ATC CTA: Cognitive Task Analysis of Future Air Traffic Control Concepts

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Abstract. Traffic Collision Avoidance System (TCAS) is a flight deck tool to display and help avoid proximate air traffic. Until now, TCAS information has not been presented to the air traffic controller. Attention has focused in recent years on the potential benefits of "downlinking" to the air traffic controller TCAS Resolution Advisories (RAs) in near real time, Such presentations, it is thought, could benefit situation awareness and joint decision making between controller and pilot.

A cognitive task analysis (CTA) was recently conducted into the present-day and future RA Downlink (RAD) operational concepts. The aim was to identify the cognitive elements underlying performance in the RAD scenarios, and to hopefully identify potential error mechanisms. On the basis of a functional task description and cognitive walkthroughs, CTA proceeded to decompose the tasks imposed on the controller. The impact of various specific non-nominal events (e.g. pilot reports RA, but does not initiate an evasive maneuver) was investigated. Finally, a set of cognitive elements and potential error mechanisms was identified.

1 Background

Traffic Collision Avoidance System (TCAS) is a 'last-resort' method of preventing mid-air collisions or near-collisions between aircraft. TCAS 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. A 2002 midair collision over Überlingen Germany was triggered, in part, by incompatible clearances issued by air traffic control (ATC) on the one hand, and the airborne TCAS on the other. Until now, ATC has not had access to TCAS indications as they are displayed to the pilot. Instead, the controller currently relies 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 is unaware and may therefore attempt to resolve the conflict by issuing (potentially incompatible) instructions to the incident aircraft, thereby introducing the risk that the pilot may choose to override TCAS advisories. It was just this situation that occurred over Überlingen.

Increased attention is now being paid to the possible benefits of displaying to ATC any RA messages as they are displayed to the pilot. Such alerting, it is thought, could

* The views presented here are those of the author, and do not necessarily reflect those of any agency.

D. Harris (Ed.): Engin. Psychol. and Cog. Ergonomics, HCII 2007, LNAI 4562, pp. 497–503, 2007.

benefit situation awareness and joint decision making between controller and pilot. Under EUROCONTROL's Feasibility of ACAS Downlink Scenario (FARADS) program, an operational concept is being defined in which cockpit-generated RAs would trigger a downlink to ATC details of the conflict, including involved aircraft, prescribed evasive maneuver and clear-of-conflict indications. As part of this effort, a Cognitive Task Analysis (CTA) was conducted to help compare the potential for human error under current RA operations and the RAD operational concept.

Task analysis refers to a family of techniques used to describe and analyze 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.

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 recognizes 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, analyzing, 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 behavior. 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 behavioral 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

2 Method

A functional task description was developed in a previous Functional Hazard Analysis (FHA), and this served as the basis for the CTA. Figure 1 shows a functional description of the overall analysis, into which CTA fit. On the basis of FHA, CTA aimed to identify the cognitive elements underlying performance in the RA scenarios, and to identify potential error mechanisms. 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.

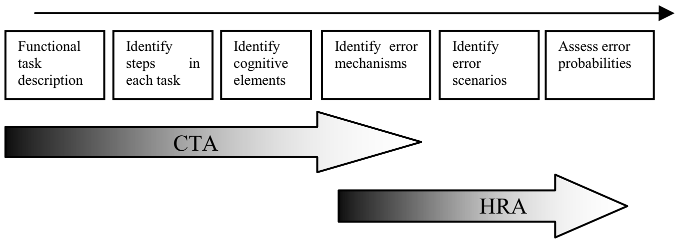


Fig. 1. Analysis of the RAD operational concept

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. As shown in table 1, each of the five scenarios was considered in the context of two operational concepts: current day and RAD variants.

Table 1. The ten scenario variants

Scenario	**Operational Concept**	
	Current day	*RAD*
1: Nominal RA: The pilot reports correctly and in a timely fashion, and follows the RA correctly	**1**	**1R**
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 maneuver: No pilot report, and no RA	**4**	**4R**
5. Correct report, no maneuver: Pilot reports correctly, but does not maneuver	**5**	**5R**

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 (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 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). Tasks were decomposed into 3-6 subtasks, as recommended in [13]. A mental walkthrough was conducted to identify (based on prompt questions, as needed) the following types of information:

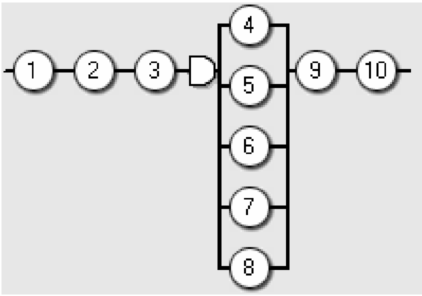
- Who was responsible;
- What, if any, decision was required at the moment;
- What information was required;
- Whether long term knowledge was required;
- What information was exchanged;
- Sequence dependencies in the information flow (e.g. “if he doesn’t give me that information now, I need this information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

On the basis of notes, sketches, and transcribed discussion, a formal CTA flowchart was developed for the two operational concepts (i.e. with and without RAD) under nominal conditions. Except where decomposition revealed relevant differences between the operational concepts, 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 two operational concepts.

3 Results

The CTA focused on the period between when an RA is activated, through when the controller detects the RA (generally via pilot report or RAD, but sometimes on the basis of noticing a maneuver) until when ATC ultimately resumes authority. As shown figure 2, a total of ten high level tasks fell out of the CTA. In the process of normal scanning and control, the steps of confirming an RA encounter, confirming 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.

Detailed presentation of results (expanded flowcharts ran into many pages) is well beyond the scope of this article. Instead, summary findings are presented here. On the



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

Fig. 2. CTA-identified high level tasks, for the nominal RA scenarios

basis of the CTA, a number of potential issues came to light, with respect to the RAD concept. Among these are the following notable examples:

- That the chief benefit of RAD appears to lie in the speed with which changes (i.e. aircraft evasive maneuvers) can be anticipated and traffic located onscreen;
- That RAD can introduce potentially ambiguous control situations between air and ground;
- The RAD visual " pop-out" effect transforms some current ATC tasks (scanning screen, locating aircraft, etc) to largely perceptual ones;
- RAD could prime controllers to mistakenly hear what they expect to hear;
- Given the near certainty of RAD false alarms, the issue of trust must be addressed further.

4 Discussion

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 (remembering call sign, scanning screen, identifying aircraft calling) to a largely perceptual one. 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 confirm the presence of both an RA and the presence of a coordinated maneuver-- but it also pays potential dividends during and at the end of 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. In fact, pilots are now trained to report “Unable TCAS" in response, so the risk lies not in the aircraft following a clearance after RA, but in ATC mistakenly thinking it has authority, and planning other traffic accordingly;
- 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. maneuver, report);
- The potential costs of RAD in terms of attention-tunneling, and the risk of neglecting other traffic, must be clarified.

CTA was a judged afterward to have been an extremely valuable exercise. This was not a foregone conclusion, given the (deceptively) simple scenario apparent in the TCAS RA scenario. In retrospect, it is only by systematically stepping through such scenarios and identifying underlying information flows and decision points, that certain tasks, decision voids and error possibilities can become apparent.

References

[1] Kirwan, B., Ainsworth, L.K. (eds.): A Guide to Task Analysis. Taylor and Francis, London (1992)
[2] Beevis, D., et al.: Analysis techniques for man-machine system design. In: NATO document AC/243 (Panel 8)TR/7. vol. 1(2), Brussels, NATO, Belgium (1994)
[3] Schraagen, J.M.C., van Chipman, S.F., Shalin, V.L.: Cognitive Task Analysis. Lawrence Erlbaum Associates, Inc. Mahwah, NJ (2003)
[4] Stammers, R.B., Carey, M.S., Astley, J.A.: Task analysis. In: Wilson, J.R., Corlett, E.N. (eds.) Evaluation of Human Work, Taylor and Francis, London (1990)
[5] Latorella, K.A., Pliske, R., Hutton, R., Chrenka, J.: Cognitive task analysis of business jet pilots’ weather flying behaviors: Preliminary results. In: NASA-TM-2001-211034, NASA Langley Research Center, Hampton, VA (2001)
[6] Manning, Carol, A.: Measuring Air Traffic Controller Performance in a High-Fidelity Simulation. In: FAA technical report, FAA CAMI, Oklahoma City, USA (January 2000)
[7] Petersen, B., Stine, J.L., Darken, R.P.: Eliciting knowledge from military ground navigators. In: Montgomery, H., et al. (ed.) How professionals make decisions: Research and applications, pp. 351–364. Erlbaum, Mahwah, NJ, USA (2005)
[8] Rasmussen, J.: Information Processing and Human-Machine Interaction: An Approach to Cognitive Engineering. North-Holland, New York (1986)
[9] Vicente, K.J.: Cognitive work analysis: Toward safe, productive, and healthy computer-based work. Lawrence Erlbaum & Associates, Mahwah, NJ (1999)
[10] Gordon, S.E., Gill, R.T.: Question probes: A structured method for eliciting declarative knowledge. AI Applications In. Resource Management 3, 13–20 (1997)
[11] Reynolds, R.T., Neville, K.: Job Analysis versus Cognitive Task Analysis of Air Traffic Controllers. In: Paper presented at the Military Psychology Conference, VA (2002)

Glossary

ATC	Air Traffic Control
CTA	Cognitive Task Analysis
FARADS	Feasibility of ACAS RA Downlink Scenario
FHA	Functional Hazard Analysis
HRA	Human Reliability Analysis
RA	Resolution Advisory
RAD	Resolution Advisory Downlink
TCAS	Traffic Collision Avoidance System