominal task 6: Prevent third party conflicts

OC1 Plan: do in sequence 1-2	**OC7 (RAD) Plan: do in sequence 1-2**
6.1 Determine appropriate avoiding action 6.1.1 Recall call signs of third party conflict aircraft 6.1.2 Recall trajectories of third party conflict aircraft 6.1.3 Determine avoiding action as appropriate 6.2 Issue clearance to third party aircraft 6.2.1 Recall call sign third party aircraft 6.2.2 Contact third party aircraft via RT 6.2.2.1 Issue clearance avoiding action 6.2.2.2 Confirm read back	6.1 Determine appropriate avoiding action 6.1.1 Recall call signs of third party conflict aircraft 6.1.2 Recall trajectories of third party conflict aircraft 6.1.3 Determine avoiding action as appropriate 6.2 Issue clearance to third party aircraft 6.2.1 Recall call sign third party aircraft 6.2.2 Contact third party aircraft via RT 6.2.2.1 Issue clearance avoiding action 6.2.2.2 Confirm read back

Task 6: Prevent third party conflicts

This task essentially involves acting on the information gathered in Task 5, to determine an appropriate avoiding action for the third party aircraft, and to issue a clearance to that aircraft. There is no apparent change to these tasks under OC7.

Once a potential third party conflict is verified (task 5.2.8), the task of preventing the conflict consists of simply determining an avoiding action (task 6.1) and issuing an RT clearance to that effect (task 6.2). This task 6 would not be affected by the presence of RAD.

3.7. Nominal task 7: Provide traffic information to encounter aircraft

This task amounts to informing encounter aircraft of any potential third party conflicts verified in task 5.2.8. As such this task 7 would not be affected by the presence of RAD (apart from the possibility that the RAD condition will lead to more frequent performance of this (error-prone) task).

OC1 Plan: do only 1	OC7 (RAD) Plan: do only 1
7.1 Contact encounter aircraft via RT 7.1.1 Confirm read back	7.1 Contact encounter aircraft via RT 7.1.1 Confirm read back

Task 7: Provide traffic information to encounter aircraft

3.8. Nominal task 8: Provide traffic information to third party aircraft

OC1 Plan: do only 1	OC7 (RAD) Plan: do only 1
8.1 Contact third party aircraft via RT 8.1.1 Confirm read back	8.1 Contact third party aircraft via RT 8.1.1 Confirm read back

Task 8: Provide traffic information to third party aircraft

This task consists of simply informing third party aircraft of the potential conflicts verified in task 5.2.8. For verified conflicts, this task was in fact already completed in task 6.2.2. This task (8) is only broken out as a separate task to capture the possibility that ATC might inform third party aircraft of less-imminent potential conflicts identified in task 5.2.8.

3.9. Nominal task 9: Determine end of RA manoeuvre

OC1 Plan: do only one 1-2	OC7 (RAD) Plan: do only one 1-3
	9.1 Notice RAD OFF 9.1.1 Identify both encounter aircraft 9.1.2 Detect stabilised altitude both aircraft 9.1.3 Determine Clear of Conflict 9.1.3.1 Remember trajectories aircraft 1 and 2 9.1.3.2 Compare trajectories aircraft 1 vs. 2 9.1.3.3 Determine Clear of Conflict 9.1.4 Call aircraft via RT 9.1.4.1 Query aircraft for Clear of Conflict confirmation 9.1.4.2 Affirm Clear of Conflict
9.1 Receive RA report Clear of Conflict 9.1.1 Identify both encounter aircraft 9.1.2 Detect stabilised altitude both aircraft 9.1.3 Determine Clear of Conflict 9.1.3.1 Remember trajectories aircraft 1 and 2 9.1.3.2 Compare trajectories aircraft 1 vs. 2 9.1.3.3 Determine Clear of Conflict 9.1.4 Call aircraft via RT 9.1.4.1 Query aircraft for Clear of Conflict confirmation 9.1.4.2 Affirm Clear of Conflict	9.2 Receive RA report Clear of Conflict 9.2.1 Identify both encounter aircraft 9.2.2 Detect stabilised altitude both aircraft 9.2.3 Determine Clear of Conflict 9.2.3.1 Remember trajectories aircraft 1 and 2 9.2.3.2 Compare trajectories aircraft 1 vs. 2 9.2.3.3 Determine Clear of Conflict 9.2.4 Call aircraft via RT 9.2.4.1 Query aircraft for Clear of Conflict confirmation 9.2.4.2 Affirm Clear of Conflict
9.2 Notice end of manoeuvre 9.2.1 Detect stabilised altitude 9.2.2 Determine Clear of Conflict 9.2.2.1 Remember trajectories aircraft 1 and 2	9.3 Notice end of manoeuvre 9.3.1 Detect stabilised altitude 9.3.2 Determine Clear of Conflict 9.3.2.1 Remember trajectories aircraft 1 and 2

9.2.2.2 Compare trajectories aircraft 1 vs. 2 9.2.2.3 Determine Clear of Conflict 9.2.3 Call aircraft via RT 9.2.3.1 Query aircraft for Clear of Conflict confirmation 9.2.3.2 Affirm Clear of Conflict	9.3.2.2 Compare trajectories aircraft 1 vs. 2 9.3.2.3 Determine Clear of Conflict 9.3.3 Call aircraft via RT 9.3.3.1 Query aircraft for Clear of Conflict confirmation 9.3.3.2 Affirm Clear of Conflict

Task 9: Determine end of RA manoeuvre

Similar to the beginning of an RA encounter, the end of RA can only be positively established on the basis of a pilot report (and ATC acknowledgement). As with the initial detection / verification of an RA (task 1), RAD presents in task 9 an additional "pre" task in the form of the RAD extinguishing. Under either OC1 or OC7, ATC has a means to anticipate the clear of conflict report, through iterative monitoring of the RA encounter (task 4) and detection of manoeuvre-end.

Notice how RAD-on (task 1) and RAD-off (task 9) are qualitatively different. Under nominal conditions, RAD-on preceded manoeuvre-start, prompting ATC to expect a report and manoeuvre in tasks 1-3. Here in task 9, manoeuvre-end is likely to precede RAD-off, removing the possible cueing (early warning) benefit of RAD. Notice that RAD-off under OC7 is likely to prompt a query by ATC (OC7-9.1.4.1) for clear of conflict confirmation.

There were two risks associated with task 9 under OC7. The first is that a query (driven by RAD-off) would interfere with flight crews, though the impact of this risk would seem low, given that ATC would by now have evidence (from RAD-off but also likely manoeuvre-end) that the RA encounter had indeed ended. The motivation to pre-emptively query, especially if a presumed end of manoeuvre is observed, is likely greater than under task 1, when ATC first detected the RAD. A second risk concerns the task of identifying the (ex) encounter aircraft (OC7-9.1.1). At this moment, ATC must shift from a strategy of using the highly salient RAD for aircraft identification, to relying on traditional ATC scanning. Though the risk would appear to be low (ATC should have a good recall of roughly where onscreen the encounter aircraft were located), it cannot be completed discounted.

Annexes A and B present summary tables of likely errors in the two nominal scenarios for OC1 and OC7, respectively.

3.10. Nominal task 10: Resume ATC authority

OC1 Plan: do in sequence 1-2	OC7 (RAD) Plan: do in sequence 1-2
10.1 Verify resumption of clearance 10.1.1 Contact aircraft via RT 10.1.2 Recall aircraft original clearance 10.1.3 Acknowledge aircraft resumption of clearance 10.2 Issue new clearance as appropriate 10.2.1 Compare trajectories 10.2.2 Determine whether new clearance necessary 10.2.3 Issue new clearance as appropriate	10.1 Verify resumption of clearance 10.1.1 Contact aircraft via RT 10.1.2 Recall aircraft original clearance 10.1.3 Acknowledge aircraft resumption of clearance 10.2 Issue new clearance as appropriate 10.2.1 Compare trajectories 10.2.2 Determine whether new clearance necessary 10.2.3 Issue new clearance as appropriate

Task 10: Resume ATC authority

Task 10 essentially involves ATC's resumption of positive control at the end of the RA encounter. This is accomplished by ATC's acknowledging the clear of conflict report, and

reporting the old (or as necessary issuing a revised) clearance to aircraft. As such, the task would not be expected to differ on the basis of RAD.

3.11. The Influence of non-nominal and contextual factors

The following summarises the potential influence of non-nominal and other contextual factors across the 10 task, as outlined above. Notice that the influence of non-nominal scenarios is felt primarily at the beginning of the RA encounter, when the encounter must be detected and verified, and authority transferred to the aircraft.

3.11.1 Non-nominal scenarios

No report (scenario 2/2R – a report is necessary to cede authority. Notice that OC7 introduces the possibility of an RAD in the absence of a report, either because the report is never made (as defined in non-nominal scenario 2/2R) or is delayed. In this case, OC7 introduces the possibility that ATC will query the pilot to confirm (task 1.2.1.1.1), and quite possibly (though not explicitly captured in the CTA) issue clearances to one or more aircraft in the absence of a pilot report. If ATC fails to query, the situation is identical to OC1, except that ATC has a working understanding of the situation, and attention will be focused to (1) anticipate a report, and (2) monitor for signs of a manoeuvre. However, there is no report in this case. Instead, ATC must query, and await evidence of a manoeuvre. In this case, there is no transfer of authority to the aircraft under either OC1 or OC7.

The manoeuvre is generally later, and might not be apparent until near the end of the RA encounter. Further, the manoeuvre is not very noticeable, and there is a likelihood that the controller (whose monitoring performance has, by definition, been poor) would not detect manoeuvre changes, or not detect them in a timely fashion. The attention-focusing aspect of RAD would thus appear an advantage of RAD (OC7) in terms of detecting a manoeuvre.

The main risk of OC7 would lie in the possibility of a mistaken provisional transfer of authority. In the absence of a report, ATC should maintain authority. But if no report is received, and a query (1.2.1.1.1) gets no response (as it might not under high pilot workload and time pressure), then ATC can neither confirm nor deny the authenticity of the RA, which from ATC's perspective leads to an ambiguous situation.

In the absence of a report, there is no verification of RA (OC1-1.1.1; OC7-1.2.1) and hence no transfer of authority (3). Thus task 2 is not necessary. However, it is likely that the attention focusing aspect of RAD will prompt ATC to monitor for signs of a manoeuvre which, if detected, prompts further querying (OC7-1.2.1.1.1) – the controller would aim to elicit a pilot report. This is not defined as a specific task for OC1, since ATC does not have the indication (other than through normal scanning) that a possible RA encounter might be occurring. The advantage would therefore seem to lie with OC7 in terms of ATC general situation awareness.

Incorrect report (scenario 3/3R) – would be the case in which an aircraft reports incorrectly (e.g. CLIMB), but correctly follows the RA commanded manoeuvre (DESCEND). Under OC1, ATC has no means to detect an incorrect report in the absence of the (presumably later) manoeuvre (see task 2), whereas OC7 provides a means of early detection (tasks 1.2.2.1.3, 1.2.2.1.4). Under OC7, ATC is prompted by the presentation of both report and RAD to detect a discrepancy between the two. However, there is a chance that ATC would mishear the report (through expectancy brought on by the RAD). This would in theory be captured

later when discrepancies between RA commanded and reported manoeuvre should be caught, and prompt a query (after tasks 1.2.2.1.3 / 1.2.2.1.4).

In this case, the report (though incorrect) will probably serve to transfer authority, since the pilot (having reported) will likely not respond to follow-up ATC queries during the RA. So the RAD might serve only to alert ATC to a situation (discrepancy between RA and report) that they cannot immediately correct. If the flight crew fails to respond to queries, ATC must wait for the manoeuvre, and in this sense task performance is identical to that under OC1.

Again, it is likely that transfer will occur even on the basis of an incorrect report (albeit with ATC query). OC7 provides a direct means of detecting a discrepancy between RAD command and pilot report, and this should have been detected in task 1 (OC7-1.1.1.1-1.2.2.1.3; OC7-1.1.2.1-1.2.2.1.4). If not, the RAD serves as a reminder during the manoeuvre that the initial pilot report was incorrect. At this point, during task 2, there is no difference between OC1 and OC7, since the appearance of the manoeuvre (contradictory to the report) should trigger a query by ATC, irrespective of whether RAD is present.

No report, no manoeuvre (scenario 4/4R) – In this case, there is no transfer of authority to the aircraft under either OC1 or OC7. If an RAD were present, this indicates either a false/nuisance alert, or a delayed/absent evasive manoeuvre. Again, the advantage seems to lie with OC7, in that the RAD would prompt ATC to anticipate both a report and a manoeuvre, but also begin verification of the RA encounter (OC7-1.2.2.3) by comparing trajectories which can help identify patently false RADs. Thus OC7 provides a means of detecting false/nuisance alerts including preventative RAs (albeit at some cost in time), whereas under OC1 ATC would (in the absence of a pilot report) not be alerted to the possibility. Unless an RA encounter can be clearly refuted in task 1 (OC1-1.1.2.8, OC7-1.2.2.3), the ongoing absence of a report should prompt ATC to query. If there were an RAD for only one aircraft (say that one pilot had failed to arm ACAS), the lone RAD might prompt ATC to query the presumed intruder. The case of no RAD, no reports and no manoeuvres indicates a system failure (say that both pilots had failed to arm ACAS), and the lack of RAD would present no disadvantage over OC1.

In this case, there is no verification of RA, and no transfer of authority to the aircraft under either OC1 or OC7. However, as with task 1, the benefit of RAD would lie in its ability to help highlight the possible conflict aircraft, so ATC can check and monitor them.

4. Correct report, no manoeuvre (scenario 5/5R) – the attention-focusing aspect of RAD should help ATC anticipate both a report and a manoeuvre. However, on the basis of both RAD and report, ATC will in effect verify the transfer of authority. The lack of a manoeuvre is likely to be quite delayed, and detected only later under tasks 4.1.7 and/or 4.2.7, in monitoring their conformance with the RA. This is a difficult situation for ATC, and the presence of RAD would present no disadvantages, and possibly one advantage in the form of faster and more accurate onscreen location (OC1-4.1.1.1, OC7- 4.1.1.1). The additional benefit of OC7 would lie in the later task (2) of verifying the coordinated evasive manoeuvre.

3.11.2. Other contextual factors

One aircraft reports, one does not – ATC is likely on the basis of two RADs and one report to verify transfer, and omit query of the non-reporting aircraft, pending verification of a coordinated manoeuvre (tasks OC1- 2.5, OC7-2.6) and verification of RA compliance (OC1-4.2.6, OC7-4.2.8). Even in the absence of a report from aircraft 2, the ability under OC7 to detect aircraft 2's non-compliance with RA suggests a benefit of OC7.

Preventive vs. Corrective RA – if a pilot receives a preventive RA, ATC remains responsible for separation. However, RAD symbology can be misinterpreted by ATC as a corrective RA, and a mistaken transfer occur. Given that current pilot reports under OC1 are not likely to distinguish preventive from corrective RAs, it would seem that the risk of mistaken transfer is the same or lower under OC7.

RA encounter might force non-encounter aircraft to blunder toward one another – In task 5, evasive manoeuvres might trigger knock-on conflicts as nearby aircraft receive RAs. The risk of such blunders would seem to be identical under OC1 or OC7. There are no new tasks required under OC7. However, the ability to receive an early warning (RAD) of potential knock-on conflicts (RAs) would seem to give an advantage to OC7.

Delayed pilot report – in task 9,the possibility of pilot "gaming" – in which the rule of engagement are bent to gain advantage – was discussed. Although pilots could intentionally delay reporting clear of conflict, the costs of such gaming would seem unattractive. More conceivably, pilots might consider the clear of conflict report lower priority than other ongoing flight deck tasks, and hence delay the report. The influence of RAD in this situation would seem to be minimal, apart from the early warning function of RAD off, which would help ATC anticipate a report, and possibly prompt a query.

4. CONCLUSIONS

The chief potential benefit of RAD appears to be its value in anticipating changes and locating traffic. Specifically, it can do this by (1) preparing ATC to expect a report, and (2) by helping ATC determine (from the visual “pop-out” nature of RAD) where onscreen RAD aircraft are located. In the absence of RAD, ATC must hear a call sign, locate onscreen the aircraft calling, and identify the intruder. RAD thus potentially benefits the early stages of an RA encounter, when ATC must verify the presence of both an RA and the presence of a coordinated manoeuvre – but it also pays potential dividends during and at the end of the RA encounter. There are, however, some caveats that arose on the basis of the CTA:

Controllers will provisionally cede authority on the basis of an RAD, but seek to verify that transfer.

The timing of RAD onset can prompt ATC to query at the same time as pilot reports are to be expected, and can increase the chance of a “stepped-on´ transmission from encounter aircraft.

The greatest single danger identified in the CTA was the possibility that RAD will introduce ambiguous control situations. According to the FARADS operational concept, ATC's "legal responsibility" ends at RAD onset. However, a pilot report is also necessary for ATC to surrender authority. This suggests a potential period of ambiguity during which ATC might think it has transferred authority.

RAD does not add a concurrent task so much as it adds a “pre-task”: in the form of detecting an early warning.

The operational concept must be clear in defining when ATC cedes authority (at pilot report), so as to avoid periods of ambiguous control;

The RAD visual “pop-out” effect transforms the current-day task of locating aircraft (remembering call sign, scanning screen, identifying aircraft calling) to a largely perceptual one, and can benefit all three phases (before, during, after) of the RA encounter.

At the end of an RA encounter, the shift back from the perceptual task to current-day scanning can complicate positive identification of (ex) encounter aircraft.

RAD might prime ATC to hear what they expect to hear, and as a result mishear the subsequent pilot report.

The expert speculated that controllers under RAD might spend more time in RT contact with encounter aircraft – whilst not issuing instructions, ATC could provide traffic information and hopefully in return receive an earlier clear of conflict report. The concern is that too much radio contact with encounter aircraft could be distracting for the flight crew.

Under OC7, ATC has the means to verify a patently false RAD (e.g. by verifying that no conflict situation exists), albeit at the cost of time.

The potential costs of RAD in terms of attention-tunnelling, and the risk of neglecting other traffic, must be clarified.

ATC might be inclined to pre-emptively query for clear of conflict under OC7.

One area that the CTA did not explicitly touch upon, but which arose several times, was trust. Trust, both in the system (Is it prone to false alarms? Does it ever miss RA situations?) and also in the other party(ies), is essential in the RAD scenario. Controllers' experience with the system will ultimately determine how much trust they come to place in the RAD concept.

The notion of complacency was also mentioned. The RAD scenario demands a negative logic from ATC– i.e. assuming a timely RAD, ATC will provisionally transfer authority to the aircraft, then seek evidence to refute this very decision. The system's tendency to either false alarm or miss conflicts will influence the complacency with which this provisional transfer is made.

CTA was judged a valuable exercise, by both researcher and expert. Systematically stepping through the RA encounter scenarios revealed certain tasks and error possibilities that had not been immediately apparent. Having said that, it is now the role of HRA to assess the probabilities behind these potential errors, and the job of subject matter experts to weigh the operational realities of the RAD concept.

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ANNEX A: POTENTIAL ERRORS, SCENARIO 1

TASK(s)	ERROR /IMPACT	CAUSE	FACTORS	COMPARED TO RAD	NOTES
1-3	Inappropriate clearance	Between RA and report, ATC might issue clearance	ATC unaware that RA encounter has commenced	Higher risk	Can be exacerbated by timing of STCA
1.1.2.2	Delayed visual location of reporting aircraft	Requires visual search	Search is speeded by strategy of scanning for proximate pairs	Higher risk	Visual pop-out of RAD speeds location of aircraft
1.1.2.2	Incorrect visual location of reporting aircraft	Requires recall of call sign	Similar call signs might be confused	Higher risk	Visual pop-out of RAD transforms memory task to perceptual task
1.1.2.3	Misidentify intruder	Search of proximate traffic ended prematurely	Without report from intruder, ATC cannot positively associate a call sign with intruder	Higher risk	Visual pop-out of RAD speeds identification of intruder
2.1	Delayed visual location of encounter aircraft	Requires visual search	Search is speeded by strategy of scanning for proximate pairs	Higher risk	Visual pop-out of RAD speeds location of aircraft
2.1	Incorrect visual location of encounter aircraft	Requires recall of call sign	Similar call signs might be confused	Higher risk	Visual pop-out of RAD transforms memory task to perceptual task
2.3	Delayed visual location of intruder	Requires visual search	Search is speeded by strategy of scanning for proximate pairs	Higher risk	Visual pop-out of RAD speeds location of aircraft
2.3	Incorrect visual location of intruder	Requires recall of call sign	Similar call signs might be confused	Higher risk	Visual pop-out of RAD transforms memory task to perceptual task
3	ATC issues clearance after RA, before report	Inherent delay in report		Higher risk	RAD prompts ATC to provisionally cede authority

ANNEX A: POTENTIAL ERRORS, SCENARIO 1

TASK(s)	ERROR /IMPACT	CAUSE	FACTORS	COMPARED TO RAD	NOTES
4.1.1	Delayed visual location of aircraft 1	Requires visual search	Search is speeded by strategy of scanning for proximate pairs	Higher risk	Visual pop-out of RAD speeds location of aircraft
4.1.1	Incorrect visual location of aircraft 1	Requires recall of call sign	Similar call signs might be confused	Higher risk	Visual pop-out of RAD transforms memory task to perceptual task
4.2.1	Delayed visual location of aircraft 2	Requires visual search	Search is speeded by strategy of scanning for proximate pairs	Higher risk	Visual pop-out of RAD speeds location of aircraft
4.2.1	Incorrect visual location of aircraft 2	Requires recall of call sign	Similar call signs might be confused	Higher risk	Visual pop-out of RAD transforms memory task to perceptual task
5.1.1	Delayed visual location of aircraft 1	Requires visual search	Search is speeded by strategy of scanning for proximate pairs	Higher risk	Visual pop-out of RAD speeds location of aircraft
5.1.1	Incorrect visual location of aircraft 1	Requires recall of call sign	Similar call signs might be confused	Higher risk	Visual pop-out of RAD transforms memory task to perceptual task
5.1.2-5.1.3	ATC might give wrong traffic information	Confusion about relative bearings		No difference	Risk exists under both OC1 and OC7
5.2.1-5.2.2	Delayed visual location of proximate threat	Requires visual search	Search is speeded by strategy of scanning for proximate pairs	Higher risk	Visual pop-out of RAD speeds location of aircraft
5.2.1-5.2.2	Incorrect visual location of proximate threat	Requires visual search	Search is speeded by strategy of scanning for proximate pairs	Higher risk	Visual pop-out of RAD speeds location of aircraft
9.1.1	Delayed visual location of (2) encounter aircraft	Requires visual search	Search is speeded by strategy of scanning for proximate pairs	Higher risk	Visual pop-out of RAD speeds location of aircraft

ANNEX A: POTENTIAL ERRORS, SCENARIO 1

9.1.1	Incorrect visual location of (2) encounter aircraft	Requires recall of call sign	Similar call signs might be confused	Higher risk	Visual pop-out of RAD transforms memory task to perceptual task

ANNEX B: POTENTIAL ERRORS, SCENARIO 1R (WITH RAD)

TASK(s)	ERROR / IMPACT	CAUSE	FACTORS	COMPARED TO NON-RAD	NOTES
1.1	Delayed detection of RAD	Poor monitoring / vigilance	If RAD were preceded by STCA, controller has already missed (or inappropriately responded to) STCA	New risk	Conjoint probability of missing both STCA and RAD mean that RAD "early warning" benefit might be smaller than planned
1.1.1.1	Delayed detection of RA	Only one RAD present	Second RA absent/late	Lower risk	Risk reduced if both RADs present
1.2.1.1	Mistaken assumption of false RAD	Lack of report might cause ATC to doubt the RAD	Patently false RADs can be determined from trajectories	New risk	Time required to determine RAD authenticity can vary
1.2.1.1	ATC mishears report	RAD primes ATC to hear a pilot report		New risk	RAD might force ATC to hear what they expect to hear
1.2.1.1.1	Clearance issued to encounter aircraft during RA*	No response to query should prompt ATC to issue clearance as necessary (i.e. maintain control)	ATC understanding of authority transfer rules (i.e. that a pilot report is necessary)	No difference	Can worsen situation * this is technically not an error, but can disturb the system
1.2.1.1.1	Simultaneous ("stepped-on") transmission, blocked frequency	RAD prompts ATC to query at roughly the same time that pilot should report	ATC likely to pre-emptively query in response to RAD	New risk	
1.2.1.1.1	Mistaken transfer of authority	ATC fails to query (1.2.1.1.1)	Experience with stepped-on transmissions	No difference**	**except that mistaken transfer can have knock-on effects
2.1-2.5	Not noticing / attending to other traffic	Cognitive tunnelling	If no report no query response, ATC will closely monitor potential encounter	Higher risk***	*** Same risk exists under OC1, though RAD might exacerbate cognitive tunnelling

ANNEX B: POTENTIAL ERRORS, SCENARIO 1R (WITH RAD)

TASK(s)	ERROR /IMPACT	CAUSE	FACTORS	COMPARED TO RAD	NOTES
3	Mistaken transfer of authority	In the nominal case, a preventive RA together with a vague report (e.g. “TCAS climb”) can lead ATC to mistakenly transfer authority.	Experience with preventive vs. corrective RAs	No difference	
4.1.1-4.1.8, 4.2.1-4.2.8	Fixation with RA encounter might lead ATC to disregard other traffic	Cognitive tunnelling	Salience of RAD	No difference	Same risk exists under OC1, not clear if salience of RAD will exacerbate the problem
4.1.2, 4.2.2	Misinterpret RA symbology, RA command vs. actual trajectory	ATC might mistake RA commanded direction for actual trajectory	Familiarity, training	New risk	Time pressure might exacerbate problem; Not clear that risk is large, given current HMI specs
4.1.2, 4.2.2	Misinterpret RA symbology, inability to detect predictive RA	Inexperience with RADs might lead to misinterpretation	HMI /training issue	New risk	Transfer of authority would be unclear
5.1.2-5.1.3	ATC might give wrong traffic information	Confusion about relative bearings	Training	No difference	Risk exists under both OC1 and OC7
7.3	Failure to provide traffic information to encounter aircraft	Transfer of authority might lead ATC to not offer traffic information	Training	No difference	Risk exists under both OC1 and OC7
8.2	Failure to provide traffic information to other traffic	Cognitive tunnelling	Salience of RAD	No difference	Same risk exists under OC1, not clear if salience of RAD will exacerbate the problem

ANNEX B: POTENTIAL ERRORS, SCENARIO 1R (WITH RAD)

TASK(s)	ERROR /IMPACT	CAUSE	FACTORS	COMPARED TO RAD	NOTES
9.1	Failure to identify encounter aircraft	RAD off provides no positive indication of previously-involved aircraft	Previously visual task, now with visual signal removed	New risk	ATC might have become dependent on RAD to locate encounter aircraft
9.1.4.1	ATC pre-emptively queries at RAD off	RAD off	If presumed end of manoeuvre also detected	New risk	

ANNEX C: CTA FOR SCENARIO 1

- 1 Verify RA Encounter
  - 1.1 Verify RA
    - 1.1.1 Receive REPORT
      - 1.1.1.1 Receive RA report via RT
      - 1.1.1.2 Remember call sign
      - 1.1.1.3 Acknowledge RA report via RT
    - 1.1.2 Compare aircraft trajectories
      - 1.1.2.1 Recall call sign
      - 1.1.2.2 Locate aircraft 1
        - 1.1.2.2.1 Scan PVD for proximate pairs
        - 1.1.2.2.2 Verify presence of call sign within the pair
      - 1.1.2.3 Locate potential intruder (from proximate traffic)
      - 1.1.2.4 Remember location of encounter aircraft pair
      - 1.1.2.5 Interpret aircraft 1 data block (altitude, VS)
      - 1.1.2.6 Interpret aircraft 2 data block (altitude, VS)
      - 1.1.2.7 Compare trajectories
      - 1.1.2.8 Verify RA encounter
- 2 Verify deviation
  - 2.1 Locate encounter aircraft
    - 2.1.1 Recall call sign of aircraft calling
    - 2.1.2 Search screen
    - 2.1.3 Locate aircraft calling
  - 2.2 Scan screen for proximate traffic
  - 2.3 Locate intruder
  - 2.4 Interpret aircraft 1 data block (altitude, VS)
  - 2.5 Interpret aircraft 2 data block (altitude, VS)
  - 2.6 Compare trajectories
  - 2.7 Verify coordinated manoeuvre
- 3 Cede authority to encounter aircraft
- 4 Monitor RA encounter for compliance
  - 4.1 Determine aircraft 1 following RA
    - 4.1.1 Locate aircraft 1
      - 4.1.1.1 Recall call sign of aircraft calling
      - 4.1.1.2 Search screen
      - 4.1.1.3 Locate aircraft 1
    - 4.1.2 Recall aircraft 1 reported manoeuvre
    - 4.1.3 Interpret aircraft 1 data block VS (+/-)
    - 4.1.4 Remember aircraft 1 VS (+/-)
    - 4.1.5 Compare aircraft 1 reported manoeuvre and VS (+/-)
    - 4.1.6 Verify aircraft 1 following RA
  - 4.2 Determine aircraft 2 following RA
    - 4.2.1 Locate aircraft 2
      - 4.2.1.1 Recall call sign of aircraft calling
      - 4.2.1.2 Search screen
      - 4.2.1.3 Locate aircraft 2
    - 4.2.2 Recall aircraft 2 reported manoeuvre
    - 4.2.3 Interpret aircraft 2 data block VS (+/-)
    - 4.2.4 Remember aircraft 2 VS (+/-)
    - 4.2.5 Compare aircraft 2 reported manoeuvre and VS (+/-)
    - 4.2.6 Verify aircraft 2 following RA
  - 4.3 Verify reciprocal RA manoeuvres
    - 4.3.1 Recall aircraft 1 VS (+/-)
    - 4.3.2 Recall aircraft 2 VS (+/-)
    - 4.3.3 Compare RA commands aircraft 1 vs. aircraft 2
    - 4.3.4 Verify reciprocal manoeuvres

ANNEX C: CTA FOR SCENARIO 1

- 5 Identify potential third party conflicts
  - 5.1 Identify trajectory of encounter aircraft
    - 5.1.1 Locate aircraft
      - 5.1.1.1 Recall call sign of aircraft calling
      - 5.1.1.2 Search screen
      - 5.1.1.3 Locate aircraft 1
    - 5.1.2 Interpret aircraft data block (altitude, VS (+/-))
    - 5.1.3 Interpret aircraft heading
    - 5.1.4 Remember aircraft trajectory
  - 5.2 Identify proximate threats to encounter aircraft
    - 5.2.1 Scan screen
    - 5.2.2 Identify potential proximate threat
    - 5.2.3 Interpret potential threat aircraft data block (altitude, VS (+/-))
    - 5.2.4 Interpret potential threat aircraft heading
    - 5.2.5 Remember potential threat aircraft trajectory
    - 5.2.6 Recall encounter aircraft trajectory
    - 5.2.7 Compare trajectories of encounter aircraft and potential threat aircraft
    - 5.2.8 Verify conflict
    - 5.2.9 Remember call signs of third party conflict aircraft
- 6 Prevent third party conflicts
  - 6.1 Determine appropriate avoiding action
    - 6.1.1 Recall call signs of third party conflict aircraft
    - 6.1.2 Recall trajectories of third party conflict aircraft
    - 6.1.3 Determine avoiding action as appropriate
  - 6.2 Issue clearance to third party aircraft
    - 6.2.1 Recall call sign third party aircraft
    - 6.2.2 Contact third party aircraft via RT
      - 6.2.2.1 Issue clearance avoiding action
      - 6.2.2.2 Confirm read back
- 7 Provide traffic info to encounter aircraft
  - 7.1 Contact encounter aircraft via RT
    - 7.1.1 Confirm read back
- 8 Provide traffic info to third party aircraft
  - 8.1 Contact third party aircraft via RT
    - 8.1.1 Confirm read back
- 9 Determine end of RA encounter
  - 9.1 Receive RA report Clear of Conflict
    - 9.1.1 Identify both encounter aircraft
    - 9.1.2 Detect stabilised altitude both aircraft
    - 9.1.3 Determine Clear of Conflict
      - 9.1.3.1 Remember trajectories aircraft 1 and 2
      - 9.1.3.2 Compare trajectories aircraft 1 vs. 2
      - 9.1.3.3 Determine Clear of Conflict
    - 9.1.4 Call aircraft via RT
      - 9.1.4.1 Query aircraft for Clear of Conflict verification
      - 9.1.4.2 Affirm Clear of Conflict
  - 9.2 Notice end of manoeuvre
    - 9.2.1 Detect stabilised altitude
    - 9.2.2 Determine Clear of Conflict
      - 9.2.2.1 Remember trajectories aircraft 1 and 2
      - 9.2.2.2 Compare trajectories aircraft 1 vs. 2
      - 9.2.2.3 Determine Clear of Conflict
    - 9.2.3 Call aircraft via RT
      - 9.2.3.1 Query aircraft for Clear of Conflict verification
      - 9.2.3.2 Affirm Clear of Conflict
- 10 Resume ATC authority
  - 10.1 Verify resumption of clearance

10.1.1 Contact aircraft via RT
10.1.2 Recall aircraft original clearance
10.1.3 Acknowledge aircraft resumption of clearance
10.2 Issue new clearance as appropriate
10.2.1 Compare trajectories
10.2.2 Determine whether new clearance necessary
10.2.3 Issue new clearance as appropriate

ANNEX D: CTA FOR SCENARIO 1R (WITH RAD)

1 Verify RA Encounter
- 1.1 Detect RA
  - 1.1.1 If ONE RAD
    - 1.1.1.1 Detect the RAD (from visual "pop out")
    - 1.1.1.2 Presume RA encounter
  - 1.1.2 If TWO RADs
    - 1.1.2.1 detect either RAD (from visual "pop out")
    - 1.1.2.2 Presume RA encounter
- 1.2 Verify RA
  - 1.2.1 Receive REPORT
    - 1.2.1.1 Receive RA report via RT
      - 1.2.1.1.1 Query aircraft if no report
    - 1.2.1.2 Remember call sign
    - 1.2.1.3 Acknowledge RA report via RT
  - 1.2.2 Compare aircraft trajectories
    - 1.2.2.1 If ONE RAD
      - 1.2.2.1.1 Locate aircraft 1
      - 1.2.2.1.2 Locate potential intruder (from proximate traffic)
      - 1.2.2.1.3 Interpret aircraft 1 data block (altitude, VS)
      - 1.2.2.1.4 Interpret aircraft 2 data block (altitude, VS)
      - 1.2.2.1.5 Compare trajectories
    - 1.2.2.2 If TWO RADs
      - 1.2.2.2.1 Locate aircraft 1
      - 1.2.2.2.2 Locate potential intruder (from RAD "pop out")
      - 1.2.2.2.3 Interpret aircraft 1 data block (altitude, VS)
      - 1.2.2.2.4 Interpret aircraft 2 data block (altitude, VS)
      - 1.2.2.2.5 Compare trajectories
    - 1.2.2.3 Verify RA encounter

2 Verify deviation
- 2.1 Locate encounter aircraft
  - 2.1.1 Detect either encounter aircraft
- 2.2 Scan screen for proximate traffic
- 2.3 Locate intruder
- 2.4 Interpret aircraft 1 data block (altitude, VS)
- 2.5 Interpret aircraft 2 data block (altitude, VS)
- 2.6 Compare trajectories
- 2.7 Verify coordinated manoeuvre

3 Cede authority to encounter aircraft

4 Monitor RA encounter for compliance
- 4.1 Determine aircraft 1 following RA
  - 4.1.1 Locate aircraft 1
    - 4.1.1.1 Detect RAD
  - 4.1.2 Interpret RA symbology aircraft 1 (CLIMB/DESCEND)
  - 4.1.3 Remember aircraft 1 commanded RA
  - 4.1.4 Interpret aircraft 1 data block VS (+/-)
  - 4.1.5 Remember aircraft 1 VS (+/-)
  - 4.1.6 Recall aircraft 1 RA command (CLIMB/DESCEND)
  - 4.1.7 Compare aircraft 1 RA command and VS (+/-)
  - 4.1.8 Verify aircraft 1 following RA
- 4.2 Determine aircraft 2 following RA
  - 4.2.1 Locate aircraft 2
    - 4.2.1.1 Detect RAD
  - 4.2.2 Interpret RA symbology aircraft 2 (CLIMB/DESCEND)

- 4.2.3 Remember aircraft 2 commanded RA
- 4.2.4 Interpret aircraft 2 data block VS (+/-)
- 4.2.5 Remember aircraft 2 VS (+/-)
- 4.2.6 Recall aircraft 2 RA command (CLIMB/DESCEND)
- 4.2.7 Compare aircraft 2 RA command and VS (+/-)
- 4.2.8 Verify aircraft 2 following RA

4.3 Verify reciprocal RA manoeuvres

- 4.3.1 Recall aircraft 1 RA command (CLIMB/DESCEND)
- 4.3.2 Recall aircraft 2 RA command (CLIMB/DESCEND)
- 4.3.3 Compare RA commands aircraft 1 vs. aircraft 2
- 4.3.4 Verify reciprocal manoeuvres

5 Identify potential third party conflicts

5.1 Identify trajectory of encounter aircraft

- 5.1.1 Locate aircraft
  - 5.1.1.1 Detect RAD
- 5.1.2 Interpret aircraft data block (altitude, VS (+/-))
- 5.1.3 Interpret aircraft heading
- 5.1.4 Remember aircraft trajectory

5.2 Identify proximate threats to encounter aircraft

- 5.2.1 Scan screen
- 5.2.2 Identify potential proximate threat
- 5.2.3 Interpret potential threat aircraft data block (altitude, VS (+/-))
- 5.2.4 Interpret potential threat aircraft heading
- 5.2.5 Remember potential threat aircraft trajectory
- 5.2.6 Recall encounter aircraft trajectory
- 5.2.7 Compare trajectories of encounter and potential threat aircraft
- 5.2.8 Verify conflict
- 5.2.9 Remember call signs of third party conflict aircraft

6 Prevent third party conflicts

6.1 Determine appropriate avoiding action

- 6.1.1 Recall call signs of third party conflict aircraft
- 6.1.2 Recall trajectories of third party conflict aircraft
- 6.1.3 Determine avoiding action as appropriate

6.2 Issue clearance to third party aircraft

- 6.2.1 Recall call sign third party aircraft
- 6.2.2 Contact third party aircraft via RT
  - 6.2.2.1 Issue clearance avoiding action
  - 6.2.2.2 Confirm read back

7 Provide traffic info to encounter aircraft

7.1 Contact encounter aircraft via RT

- 7.1.1 Confirm read back

8 Provide traffic info to third party aircraft

8.1 Contact third party aircraft via RT

- 8.1.1 Confirm read back

9 Determine end of RA encounter

9.1 Notice RAD OFF

- 9.1.1 Identify both encounter aircraft
- 9.1.2 Detect stabilised altitude both aircraft
- 9.1.3 Determine Clear of Conflict
  - 9.1.3.1 Remember trajectories aircraft 1 and 2
  - 9.1.3.2 Compare trajectories aircraft 1 vs. 2
  - 9.1.3.3 Determine Clear of Conflict
- 9.1.4 Call aircraft via RT
  - 9.1.4.1 Query aircraft for Clear of Conflict verification
  - 9.1.4.2 Affirm Clear of Conflict

9.2 Receive RA report Clear of Conflict

- 9.2.1 Identify both encounter aircraft
- 9.2.2 Detect stabilised altitude both aircraft
- 9.2.3 Determine Clear of Conflict
  - 9.2.3.1 Remember trajectories aircraft 1 and 2

- 9.2.3.2 Compare trajectories aircraft 1 vs. 2
- 9.2.3.3 Determine Clear of Conflict
- 9.2.4 Call aircraft via RT
- 9.2.4.1 Query aircraft for Clear of Conflict verification
- 9.2.4.2 Affirm Clear of Conflict
- 9.3 Notice end of manoeuvre
- 9.3.1 Detect stabilised altitude
- 9.3.2 Determine Clear of Conflict
- 9.3.2.1 Remember trajectories aircraft 1 and 2
- 9.3.2.2 Compare trajectories aircraft 1 vs. 2
- 9.3.2.3 Determine Clear of Conflict
- 9.3.3 Call aircraft via RT
- 9.3.3.1 Query aircraft for Clear of Conflict verification
- 9.3.3.2 Affirm Clear of Conflict
- 10 Resume ATC authority
- 10.1 Verify resumption of clearance
- 10.1.1 Contact aircraft via RT
- 10.1.2 Recall aircraft original clearance
- 10.1.3 Acknowledge aircraft resumption of clearance
- 10.2 Issue new clearance as appropriate
- 10.2.1 Compare trajectories
- 10.2.2 Determine whether new clearance necessary
- 10.2.3 Issue new clearance as appropriate