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Investigating Air Traffic Controller Conflict Resolution Strategies

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Abstract

This document reports a study investigating how controllers develop resolutions for aircraft conflict situations in en route air traffic management. Forty-five controllers in seven countries were interviewed individually and in groups, to determine their best resolutions for a series of statically presented conflict scenarios. Factors, rules and principles that they used to generate their resolutions, as well as actions they would not take (seen as poor practice) were elicited. The study showed sufficient agreement between controllers to suggest that an advisory system for controllers, such as is envisaged by the Conflict Resolution Assistant (CORA2) system, is viable. The information collected in this study can therefore be used to inform the developing CORA2 algorithm.

Keywords

Conflict	Resolution	Rules	Factors
Principles	Expertise	Human Factors	

Contact Person(s)	Tel	Unit
Barry Kirwan	7886	System Safety, EEC
Mary Flynn	7410	CORA team

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EATMP Infocentre
EUROCONTROL Headquarters
96 Rue de la Fusée
B-1130 BRUSSELS

Tel: +32 (0)2 729 51 51
Fax: +32 (0)2 729 99 84
E-mail: eatmp.infocentre@eurocontrol.int

Open on 08:00 - 15:00 UTC from Monday to Thursday, incl.

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AUTHORITY	NAME AND SIGNATURE	DATE
Project Manager	Mary Flynn	
Programme Manager	Seppo Kauppinen	

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EXECUTIVE SUMMARY

As air traffic increases, the ability of controllers to handle the traffic safely and efficiently becomes strained. One way to assist controllers in managing such traffic level increases, is via a computerised tool that will provide conflict detection and resolution advice when they need it. Whilst conflict detection systems are well under development and have been partly implemented in the US, for example, conflict resolution systems have not yet reached that level of maturity. Furthermore, conflict resolution systems are in some senses more challenging and ambitious, and also more contentious, as they encroach on the very heart of the controller's expertise and function.

Therefore, a project has been undertaken to provide a tool that is to a large extent 'human-centred', and clearly maintains the role of the controller, but which will also enable the controller to handle increased traffic levels, via providing conflict resolution advice. This tool is called the Conflict Resolution Assistant or CORA.

CORA is intended to provide resolutions that would seem reasonable (or even 'smart') to controllers, enhancing both trust and the 'rapport' between controller and automated tool, so that the joint system response will be fast and efficient. In order to achieve this, the controller conflict resolution process needs to be better understood, in terms of what resolutions controllers offer for a range of scenarios, what factors affect that choice process, and what controllers would decide not to do. This report details an investigation into this process which has elicited many resolution types, influencing factors, principles and rules controllers use, and has also considered the variability between controllers.

The investigation used a standardised set of twelve conflict scenarios of varying complexity, which were presented to 45 controllers in seven countries, as static scenarios. Each controller individually resolved the scenario, stating what factors affected the choice of resolution, what principles or rules were used, and also mentioned potential solutions that would not be seen as good practice by controllers. Controllers in five of the countries then considered the scenarios in a group exercise, again resolving the scenarios.

The results have provided a rich data source on controller conflict resolution. Many principles have been elicited, and these have been classified into different levels, from general to conflict-geometry specific resolutions. Over fifty factors have been elicited, and the main ones have been prioritised across scenarios. Such information can inform the next stage of the CORA development process, which is the production of the conflict resolution algorithm, the 'engine' or heart of the CORA system.

The results in general are favourable towards the CORA approach and philosophy. There has been a concern that controller variability will make it difficult for a system such as CORA to provide advice that would satisfy most controllers. Nevertheless, the results of this study show that across all subjects and scenarios tested, four resolutions for the conflict pair of aircraft would satisfy >80% of all

subjects, and in some cases >90%. This result endorses the CORA approach, suggesting that a human-informed conflict resolution assistant is feasible. The next phase of the CORA project aims to turn this feasibility into a reality, so that capacity can be safely and efficiently increased.

1. INTRODUCTION

1.1 The Need for a Conflict Resolution Assistant (CORA) tool

European air travel is predicted to double in capacity over the next ten years, placing considerable burden on the current air traffic management system, and controllers. One approach to alleviate this burden and to reduce controller workload, is to provide automated support, in the form of computerised tools, for key tasks, such as conflict detection, and conflict resolution. Such tools, in theory, will allow the controllers to manage more aircraft and to avoid conflicts, and at the same time to give a better service to aircraft in terms of preferred routes and minimised deviations.

Controllers are masters at real-time conflict detection and resolution, and this expertise in these particular system functions is the result of rigorous selection and intensive training in air traffic control over a prolonged period. Conflict detection and resolution are indeed seen as core functions of the controller today, i.e. controllers, when asked to define their job simply, often say ‘separating aircraft’. Any tools that therefore purport to support such functions have two main obstacles to overcome. The first is the development and provision of a viable alternative that is at least as good as controller expertise (and preferably better). The second is ensuring that such tools will be used by controllers, when those very tools can be seen as a threat to those same controllers. One approach being developed at Eurocontrol is the Conflict Resolution Assistant (CORA) project. This project aims to develop a conflict resolution system which is ‘controller-friendly’, and in fact will borrow heavily from controller expertise to develop resolutions to future conflicts. The justification for this approach is given in the literature review companion report to this current work (Kirwan, 2001a). In essence, this review argues for a ‘Human Informed Design’. The following sub-section summarises the philosophy being pursued in the CORA project.

1.2 Towards a human informed system

Currently, assistance with conflict detection exists in many places via various forms of short term conflict alert, and in several air traffic centres, medium term conflict detection is now being piloted and implemented. It is too early to say whether the medium term conflict detection tools will be successful. However, assuming they are at least moderately successful (i.e. they enhance air traffic management and are used effectively by the controllers), the next step to consider is conflict resolution.

A prior European study (Nijhuis, 2000) called the RHEA project (Role of the Human in the Evolution of ATM) considered future automation prospects and their likely impact on the controller. The study tried to determine what level of automation would result in best performance. Different levels were considered, from full automation to fully manual, but with many levels in between, such as computer-generated advice, with the controller making the decision, to the computer implementing its own decision unless the controller vetoed it. There were also some flexible levels of automation (e.g. the automation taking over when the controller's workload became too high, or when the controller requested it). These different levels were evaluated qualitatively, and also a predictive error analysis was carried out to try to determine the best level of automation (Kirwan, 2001b). The results were that the best levels involved the computer or machine giving advice, and then the controller deciding to accept or reject it. Furthermore, one condition that favoured particularly well at this level of automation, was called *'cognitive tools'*. The concept of a cognitive tool is that the tool itself, which gives advice to the controller, is based around the controller's own mental model of how the situation should be resolved, as opposed to being derived from purely mathematical models etc. Such an approach can be seen as a form of 'Human Centred Automation' (Billings, 1996). The Eurocontrol Conflict Resolution Assistant (CORA) Project aims therefore to produce a controller-centred approach to conflict resolution (for a fuller justification of this rationale, see Kirwan 2001b).

1.3 Allocation of function between human and machine

In conflict resolution, there are often many potential resolutions. The two principal problems for a controller or an automated tool are essentially the same – the first is one of trying to define the possible solutions, and the second is that of trying to derive an optimal resolution. In practice, the 'solution space' is often comparatively large. Optimising according to numerous factors is actually something humans are good at, as they can use their judgement skills and can build up an extensive experience base. In terms of finding all possible resolutions, and identifying the 'solution space', this is something that is probably best achieved by a machine – it will be faster, less bound by experience, and more accurate. Many of the resolutions found, however, would not be optimal, and some of those that remained would seem to controllers to be strange or not good practice, or simply failing to take account of numerous contextual factors they themselves use to deliver a safe and expeditious service to air traffic. This body of opinion should not be ignored, as it has worked effectively and safely for half a century. If it can be understood, and in some way captured, then aspects of it can be used to refine the resolutions identified by a mathematical computerised algorithm. Such a refinement process would then lead to a set of resolutions that should seem reasonable to controllers.

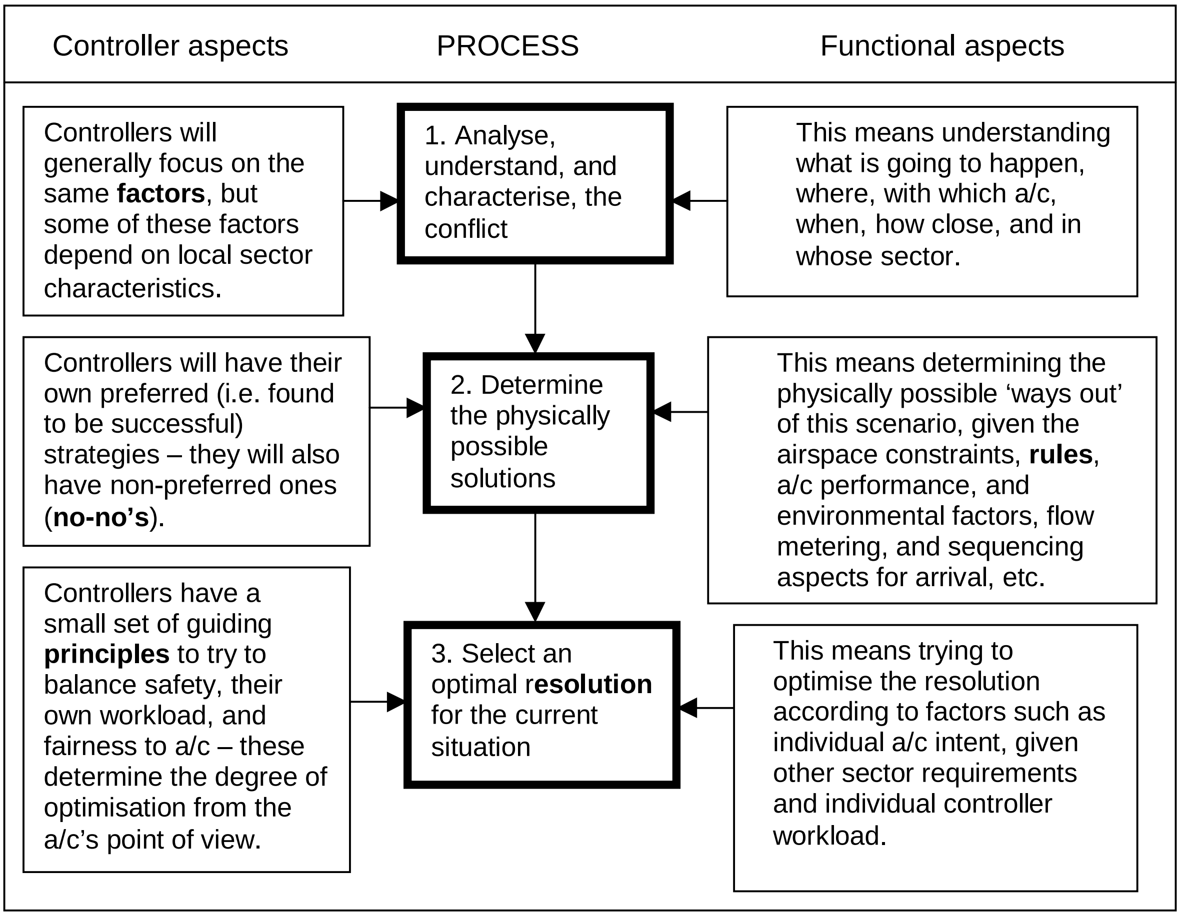
The added value of such a process, would be possibly a wider set of resolutions, and certainly a more quickly-derived set of resolutions. This added value might not count for much in today's airspace with current traffic levels, but in future airspace with much higher traffic, and more flexible defined route structures, such assistance might make the difference between high delays and a good quality of service. Such a system need not be used all the time by controllers (indeed, for the sake of skill retention, this would not be a good idea). Additionally, the controllers would still need to evaluate the resolutions. There will always be local factors that a computerised system will not be able to deal with or anticipate. The human controller will still be the most critical element in the system to ensure both safety and quality of service, but with such a computerised tool, a better quality of service at higher traffic levels should be deliverable.

Having outlined the respective functions of human and machine, and having seen that it should indeed enhance air traffic management system performance, and maintain a critical role for the controller, the next question is therefore one of how controllers actually do conflict resolution.

1.4 The Controller Conflict Resolution Process – what information are we looking for?

If CORA is to be human-informed, then there must be an understanding of how controllers perform the task of conflict resolution. A literature review carried out for this work (Kirwan 2001a) led to the formulation of a simplified model of how controllers perform conflict resolution, a shown in Figure 1.

Figure 1 – The Controller Conflict Resolution Process



The above process leads to the selection of a resolution. Essentially the types of instructions given will be in the following dimensions:

- Lateral (turn one or both a/c)
- Vertical (climb or descend a/c)
- Speed (increase or reduce)

The exact format of that resolution will be up to the controller. For example, a controller may be less inclined to give compound instructions (e.g. turn and descent). Also, controllers will tend to be more categorical, e.g. giving vectors of 5, 10, or 15 degrees etc., rather than selecting other integers or even decimals between 5 and 15 degrees (e.g. '..turn 14.3 degrees right..').

There are therefore several key elements of the process that can be captured. These elements are the rules that controllers use (that define 'legal' resolutions), the principles or strategies that help to reduce the solution set and underpin their resolutions, and the factors that help both to characterise the conflicts and also arrive at the best resolutions. There is also knowledge of the circumstances in which certain possible solutions are in fact seen as not being best practice, and in fact are seen virtually as violations by controllers (these are called 'no-no's ' in this study). Together, these are the elements that can in theory be captured – they are not the conflict resolution process itself, but are the elements that characterise this process. If these elements can be elicited, then they can in theory be used to inform the design of a computerised tool. If this process of informing is successfully implemented, the resultant tool will produce resolutions that will be judged to be both realistic and reasonable to controllers, as they are using many of the same elements and, ultimately, the same values that controllers already utilise.

To summarise, in terms of what information we are looking for from controllers, that could inform the design of a computerised tool, there are four main categories of information. First it is useful to know the rules that controllers apply when carrying out conflict resolution. These rules bound the possible resolutions. Second, the factors that controllers consider when analysing conflicts, and their relative importance, are clearly important, as they help to determine the nature of the actual resolutions that will be seen as possible, and also enable optimisation of the resolution chosen. Third, the principles controllers use to pick between alternative potential solutions, are of significant interest. Fourth, the types of solutions that are theoretically possible, but which real controllers would never do, called 'no-no's ' in this project, are important for retaining trust in the CORA support environment. If a computerised tool were to suggest 'no-no's', controllers would quickly lose trust in the system and it would not be used.

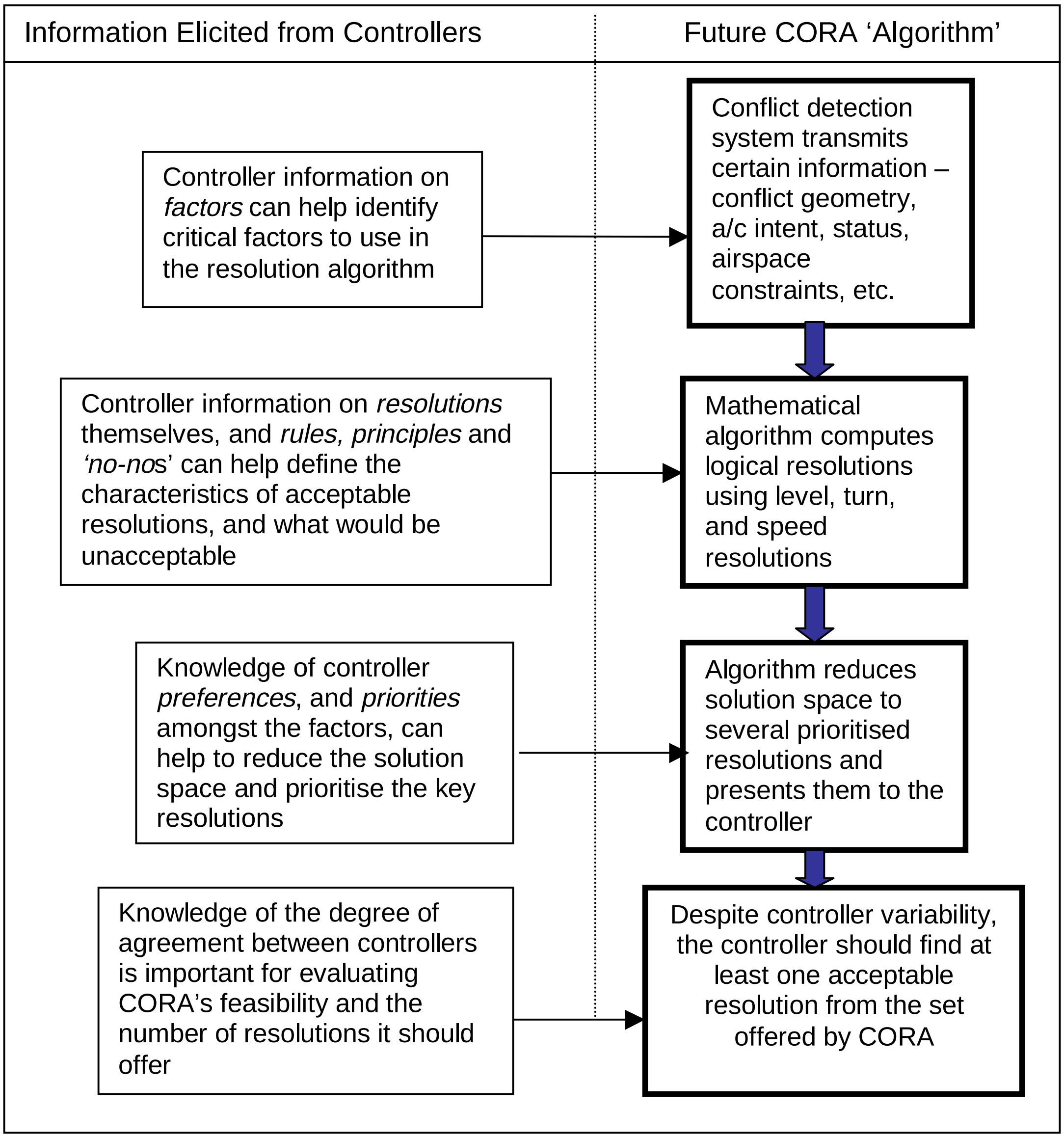
As an example, in a two-aircraft 90 degree crossing situation, there are many potential solutions using turns, speed, and level, applied to one or both aircraft. However, a climb to a safe intermediate level might violate the semi-circular **rule**, so this would not be selected as an option (although some controllers might use it temporarily as a safe intermediate level). A controller might therefore instead elect a solution to turn one of the a/c left. The controller may use the simple **principle** of turning one a/c behind the other, usually the one to get to the crossing point last. This determines which a/c to turn. However, the first question is why left and not right, and why a turn and not a climb or descent, or a speed manipulation, or even a combination of these? Perhaps it is because the left turn takes this aircraft closer to its intended destination (a **factor**) than a right turn, and that small turns are seen as more efficient (another **factor**) for the aircraft than undesired level changes. There could be other factors involved such as wind direction. If there was enough time before the conflict, a mathematically plausible solution might be to accelerate this aircraft and cut across in front of the other one. But it might be that few controllers would countenance such a resolution, seeing it as dangerous and against their training (therefore a **no-no**), no matter what the predictions say. This example highlights the size of the solution space (many potential solutions), the application of principles (turn the second one behind), no-no's (don't cut in front), and the factors (a/c intent; fuel efficiency) that fine-tune the resolution type (in this case 'turn') to go left rather than right. The idea behind CORA is that its algorithm should consider such information and narrow down the solution space to a few resolutions that a controller would find reasonable, and hopefully 'smart'.

Controller strategies may thus be thought of as the (overt) top level of conflict resolution behaviour. They are the very conscious and observable behaviour resulting from the controllers' thinking and experience. Underlying these strategies, however, are the factors, principles, rules and no-no's that determine those strategies for each scenario. Therefore, if controller strategies, factors, principles etc. can be elicited, they can be used to fine-tune a conflict resolution tool, and indeed to inform the conflict resolution algorithm. This is shown schematically in Figure 2.

In Figure 2, an additional factor is added in the final box on the left. It is necessary to evaluate the 'stability' of the controller information. If controllers have widely differing opinions, it will be hard to incorporate the information into a computerised system, and hard to present a small set of candidate resolutions that will satisfy most controllers. In short, if there is too much variability between controllers, then CORA may have a harder time gaining the trust of controllers. The amount of agreement and overlap between controller resolutions for various scenarios therefore needs to be assessed.

In summary, a Human-Informed-Design approach or philosophy has been outlined for the CORA system, and the types of information needed to achieve such a system have been outlined. The most serious question, therefore, is whether development of such a system is feasible. This feasibility rests upon whether controller factors and principles used in conflict resolution are relatively stable, and whether such information can in fact be elicited reliably so that it can be used to inform the design of a computerised tool. This feasibility is evaluated in the field study reported in this volume.

Figure 2: How Controller Information Informs a Computerised Tool



2. AIMS OF THE STUDY

There are two main aims of this study:

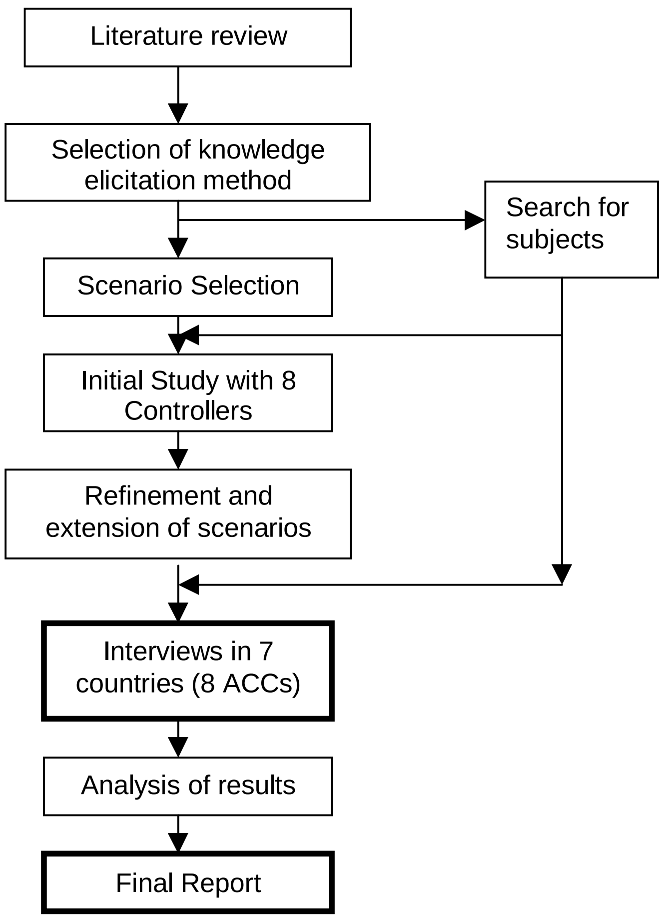
- To elicit data from controllers on the rules, factors, principles, and 'no-no's' that influence their conflict resolution behaviour.
- To evaluate whether there is sufficient agreement between controllers to support the development of a workable CORA system.

Having decided to develop a controller-centred approach, the next question becomes one of how to elicit the expertise from controllers. The approach adopted is defined in the next section.

3. APPROACH

The overall approach is shown in Figure 3.

Figure 3: Approach for the Investigation of Controller Conflict Resolutions



3.1 Literature review

The literature review considered the human-centred design approach in this area, and reviewed other tools (human-centred and other) for conflict resolution assistance. The review also looked for scenarios used in controller conflict resolution studies, and factors affecting conflict resolution performance. The review is fully documented in Kirwan (2001a), and acted as the basis for the following methodological approach.

3.2 Selection of knowledge elicitation approach

The basic approach adopted was to elicit the expertise from controllers directly. This followed on from the related literature review which showed that there was little [publicly] available and consolidated evidence of how controllers solve the variety of conflict solutions they can be faced with, with the exception of the AERA and PARR programmes of work (see Kirk et al, 2000). Since these works were of US origin, with different operational cultures and constraints than in Europe, it was decided to attempt to elicit the information more directly from controllers.

Two methods were considered. The first would have entailed extensive high fidelity laboratory simulator-based studies of controllers solving conflicts in realistic and dynamic airspace scenarios. The second approach was usage of relatively simplified scenarios shown statically to controllers. The advantage of the former approach is contextual realism. There were two main potential disadvantages however. The first was the expense, which would be considerable in terms of simulation study preparation and running time and controller resources. The second was that many of the factors that affect and influence conflict resolution might be over-looked, because they are embedded in the scenario context, and would remain 'implicit' or 'tacit'. For example, a controller might be using 'wind direction' as a factor, but actually be unaware of the fact. In a simulation it would be hard to realise that such a factor was being used, as the analyst might not spot its usage, and the controller might not mention it. An alternative approach therefore is to use a simpler set of static scenarios that are generic and minimally described. Then, the controller has to ask questions to determine the status of factors important to that controller. This is known as the '*with-held information technique'* and has been used before in air traffic control research (see Kirwan & Ainsworth, 1992 for a description of the method, and Lamoureux et al, 1999 for an example of an application of the method).

3.3 Scenario selection and refinement

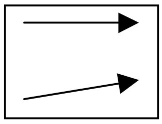
The literature review, and discussions with controllers and instructors at the EEC, IANS (Institute of Air Navigation Services) and NATS CATC (College of Air Traffic Control), led to the selection of a number of scenarios for eliciting conflict resolution factors, principles, and rules, and for investigating the degree of agreement between different controllers. It was decided to test a number of these scenarios with a number of controllers before the main study took place, to maximise the chances of gaining the information required for CORA. The initial scenarios developed were as follows: Catch-up, Head-on, Crossing (narrow angle), Climb-through, Descend-through, Descend-through – opposing traffic, Vertical convergence (opposing traffic, both climbing), Opposing traffic (one a/c climbing one descending)

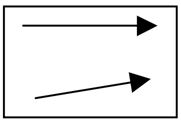
Thus, eight simple conflict geometry scenarios were presented in the same sequence to eight individual controllers, the sequence being intended to represent progressive complexity. In a few cases an additional ninth scenario was added (right angle crossing). The scenarios used, in order, were as follows:

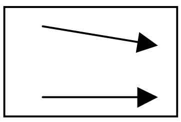
1. Head-on  (plan view)

2. Catch-up  (plan view)

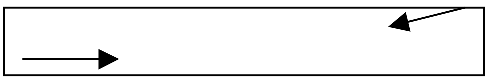
3. Narrow angle of lateral convergence (same level) (plan view)



4. Climb-through (same vertical plane)  (side view)

5. Descend-through (same vertical plane)  (side view)

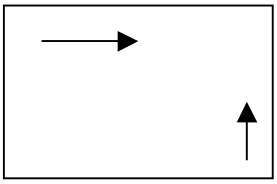
6. Descend-through & opposing traffic (head-on & same vertical plane) (side view)



7. Climbing conflict – 2 a/c climbing and converging, same vertical plane (side view)

8. Opposing climbing and descending traffic – same vertical plane (side view)

9. Right angle crossing traffic (same level – plan view)



The literature review and these preliminary controller interviews led to a number of insights on the types of scenarios that would be best to elicit controller information. First, it was obvious that certain simple aircraft pairings could still yield good information. In terms of finding heuristics that controllers use, simple scenarios are quite effective, as the rules are less complex and easier for the controller to elucidate. The resulting heuristics may be seen as the basic building blocks for conflict resolution. Second, and somewhat paradoxically, some seemingly more complex resolutions may be easier to resolve. This is because some extreme conflict scenarios will leave the controller with only one logical resolution, i.e., only one way out. In such a case the controller does not need to consider the complex trade-offs between other competing factors (e.g. which a/c has been manoeuvred already, which aircraft is meant to be at start of descent first, etc.), because they are ultimately secondary in safety terms. The controller's job therefore clarifies because there is only one way out, so the controller will take it. This aspect highlights that there are two principal aspects to conflict resolution:

- finding the physically possible and practicable solutions (the 'legal solution space')
- finding the optimal solution from the solution space available (the best resolution(s))

Therefore, as the 'logically available' solution space decreases, the optimisation process reduces – there are less degrees of freedom to choose between. The implication for this study was that scenarios should not necessarily reduce the solution space to the point where only one solution is available – such scenarios may be testing for controllers if sufficiently complex, but may well yield less information on strategies. Such scenarios may therefore be useful for the later validation of CORA, but would not be useful at this more formative stage.

A further insight gained from the initial study was that all the basic scenarios were seen as relatively straightforward and of 'low uncertainty' for the controllers, i.e. the controller had low uncertainty that their resolution would work and would be safe. The scenarios that led to slightly less certainty for controllers were those involving two vertically moving aircraft. However, it was possible for the controllers to envisage conditions (i.e. detailed factors) that could render even the simple basic conflict geometries into more difficult problems to solve and derive optimal solutions. These detailed factors could involve other traffic 'boxing them in', or could be less geometric in nature, e.g. referring to arrival sequences making an 'arrival-sequence-sensitive' solution more difficult to achieve. This led to the consideration of using 'context a/c' in the scenarios, as several other authors in this field have done (see the Literature Review), which not only add a dimension of realism to the scenario, but can also cause the controller to produce more varied resolutions.

Additionally some controllers at first said that certain scenarios should not occur, e.g. head-on or opposing descend-throughs, e.g. due to the semi-circular rule[1] and other ATM conventions. However, most controllers on reflection said that such situations do indeed occur, even if they are less frequent, and the controllers would in fact sometimes cite sectors of airspace where such events would be seen relatively frequently.

Finally, there was some overlap of solutions, and most controllers identified between 2 and 3 solutions for each scenario. This suggested that the search for 'standard' solutions that may be acceptable to a wide range of controllers, could be a fruitful one.

From the literature review and the preliminary interviews, it therefore appeared that a mixture of scenarios was required: relatively simple conflict geometries, and significantly more complex ones, involving context a/c, some of which would 'block' certain resolutions. The former would be useful to elicit the basic principles of conflict resolution, and the latter the more complex mechanics of dealing with multiple aircraft in confined airspace with additional constraining a/c and conflicting requirements, as well as conflicting trajectories. This 'progressive' strategy enabled the main solutions to be elicited at the first (simple) presentation, effectively defining the solution space referred to earlier. The second more detailed scenario would then be more helpful in eliciting factors, and seeing how the controllers would narrow down the solution space to get to a reasonable and safe/efficient resolution. This two-levelled approach was therefore adopted for the study, to maximise information gained on resolutions and related factors/principles.

[1] This rule basically is aimed to ensure that flights in opposite directions are at different flight levels.

The primary candidates for 'simple' scenarios were head-on, catch-up, crossing, descend-through, climb-through, and right-angle crossing climb-through. Candidates for more complex scenarios would then involve the conflict pair, and other aircraft and airspace restrictions that constrain the most obvious solutions. Some of these scenarios should have the potential for secondary conflicts. It was decided therefore that six main scenarios would be used, which would be presented in simple (only 2 a/c present) and complex (same conflict pair, but with addition of context a/c and other factors) formats. Some of the context a/c would be potential secondary conflictors, making it more difficult for the controllers.

Additionally, it was decided to add two other scenarios, which would involve multiple a/c conflicts, e.g. more than one conflict pair in the scenario, and more than 2 a/c in the conflict. These scenarios were designed to be demanding for the controllers, and were indeed found to be fairly challenging, though all but one controller successfully resolved these additional scenarios. The reason for having these additional two scenarios was to test resolution strategies in such multiple conflict scenarios, since CORA is intended to be used in heavier traffic situations than exist today. In particular, there was a desire to see whether controllers solved conflicts 'pairwise', i.e. one conflict at a time, or aimed for a 'global resolution', which optimally resolved the conflicts for all a/c in the 'frame'. This issue is important for the algorithm underlying any conflict resolution tool.

Therefore, the scenario selection has three components:

- 6 Main conflict geometries (single conflict pair)
- 6 Main conflict scenarios plus context and blocking a/c
- Complex scenarios involving multiple a/c

These scenarios were reviewed by controllers and it was agreed they were a good basis from which to elicit conflict resolution strategies, factors and principles. This meant that they had 'elicitation power'. However, there was concern over the realism, and the need to have more context in the scenarios than had been the case in the initial study trials. Therefore, a hypothetical and generic airspace was created, as shown in Figure 4, which represented medium fidelity for an air traffic scenario. This airspace had the following characteristics:

- Several airways
- Areas of non-civil-controlled airspace (Class G airspace) – the open Flight Information Region (FIR) – transiting an a/c through these regions would depend on military activity in the FIR and therefore required permission and/or civil-military co-ordination
- Exit areas for aircraft (A, B, C and F)
- A smaller and a larger airport (D and E)

- A/c leaving by exits A or B were probably over-flying and heading for the Atlantic
- A/c leaving via C or F could be landing in the next sector or could be over-flights
- An airway width of either 15 nm (for six of the ACCs) or 30 nm (for Shannon and Maastricht Area Control Centres [ACCs])

The different airway widths (the last bullet-point above) were chosen for two reasons. First, many sectors in Europe are relatively short, and so the 15nm width gave a realistic sector width for many controllers, whereas in Maastricht and Shannon, these centres have some much longer sectors to control. Second, it was desirable to have two different 'look-ahead times'. Thus, for 15nm airways, the time-before-loss-of-separation ranged from 5 – 12 minutes, whereas with the larger sector airways, the range was 8 – 14 minutes. The latter was perhaps more related to planning control, the former more tactical. It was of interest to see whether resolutions changed dramatically as a function of these two different time-frames. In practice, they did not vary significantly, suggesting that conflict geometry and other factors were more dominant.

The scenarios were shown to controllers in the same progressive sequence, moving from catch-up, to head-on, to narrow angle convergence (crossing), to a climb-through, a descend-through, and a right-angle crossing and climb-through, and then two complex scenarios with multiple aircraft in multiple conflicts. The entire set of fourteen scenarios, with attendant descriptive details, is given in Appendix 1.

3.4 Selection of main subjects

Since CORA is a pan-European project (i.e. aimed at supporting a number of European States), it was necessary to consider a number of different countries. In total nine countries were invited to participate, but because it was the summer period when air traffic is highest, two countries were unable to take part. Therefore controllers from seven countries were interviewed individually and in groups (within a country), with the same standardised set of conflict scenarios. In two cases group sessions could not be carried out due to controller resource pressures during busy summer periods. The focus was on En Route (Area) Control, but in one case [Gothenburg] a group of Terminal Manoeuvring Area controllers (all of whom also had Area experience) were interviewed.

Table 1 (see also Figure 5) shows the countries and centres visited during the study, the number of controllers that participated in the individual interviews (typically 90 minutes long) and the group interviews.

Table 1 – Participation in the Study

Country	ACC	Individual interviews	Group interview
Area Control			
Italy	Rome[2]	6	Y (n=8)
Sweden	Malmo	6	N
UK	NERC	6	Y (n=3)
Portugal	Lisbon	6	Y (n=5)
France	Athis Mons	6	Y (n=4)
Ireland	Shannon	5	Y (n=5)
Holland	Maastricht	6	N
Terminal Manoeuvring Area (TMA) Control			
Sweden	Gothenburg (TMA)	4	Y (n=4)

3.5 Procedure

After having been briefed on the nature of the study, and being given an example of the scenarios, the controllers were asked to solve each scenario in sequence. The interviews were confidential, although number of years controlling experience was noted. There was no time pressure, except the controller's own constraints. The time to complete the scenarios was between 38 minutes and 2.5 hours. The group sessions typically lasted 1.5 - 2 hours.

[2] Participants in Rome were from four different Italian ACCs.

Figure 4 – Example of Conflict Scenario, Showing Airspace Environment

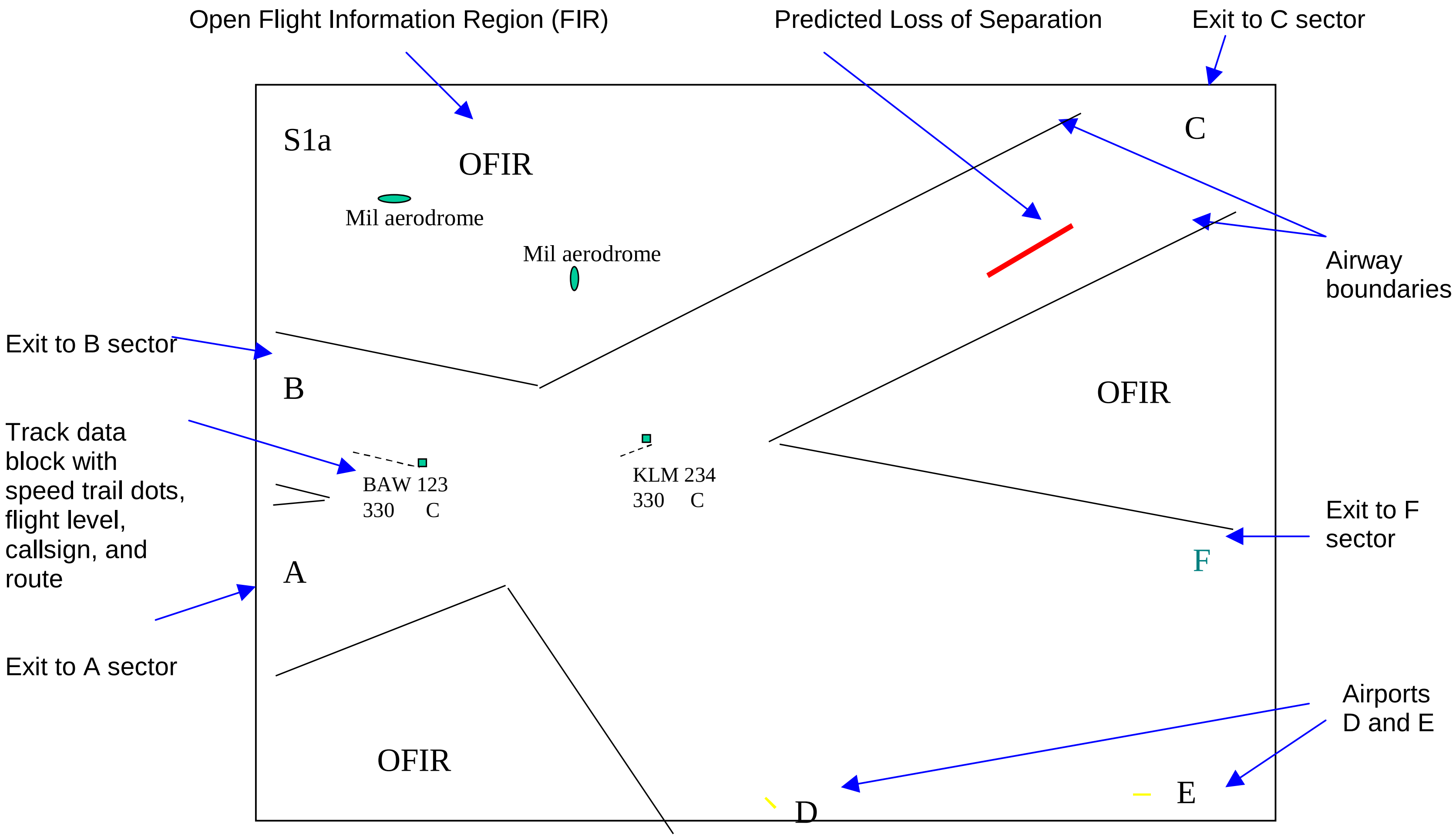
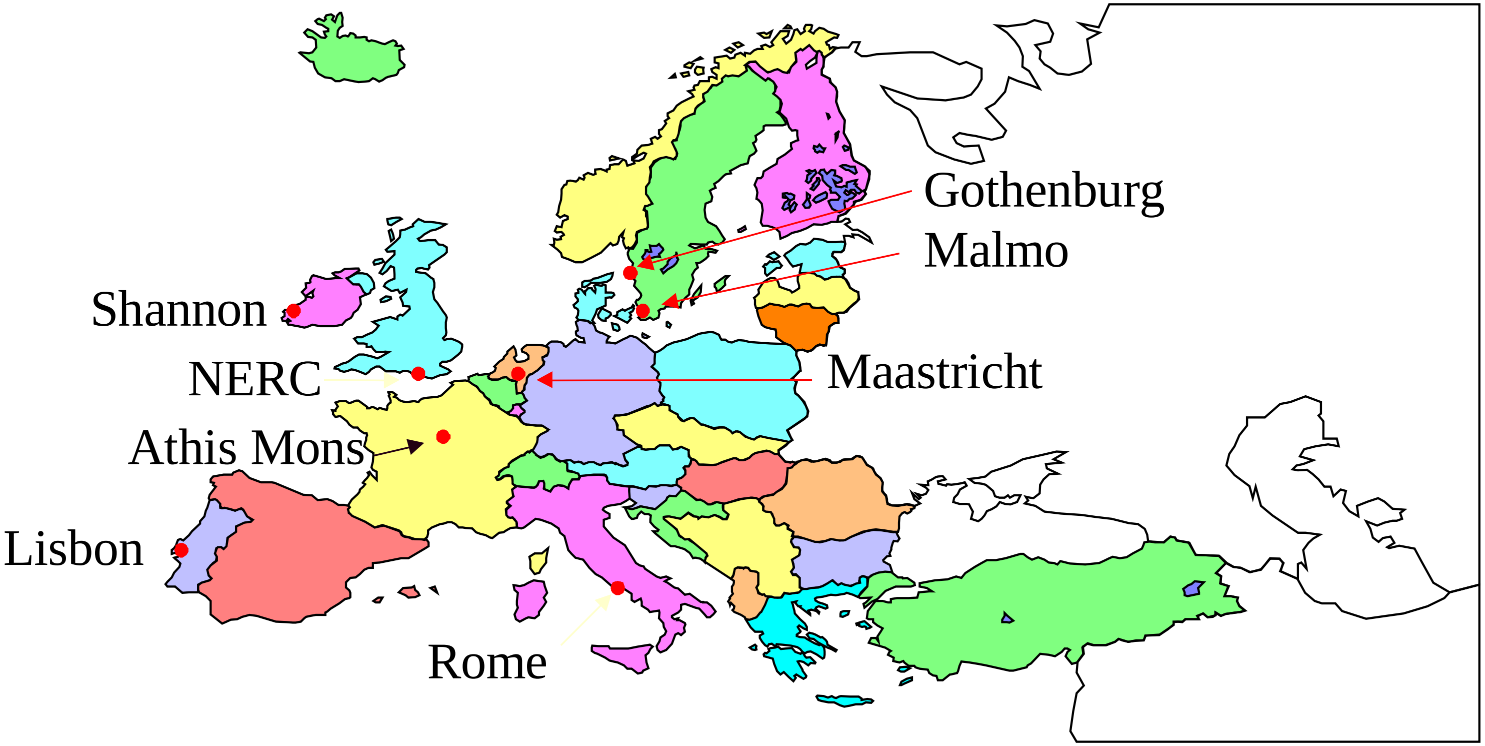


Figure 5: Participating Area Control Centres



In each individual interview, the controller was asked how (s)he would resolve the scenario. The answer, due to the minimal amount of information in the scenario representation, was often '*that depends…*'. The controller would then ask questions or make assumptions, until he or she was happy enough to state the principal resolution he or she would propose. The interviewer would note the order of questions/assumptions and list these as 'factors' affecting the determination of the resolution advisory. The controller interviewee was then probed for more than one solution, and these solutions were then placed in rank order. Typically there were around three or four potential solutions for each of the simple problem scenarios, less for the more complex ones.

The last part of this particular interview approach was to ask the controller if there were any actions (*no-no's*) that should definitely not be executed in this scenario. Such potential resolution advisories might appear reasonable to a non-controller and might even appear mathematically optimal, but would be seen as incorrect by a controller, and would be rejected immediately and could cause loss of trust in the proposed computerised assistant tool.

The same analyst carried out all but five of the interviews. If questions were asked by one subject, the analyst would ensure that the same reply was given to each future subject that asked the same question. In this way the potentially available information was rendered the same for each participant. All responses were recorded on-line in a computerised template, for each scenario. The subjects were able to see the template, and would point out if the analyst had misunderstood an aspect of their resolution or associated factors. The scenario descriptions in Appendix 1 document the information available to the controllers.

4. RESULTS

The results are presented in five sub-sections, and then their implications are discussed in Section 5. The first sub-section briefly discusses the adequacy of the scenarios and testing procedure from the controllers' viewpoint. This is relevant, because if the controllers felt it was not a serious exercise, then the results would be of no use. The next three sub-sections detail the results gained in terms of the rules, principles and factors elicited. The fifth section explores the level of agreement of the different controller opinions. Because the data set gained from the study is very extensive, and because the main objective of the study was to gather the data and assess the feasibility of the CORA approach, only examples of the results are given. The full data set and analysis of results are to be found in the CORA files[3] at the Eurocontrol Experimental Centre in Bretigny-sur-Orge, France.

4.1 Adequacy of the investigation exercise

The adequacy of the scenarios and the investigation as a whole can be judged in two ways. First, all subjects completed the exercise, and were not under any pressure to do so. In most cases, there was no sense of rushing, nor of omitting detail – the task, although simplified and static, was entirely relevant to the nature of their job, and was not always easy (many controllers found several of the scenarios significantly challenging). Controllers therefore generally had a natural interest in the study. Second, subjects were asked outright what they thought of the exercise and in particular the scenarios. There were three main responses. The first, and most common response, was that the scenario content was quite realistic (although low fidelity), that such scenarios did happen, including some of the 'poor co-ordinations' or 'bad clearances' that appeared in several of the scenarios in order to cause 'blocking a/c' situations. The second, was that some scenarios (in particular 4a and 4b) were only of borderline credibility. Nevertheless, all subjects solved these scenarios, and there is reasonable agreement in their resolutions (see later). Additionally, one centre (the first) had some reservations about the type of a/c used in the scenarios, and this led to some minor changes for all further interviews. In a later ACC two subjects found some of the scenarios (4a, 4b, and 8) of border-line credibility, and in one case a subject declined to finish the last scenario (Scenario 8). Although scenarios 7 and 8 are very complex, most subjects accepted that this was a genuine attempt to look at global versus pair-wise conflict resolution, and found these scenarios interesting, if sometimes hard to resolve.

The third response is interesting for the development of CORA. A small number of controllers stated that their responses for static scenarios might not be the same if the scenarios were dynamic, since they would have followed the dynamic evolution of the a/c conflict 'in the making', and might have resolved the conflict before it reached this stage. It is not believed that this invalidates the data gained from the study. However, it does suggest that later studies and perhaps validations must utilise more dynamic scenario formats, e.g. via simulations.

In summary on the adequacy of the scenarios and investigation process, there was generally a positive response. Indeed, in more than one location, several controllers not scheduled to participate, asked to be involved (this was not possible unfortunately due to the timing constraints of the study).

[3] In ':/Z/CORA/CORA Project/CORA2/Resolution-Strat_Study'.

Two further aspects that are limitations of the study must also be mentioned in connection with the validity of the data set gained from the investigation. First, the scenarios are of course only a subset of the total possible range of scenarios that controllers, and a conflict resolution tool, have to face. Secondly, even though 45 controllers participated from seven countries, this is still a small sample of the large population of European controllers currently employed.

Despite such limitations, it is believed that the investigation has been a reasonable attempt to show that such data can be elicited, and therefore used, to inform design of conflict resolution assistant tools. Although such a data set will not be complete, and there may be a need to gather further data as the algorithm development proceeds, the data set gathered, as shown in the following pages, support the attempt to develop a human-informed conflict resolution assistant tool.

Therefore, having ascertained that the scenarios and the resultant data gained have a reasonable degree of validity, the next four sub-sections outline the results from the investigation.

4.2 Rules used by controllers

The first set of results concerns the rules that controllers appear to pay attention to. It must be said that there appeared to be less rules used than expected: the main controller aim is to separate aircraft, and to do this first safely, and then expeditiously. Many rules appear ‘sacrificial’, at least temporarily, as long as these two requirements are met.

The formal rules used by the controllers during the study are shown below. Other ‘informal rules’ mentioned by controllers have been included as principles rather than rules (see section 4.3).

<u>Formal Rules</u>

- Semi-circular rule
- Letters of agreement (e.g. about sector entry requirements – whether a/c are allowed to be on parallel headings; sector entry points and allowable levels; etc.)
- Open Flight Information Region Constraints – the need to co-ordinate with military ATC Units, and whether there is flexible usage of military airspace, etc.
- Quadrantal rule (this was rarely mentioned)
- Allowable proximity to the edge of airways – this is typically half the prevailing minimum separation distance in the sector (i.e. 2.5 nm)
- Separation against military aircraft – this varies, but applies to areas of airspace where there are both civil and military traffic

(e.g. Maastricht controllers mentioned this for some of their sectors)

- Speed regulations in certain sectors
- Rules of the air (pilot rules) – these strictly relate to unknown a/c and are for pilots. All controllers of course know these rules, but do not see them as relevant to most of the situations they face
- Locking a/c on headings – in some areas, it was seen as a rule that conflict a/c and context a/c may need to be locked onto headings in order to ensure that a resolution is effective
- Minimum descent rates – a/c are supposed to let controllers know if their descent rate is less than a certain minimum (e.g. 500 feet per minute)
- Co-ordination of vertical changes with the military in shared airspace – this is a requirement in certain sectors, and was mentioned by Maastricht controllers.
- Turbulence as a priority – this varied between ACCs, and some controllers take turbulence as a high priority, others do not. This depends on the severity classification of turbulence (e.g. low, moderate, and severe turbulence)

A more general insight from the rules elicited, is that their variety highlights the need to tailor CORA or its algorithm to the local considerations and constraints in operation in an ACC. Even the often-cited semi-circular rule has a number of different interpretations, depending on the prevailing traffic flows in the ACC region.

As a more general observation, rules need to be considered by a conflict resolution system, but in most cases will not reduce the resolution space sufficiently to lead to a small set of resolutions. Principles are more likely to achieve this aim, and are discussed next.

4.3 Principles used by controllers

Many principles were identified during the interviews. These were grouped into five categories in terms of increasing specialisation. This was done to aid the integration of such principles into the algorithm or its constraints. The categories were as follows:

- Generic & non-contextual (n=17)
- Generic and contextual (n=38)
- ACC-based (n=4)
- Airspace-based (n=8)
- Conflict-based (n=42)

Examples of the principles are given in Table 2. The principles ranged from very high level strategies ('keep it simple') to more contextual scenario specific ones (e.g. 'don't rely on climb performance above FL200'). Many of the principles were only cited once, by an individual controller. This suggests that there is a high degree of individuality about these principles, or else that controllers do not tend to cite them as they are 'implicit' or 'tacit' knowledge rather than formal principles. It would be interesting to carry out a separate exercise to see how controller instructors view these principles, and to consider their suitability for use in training.

In general though, many of the principles support each other and do not conflict, and offer potentially useful ways of narrowing down the solution space in conflict resolution problem analysis. These principles can therefore be utilised to inform the development of the algorithm or its output, to lead to effective and acceptable resolutions. Such a process may require further controller input to refine and reduce the set of principles, and attach them to the context of different scenarios, but they nevertheless represent the basic building blocks for reducing the solution space to a manageable level.

Table 2 – Extract of Principles & Strategies Used by Controllers

Category	Ref.	Principle	Scenarios
Generic & Non-Contextual		**Simplicity**	
	GN1	Keep it [the resolution] simple	1a, 2b, 3b, 8
		Deciding who to move, and how	
	GN2	Penalise the one that needs something (leave alone the ones in steady state)	1b, 2a, 5a,
	GN3	Inconvenience least people	2a
	GN4	Minimise the penalty for a/c	1a, 2a, 3a
	GN5	Give them what you can	1a, 4b
	GN6	Change in line with a/c intentions	3a
		Workload management	
	GN7	Keep workload manageable	2a, 5b
		Safety	
	GN8	Make it safe first, before go further [with additional considerations etc.] [safety before convenience]	2b, 5b
	GN9	Need to have a fail-safe plan B	2a, 4b, 8
	GN10	The bottom line is safety	4b
	GN11	Things can deteriorate [Murphy's Law]	3b, 4a
		Understanding	
	GN12	Determine who is in the game	4b, 5b
	GN13	Reduce the complexity (eliminate problems)	7, 8
Category	Ref.	Principle	Scenarios
Generic & Contextual		**Narrowing the problem & resolution space**	
	GC1	Check other a/c and rule them out (narrow down the problem space) – identify the conflict pair(s)	1b, 2b, 3b, 4b, 8
	GC2	Minimise the number of a/c to move	1b, 2a, 4b, 5b,
	GC3	Look for one key action that will resolve the situation	4b, 5b, 7
	GC4	Leave the over-fliers alone	5a
		Controlling the problem	
	GC6	Give initial (level) change early on and then fine-tune later	5a, 6a
	GC7	Solve easy conflicts first	8

Table 2 - Extract of Principles & Strategies used by controllers – *continued*

Category	Ref.	Principle	Scenarios
		Controlling the resolution	
	GC10	Prefer resolutions which require less co-ordination	4a, 3a
	GC11	Decide the priority of communication	7
	GC12	Hand-off traffic in a way that is acceptable to next sector	1a
	GC15	Lock a/c on headings when using vectors	4a
		Lateral dimension	
	GC19	Minimise additional track miles flown	4a
Category	**Ref.**	**Principle**	**Scenarios**
Generic & Contextual		**Vertical dimension**	
	GC21	Continuous climb and descent profiles are preferable	4a, 2b
	GC22	When complex, use vertical separation	7, 2b
		Speed dimension	
	GC25	Speed solutions – at cruising altitude their speed envelope is small, e.g. 10 – 20 kts, therefore cannot change much	3b
	GC26	If using the FIR, use a very simple solution	4b
	GC27	Level changes can introduce extra conflicts	1b
	GC28	Leave the over-fliers alone	5a
		Emergencies	
	GC30	With an emergency, keep it simple and safe	6b
	GC31	Handle the emergency first – everyone else can wait	6b
		Pairwise approach	
	GC34	Solve conflicts in pairs	2a, 7, 8
	GC35	Solve pairwise, but if many pairs, plan B's will not work. Therefore need a plan C	2a
		Global approach	
	GC36	Aim for a more global solution – not penalising anyone	5b
	GC37	Will not go down to the minimum of 5nm – need more than this to be safe	1b
	GC38	Not simply pairwise – consider the priorities of the pairwise solutions, and the impact of each resolution on the remaining pairs	8

Table 2 - Summary of Principles & Strategies used by controllers – *continued*

Category	Ref.	Principle	Scenarios	Country[4]
Country-based		**Use of military airspace**		
	C1	Don't tend to use military airspace	2a	L
	C2	Have a very good relationship with the military	3a	L
	C3	If work closely with the military, as do in Sweden, can often find the optimal short-cut	2a	G
		Use of predictive information on current system		
	C4	Use vector lines in Lisbon – not trail dots	8	L
Category	**Ref.**	**Principle**	**Scenarios**	**Country**
Airspace-based		**Preferences – vertical**		
	A1	Preference for level-based solutions	1a, 1b	S
	A4	Try to keep a/c at the same levels	1a	L
		Preferences - lateral		
	A5	First approach is to vector	4a, 7	L, N
		Preferences - speed		
	A2	Use speed control if possible	1a	S
		Local solutions		
	A6	If used to a sector, will know all the best solutions	8	L
	A7	ACC supposed to think, TMA supposed to act	2b	G
		FIR		
	A9	Only use FIR if bad weather	5a	N
	A10	Need to know the availability of FIR, then and there – need the information at my fingertips	4a	A
	A8	Keep them in controlled airspace	2b	N

[4] S = Shannon; R = Rome; L = Lisbon; G = Goteborg (TMA bias); M = Malmo; N = NERC; A = Athis Mons; Ma = Maastricht

Table 2 - Extract of Principles and Strategies Used by Controllers - ***continued***

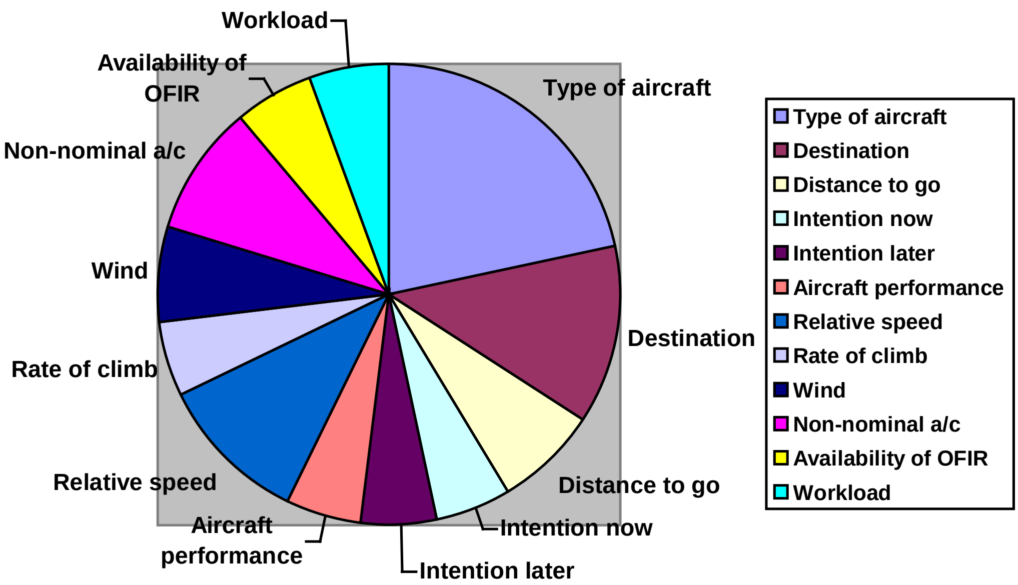
Category	Ref.	Principle	No. of controllers	Scenarios
Scenario-based		**Crossing conflicts**		
	S1	Turn slower a/c behind (in order to minimise extra distance flown)	1	3a
	S2	Stabilise until after crossing points	1	5b
		Converging/Head-on		
	S3	When there are few a/c, a temporary ODL is acceptable	1	3a
	S4	Ask the pilot whether (s)he prefers a level change or a vector	2	1b, 3b
	S5	Normally if vectoring, vector both a/c	1	3b
	S6	In turbulence, not always good to have level solutions, since they may not maintain their levels	1	7
	S8	Solve the head-on first	1	8
	S9	Turn faster one direct to route so leaves sector before slower one on same route	1	1b
	S10	Safe if locked on headings	1	2b
	S11	Sometimes not changing levels on a/c means you don't have to worry about them	1	4b
	S12	Give a short-cut which can end the conflict	1	4a
	S13	Better to put a/c behind than trying to go through the middle	1	3b

4.4 Factors elicited from controllers

A large number of factors that can influence conflict resolution choice were elicited during the interviews. However, unlike principles, there was more convergence on key factors, and there was a high preponderance of certain factors on certain scenarios. The main factors, in terms of information asked for, are shown in Figure 6. There were many other factors that were cited less often but will be still of interest to the CORA algorithm, as they represent controller expertise. As an example, climbing a/c have inertia, and can over-shoot their intended level – such insight is relevant when levelling off a climbing aircraft one flight level below another, for example.

Some factors were less focused on the specific scenarios, but are interesting given the nature of the CORA project, e.g. 'trust in computers'. There were also a few citations of culturally-linked aspects, such as airline type, European and non-European a/c, etc., and whether the pilot was normally English-speaking etc. However, such factors were the exception rather than the norm.

Figure 6 – Main Factors – Area Representing Number of Citations (all Controllers, Across Scenarios)



Some of the factors are clearly related. For example, a/c type and a/c performance are highly correlated, and also rate of climb. These have been kept separate however, firstly because the controllers described them differently, and secondly, because there can be some subtle differences behind what was meant by these terms. For example, rate of climb can vary on the day, e.g. a Lear jet (used in one of the scenarios) is generally a fast climber. However, several controllers noted that they do not always climb fast. There is therefore a danger in assuming particular performance characteristics based on aircraft type – the latter denotes the general performance envelope, but not its actual performance on that day (e.g. according to whether it is fully laden with passengers and fuel etc.).

The factors shown in Figure 6 are a useful indication of what factors need to be considered by a computerised approach aiming to produce conflict resolution advice. Two factors are worthy of discussion at this point. Workload was mentioned by a number of controllers – if the workload was high, then controllers would opt for a simple resolution (less communication requirements to less a/c, with less subsequent monitoring requirements). This was evident in certain scenarios (e.g. 5b), where there was a very simple solution which involved levelling off an a/c well below its desired level. Alternative resolutions, which would be more optimal for the individual a/c, tended to involve much more workload for the controller, in an already-busy scenario. Whilst many would nevertheless provide the 'service-oriented' resolutions, some would provide only the basic 'safe' resolution. This is an aspect that will need to be considered by the proposed CORA system, as it may be that CORA may need to be able to give 'basic' safe resolutions in certain high workload scenarios.

Another factor mentioned that warrants discussion is 'non-nominal flights'. These are a/c in the scenarios that are atypical, performing unusually, or were given poor clearances or co-ordinations, and these a/c usually added complexity to the scenario, by acting as potential secondary conflictors or at least 'ones to watch'. They were typically a/c that were climbing through a large vertical range, and although not predicted to be in conflict with any other a/c, certainly looked as though there was the possibility of conflict, particularly if they did not climb efficiently or deviated from track. These non-nominal a/c drew very consistent feedback from controllers, and most controllers would stop their ascent and/or turn the a/c out of harm's way. In some cases, these non-nominals seemed to take up more of the controller's time and concern than the actual identified predictors. A number of controllers stated that situations such as those in the scenarios do indeed happen, and do add complexity to their task.

A main consideration for CORA, arising out of the impact of these non-nominals on controllers, is that when CORA is tested, there should be non-nominals present in the simulation trials. A second aspect, is that the CORA system developers need to consider how to deal with non-nominal a/c that may occur. If for example, an a/c is climbing rapidly and is not predicted to be in conflict with an overflight, but to the controller it looks like there could be a conflict, or that if anything changed there would be a conflict, then the controller would expect the CORA tool to be able to deal with it. This is a difficult area and needs further exploration, but may be a central issue for the trust of controllers in CORA.

4.5 Resolutions the controllers would not implement – the 'no-no's'

A number of no-no's were indeed identified during the study, for each scenario type. The no-nos were scenario specific, and generally related to the following:

- Use of speed as a resolution mechanism (e.g. S1a and S1b)
- Use of expediting climb (e.g. S4a and 4b; 6a and 6b)
- Use of climb (e.g. 1a and 1b)
- Use of vectoring (e.g. S3a and 3b)
- Use of the FIR (various)
- Leaving a/c in turbulence (e.g. S2b)
- Stopping a/c climbing out of terminal areas (e.g. S4a)
- Manoeuvring over-flights against conflictors (e.g. S1b; various)
- Leaving landing a/c at high levels (e.g. 5a; 5b)
- Going 3 abreast in a 15 mile airway (S2b)
- Leaving context and conflict a/c not locked on headings (e.g. 5a and 5b)

In some cases, there was complete agreement (e.g. not to use speed control in scenarios 1a or 1b). In other cases, there was disagreement, usually between centres rather than between controllers within a centre (though this was not always the case). This usually related to a centre's preference for vertical manoeuvres or lateral ones, for example. Thus, a controller in one centre might have stated categorically that using vectors in scenario 3a would be poor practice, whereas another controller may have actually used such a resolution. This difference is usually due to the experience controllers have in their sectors. In some sectors, going through military airspace is frequent, whereas in others it is difficult to arrange and so is not done. In some airspace environments there is less room to manoeuvre laterally, but plenty of levels, and in other sectors, the reverse is the case. In still further cases, most controllers would consider a particular manoeuvre to be risky (e.g. expediting climb in scenario 4a), whereas a few controllers would indeed adopt such a resolution.

The insight gained here is that CORA may need to be tailored to the 'ACC conflict resolution culture', which is a function of the airspace design for that centre and their operating practices. Therefore, whilst some no-nos are likely to be accepted by most controllers, other no-nos may be airspace or ACC domain specific, and CORA would need to be sensitive to such ACC variations.

This mention of variations leads onto the final results section, concerned with controller variability in resolution strategy.

4.6 Convergence of controller resolution opinions

This sub-section contains an extracted set of tables documenting and analysing the resolutions elicited during the controller conflict resolution interviews, for scenarios 1a – 6b. The intention is not to try to present all the data, but to arrive at an assessment of the convergence between opinions of different controllers from the countries and ACCs visited, for all the scenarios. Table 3 therefore gives the detail of the resolutions for one ACC (Lisbon) for each scenario and each subject. Subjects are numbered 1-6, and G represents the group judgement (all except Malmo and Maastricht had a group session, where the group tried to agree a best resolution). The columns represent the different dimensions and combinations possible. These are primarily Lateral, Vertical and Speed, and their various combinations.

The rows show the conflict pair of a/c, and other key a/c referred to in the context a/c scenarios. Therefore if S1's resolution was turning BAW, a '1' appears in the row for BAW and the column for Lateral. However, if the resolution was a turn and a climb for BAW, then '1' would appear in the row for BAW and the Vc (Vertical – climb) column. If the resolution was to turn both BAW and KLM, then '1' would appear in both rows, in the same column (Lateral).

The no-no's have also been summarised for each scenario for each subject that cited them. No-no's are logically possible resolutions that the controller said he or she would nevertheless not implement or trust. As an example, speed was cited as a 'no-no' by most subjects in scenario 1a (a 'catch-up' scenario), because it would be difficult to achieve resolution by this method given the relative speeds, aircraft types, and distances involved. This does not mean that speed could not be used in catch-up scenarios in general, but merely that it would not fit this particular scenario.

The last column states how many distinct resolutions there were for that country and that particular scenario. For example, in S1a, for Lisbon, there were three distinct resolutions:

- Turn both a/c (subjects 1 and 6, and the group consensus)
- Descend BAW (subjects 2, 4 and 5)
- Descend KLM (subject 3)

Other resolutions are possible (e.g. climb one of the a/c, turn and descend the BAW, etc.), but the 6 controllers and the group came up with these as their preferred resolutions. This type of result represents a moderate amount of agreement and is good news for systems such as CORA, because three resolutions offered would satisfy this group of controllers.

Table 4 then records the gross number of times each country or ACC utilised a particular dimension or combination of dimensions, both for conflict and context a/c. At a high level, for these scenarios, five dimensions are used most frequently: [in order] climb, lateral manoeuvre, descend, turn and climb (or stop climb), and turn and descend (or stop descent). This information is then produced in Figure 6 as a 3-dimensional histogram showing the relative apparent preferences for each ACC in terms of resolution dimensions (e.g. Lisbon uses more lateral resolutions in these scenarios, whereas Malmo makes more use of climb as a resolution).

Table 4 therefore suggests that for these scenarios, across all subjects and all scenarios, and including 'context' aircraft as well as the conflicting aircraft, vertical climb-related solutions (including stopping climb and expediting climb) are the most used, followed by lateral solutions. Vertical descent-related resolutions are next most favoured, followed by resolutions involving lateral and vertical combined instructions (with climb-related more often than descent-related components). Speed on its own, and other combined resolutions, were used far less in these scenarios, including Maastricht and Shannon, where the scenarios were in effect longer (more look-ahead time) and perhaps more amenable to using speed control. It should be noted, however, that 'expedite climb' or 'expedite descent' were not treated as belonging to the speed dimension, as they relate more to the vertical dimension than speed over ground.

The non-usage of speed is partly a function of the scenarios and their construction. However, from the informal discussions it did appear that speed is generally not used except in particular scenarios or airspace configurations. Speed as a resolution tends not to have such an immediate resolving effect as, say, changing a level or turning an a/c. With speed, the controller must wait to see whether it resolves the conflict or not. Therefore, if CORA is to make usage of speed as a resolution capability, this may need further laboratory-based research and/or training, and perhaps display enhancements, to encourage more usage of this dimension. CORA may know better that speed will resolve the conflict, but there will need to be a period of adaptation during which the controller can learn to trust this machine-based judgement, reinforced by good display design.

Different ACCs appear to rely on certain types of resolution more than others. For example, Lisbon, Italy and Maastricht appear relatively more focused on lateral solutions, whereas Malmo, Gothenburg, Athis Mons and Shannon seem more reliant on level solutions[5]. This is undoubtedly due to the nature of their respective airspace, and their usual practices. This suggests that CORA may need to consider the 'dominant' resolution style of local ACCs in which it is to be installed.

The average (normalised) number of distinct resolutions per scenario ranged from 3.3 – 4.7, suggesting that 4 is a reasonable number of options to have in a menu. However, it is not clear that these resolutions are the same per country, e.g. Shannon and Maastricht may have used four main resolutions for a scenario, but this does not help the case for CORA if these represent eight different resolutions. It is most helpful if these are the same resolutions, at least most of the time. If there is such a 'convergence' of resolutions, so that CORA could identify say 4 resolutions and these would satisfy most controllers, then CORA would be more likely to become a 'trusted' tool.

In order to explore this aspect of agreement or convergence, tables 5 – 8 document the exact distinct resolutions used by countries/ACCs (for the conflict pair only, and not the context a/c), for three of the scenarios, 1a, 6a and 6b. For scenario 1a, there is a good level of agreement, although there are a total of ten solutions identified by the 'pool' of all controllers. Nevertheless, the top four resolutions would satisfy 82% of controllers. Similar analyses can be carried out for the other scenario examples. In practice scenario 1b had the lowest 'convergence', with the top four resolution only accounting for 59% of controllers. Scenarios 6a and 6b, on the other hand show greater convergence.

The results for all subjects and all the main scenarios (1a – 6b) are summarised in Table 8. As can be seen, except for S1b, there is good agreement in the main resolutions, with at least 71% of the identified resolution space being accounted for by four resolutions, and on average four resolutions would satisfy more than 80% of controllers (in some cases this is 90%). This is an encouraging result for CORA. The last table (Table 9) shows the number of distinct resolutions for the conflict pair only, for each ACC or country. This table helps gain an

[5] Although this is by no means always the case, as some controllers in Athis Mons, for example have sectors with only four levels (245 – 285), and therefore tend to use lateral solutions.

impression of agreement within the different ACCs (although each is only based on a small sample of controllers). Relatively speaking, Shannon and Maastricht controllers tended to have less diverse resolution sets for scenarios than other countries. This is not a conclusive result, but the implication for the development of CORA is that there may be large differences in the levels of agreement/diversity at different ACCs.

In summary, in general the results are positive for the CORA approach and philosophy. However, what is clear is that there may need to be ‘tailoring’ of CORA to specific types of airspace. For example, different centres appear to have different overall preferences, e.g. in terms of lateral versus vertical solutions. This issue and others are discussed in the next section.

Table 3 – Analysis of Primary Solutions - LISBON[6]

Scenario/ aircraft moved		Dimension Used: Lateral	Vertical climb	Vertical descent	Speed	LVc	LVd	VcS	VdS	LS	LVS	No-nos	No. of distinct primary solutions
1a	BAW	1,6,G		2,4,5								Speed 1,2, 3, 5,6,G Level 6	3
	KLM	1,6,G		3									
1b	BAW	4,6,G	3	2								Speed 2,	5
	KLM	1,4,6,G	5										
	KAL												
2a	DLH	4,5,6,G	(2),3									FIR 1 Descent 5,G	3
	DAL	1,4,5,6, G											
2b	DLH	4,5,6										Speed 1	7
	DAL	1,4,6,G		2,3,5									
	AFR			2,4,			1,3,5,G						
	BMA	1	Stop 3,G					Monitor 4					
3a	BAW	4	(1)(2)(3)		(5)(G)							Speed 3	4
	BMA	4,6											
3b	BAW	4	1,2,3,(6), G		(5)								3
	BMA	4											
	Other												

[6] (Note: number in bracket indicates no preference for either a/c – e.g. scenario 3a – (1) means S1 stated climb one of them, whichever would accept a climb).

Table 3 Analysis of Primary Solutions – LISBON – continued

Scenario/ aircraft moved		Dimension Used										**No-nos**	**No. of distinct primary solutions**
		Lateral	**Vertical climb**	**Vertical descent**	**Speed**	**LVc**	**LVd**	**VcS**	**VdS**	**LS**	**LVS**		
4a	DLH	2										Stop KLM 1; climb DLH 5	3
	KLM	1,2,4,5, 6,G	Expedite - 3										
4b	DLH	2,4										Leave KLM & EIN - 2	5
	KLM	1,2,4	Stop 220 6			Stop 260 & turn 3,5,G							
	EIN	2											
5a	KAL	2										Vectoring 4; stop BMA descent 1,3	3
	BMA	2,4		Expedit e 1,3,5,6, G									
5b	KAL	6				2						Vectoring – 5; maintain 310 - 5	5
	BMA			1,3,4,5, 6,G									
	SAS		Stop G	3,6									
	Other	3 (KLM)											
6a	AZA	2	Stop 1,3,4			Stop & turn 5,6,G						Vectors 4	3
	BAW	2											
6b	AZA	1,4				2,3,5,6,G							4
	BAW	1,4	3										
	EIN	FIR 3,G											

Table 4: Number of Resolutions Components per Dimension Category, Including Context and Conflict a/c, scenarios 1a – 6b (12 Scenarios)

Country/ACC	L	Vc	Vd	S	LVc	LVd	VcS	VdS	LS	LVS	Number of subjects (G = group)	No. of distinct solutions for 12 scenarios	Normalised avg. no. of distinct solutions	Normalised total no. of resolution components
Lisbon	41	21	2	3	12	4	1	0	0	0	6+G (7)	48	4.0	105 Lisbon
Malmo	20	43	29	1	9	3	0	0	0	0	6 (6)	43	4.2	123 Malmo
Gothenburg	10	29	24	1	10	5	0	0	1	0	4+G (5)	40	4.7*	112 Gothenburg
Swanwick (NERC)	31	35	19	0	20	11	0	0	1	0	6+G (7)	44	3.7	117 Swanwick
Italy	43	33	15	1	15	8	0	0	2	0	6+G (7)	54	4.5	117 Italy
Athis Mons	34	43	20	6	14	8	0	0	2	0	6+G (7)	53	4.4	127 Athis Mons
Shannon	24	45	11	0	14	3	0	0	0	0	5+G (6)	42	4.1	113 Shannon
Maastricht	45	30	8	0	15	4	0	0	0	0	6 (6)	34	3.3	119 Maastricht
TOTAL	248	279	149	12	109	46	1	0	6	0	(N = 785)			
Averaged Rank	2	1	3	6	4	5	8		7					

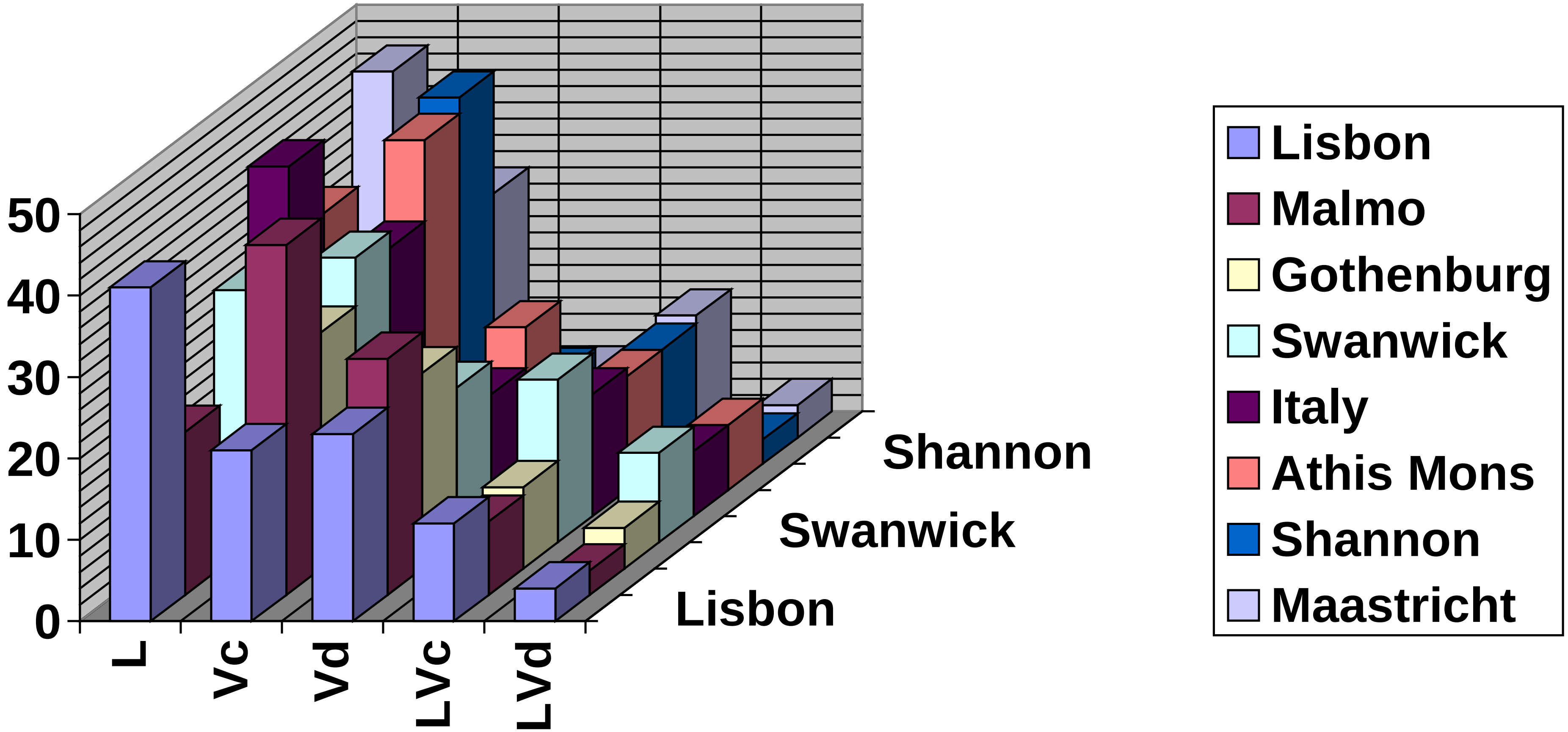


Figure 7: Comparison of Five Major Dimensions Used by Country/ACC – All Subjects, all Resolutions (Conflict Pair & Context a/c)

Table 5 – Individual scenario resolutions by Country/ACC – 1a – Catch-up

Scenario	Resolution	Lisbon	Malmo	Gothenburg	NERC	Italy	Athis Mons	Shannon	Maastricht	Total & Rank
1a Head-on	Lateral – turn both	3	1		4	1	2		2	13 (1)
	Turn BAW					2	1	2	3	8 (4)
	Turn KLM					1				1
	Use FIR					1				1
	Climb either a/c		1							1
	Climb BAW							3		3
	Climb KLM			1				1		2
	Descend BAW	3	2	1		2	4			12 (2)
	Descend KLM	1	2	2	3				1	9 (3)
	Turn BAW & descend KLM			1						1

Scenario 1a therefore has a total of nine solutions, of which four account for 82% of the solutions offered. In three cases (Sweden, Italy and Shannon), solutions are offered which no other country has offered (e.g. climb solutions for Malmo, Gothenburg and Shannon, and turning the KLM alone, and using the FIR, for Italy. This gives insight as to how to consider tailoring the CORA algorithm to such local needs.

Table 6 – Individual Scenario Resolutions by Country/ACC – 6a – Right Angle Climb-Through

Resolution	Lisbon	Malmo	Gothenburg	NERC	Italy	Athis Mons	Shannon	Maastricht	Total & Rank
Stop climb 260 & turn N	3	4	3	5	2	5	4	4	30 (1)
Stop climb 260	3	2	2	2	4	2		1	16 (2)
Turn AZA					1				1
Turn BAW									
Turn both	1								1
Stop & turn AZA and turn BAW								1	1
Stop AZA and climb BAW							2		2

This scenario has a good deal of agreement – there are really only two main solutions, and in fact one of these is an extension of the other. The two main resolutions account for 90% of the total resolutions offered. There is clearly strong agreement here across different nations and operating practices.

Table 7 – Individual Scenario Resolutions by Country/ACC – 6b – Right Angle Climb-Through – Conflict Pair Only

Resolution	Lisbon	Malmo	Gothenburg	NERC	Italy	Athis Mons	Shannon	Maastricht	Total & Rank
Stop climb 260 & turn N	4	4	3	6	6	4	6	5	38 (1)
Stop climb AZA			1			3			4 (2)
Turn AZA									
Turn BAW									
Turn both	2								2 (3)
Stop AZA & climb BAW		1							1
Stop & turn AZA and climb BAW	1			1					2 (3)
Stop & turn AZA 160 and descend BAW 270		1			1				2
AZA stop & turn FIR & descend BAW			1						1
Stop & turn KLM left								1	1

There is still a clear preferred resolution, even though this is a more complex scenario, and four resolutions account for 90% of the identified resolution space.

Table 8 – Analysis of Convergence of Resolutions Across Countries/ACCs

No.	Scenario	Proportion of preferred resolutions accounted for by the 4 top resolutions	Number of distinct resolutions (the 'identified resolution space')
1a	Catch-up	82%	10
1b	Catch-up + context a/c	59%	13
2a	Head-on	84%	8
2b	Head-on + context a/c	71%	11
3a	Converging & crossing	90%	8
3b	Converging & crossing + context a/c	80%	10
4a	Climb-through	86%	7
4b	Climb-through + context a/c	75%	10
5a	Descend-through	88%	8
5b	Descend-through + context	84%	12
6a	Right-angle crossing climb-through	90%	6
6b	Right-angle crossing climb-through + context a/c	90%	8
	AVERAGE PROPORTION	**82%** [59% - 90%]	**9** [6 – 13]

Table 9 – Number of Distinct Resolutions for Conflict Pair by Scenario and Country/ACC

Scenario	*Lisbon*	*Malmo*	*Goth'g*	*NERC*	*Italy*	*Athis Mons*	*Shannon*	*Maas't*	*Total*
1a	3	4	4	2	5	3	3	3	27
1b	5	4	3	4	4	7	4	2	33
2a	3	3	2	3	3	1	1	1	17
2b	4	3	3	5	6	3	2	3	29
3a	4	1	3	3	2	4	1	2	20
3b	4	3	2	5	4	3	2	3	26
4a	3	4	2	4	4	4	3	3	27
4b	4	2	5	5	4	3	5	3	31
5a	3	2	3	3	5	4	4	2	26
5b	3	3	3	3	2	5	3	3	25
6a	3	2	2	2	3	2	2	3	19
6b	3	3	3	2	2	2	1	2	18
Total	42	34	35	41	44	41	31	30	
N	7	6	5	7	7	7	6	6	N/A
Average	3.5	2.8	2.9	3.4	3.7	3.4	2.6	2.5	
Normal-ised average[7]	3.5	3.3	4.1[8]	3.4	3.7	3.4	3.0	2.9	

[7] Based on N = 7: e.g. for Malmo where N= 6, the average is multiplied by 7/6.

5. DISCUSSION

The discussion is set out in three parts. The first considers the meaning of the results gained for the CORA project as a whole. The second part then explores some of the more detailed implications for the generation of an algorithm to derive conflict resolution advisories. Lastly, it reviews some of the more general comments that controllers made about the CORA concept, and the desirability of a CORA-type system, from a controller's perspective.

5.1 The feasibility of CORA

The results are generally in favour of the CORA approach. Firstly, the knowledge aspects that were sought have been gained. Principles, factors, rules and 'no-nos' have all been successfully elicited. Secondly, most of these knowledge elements are not contradictory, suggesting that such information can be used meaningfully and constructively in the development of CORA. Thirdly, and importantly, there was a good degree of overlap in the resolutions derived, suggesting that CORA will be able to satisfy most controllers. In this respect, it should be explained that the analysis of the data focused only on the agreement between the first resolutions for each controller. In almost all cases, controllers produced 2 – 4 resolutions that would be acceptable. Therefore, by considering only the first resolution from each controller, this has been an exacting criterion from which to judge convergence. If all resolutions were to be considered (i.e. the complete acceptable set from each controller), it is likely that the degree of convergence would increase, i.e. the top four resolutions would satisfy a much higher percentage of controllers than 82%.

One somewhat unexpected insight was the apparent strength of the airspace environment factors dominating resolution formulation. It appears that the type of airspace, and the way that airspace is operated at an ACC, has a great effect on how controllers derive resolutions. This means that CORA may have to be 'tailored' to fit in with airspace and ACC 'cultures'. Otherwise, CORA may not be accepted since it will be proposing resolutions that would work in a generic airspace, but not a particular airspace. It may be that not many variants of CORA will be required. However, it suggests that there must be flexibility or adaptability built into the algorithm structure.

A related observation, is that this study has provided a great deal of information on a subject that is central to the job of controlling air traffic. Such information could be useful for the training of air traffic controllers, especially ab initio controllers.

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[8] The 'normalising of averages' may nevertheless skew the results – two more Gothenburg controllers may have agreed with their colleagues rather than disagreeing – this seemingly high result should therefore be taken circumspectly.

5.2 Detailed insights for the generation of the CORA algorithm

The following are a number of insights gained form the study which relate to the next stage of CORA development, the construction of the resolution advisory algorithm.

Group Judgement - the group sessions with controllers were very interesting. In some cases complete agreement was achieved, and in others there was sometimes a 5:1 split in opinion, for example. However, several individual controllers revised their original 'best resolutions' during the group process, admitting that other proposed resolutions were in fact better. There are two insights from this observed effect. The first is that the algorithm construction process itself could make use of one or more controller groups, to help in the development process. This would help to ensure that the algorithm development process remained 'controller-informed' and correctly interpreted the data and insights gained in this study, and also 'filled in' the inevitable gaps in the database that will be found during the next and most critical phase of the 'CORA story'.

Secondly, the fact that controllers realise there are better resolutions that they did not originally consider bodes well for CORA in general. It acknowledges that there is room for improvement. It is likely that given time, all individual controllers would derive the optimal resolutions in almost all cases. But controllers do not always have that thinking time. Therefore, a tool such as CORA, which in some senses would represent an expert system, like a wise group of controllers who could think very fast, would add value to an operational ATM system.

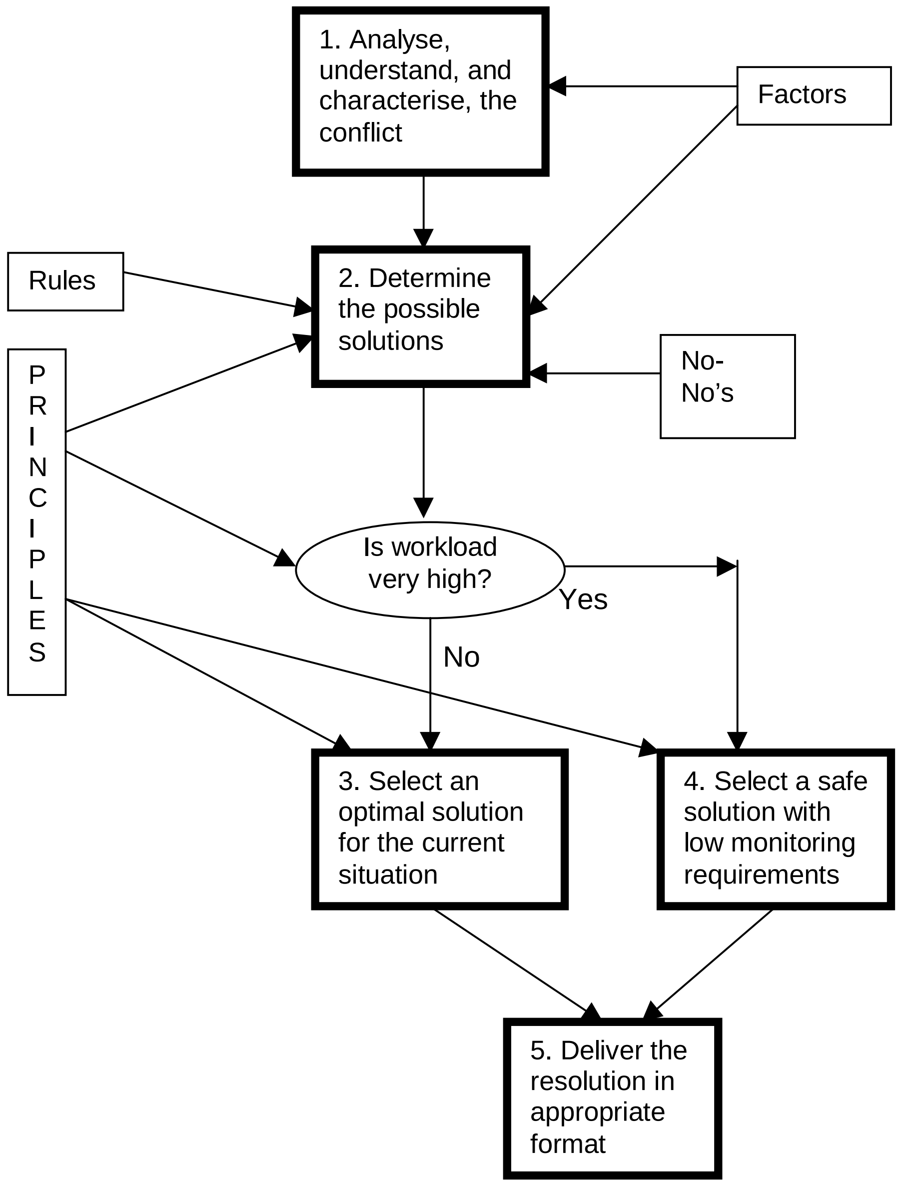
Workload & working arrangements with CORA - if the controller is very busy, that controller may not bother to optimise the resolution, but will simply pick a safe resolution, one which probably has least communication and/or monitoring requirements associated with it. This is shown in Figure 8, as an extension of the previous model in Figure 1. The implication of such a model for CORA is that if the controller is very busy, and is also expected to judge whether the CORA system is giving a reasonable output, then CORA must be able to show, in a fairly transparent way, that its offered resolutions are intrinsically safe.

Context Aircraft - context a/c (especially 'non-nominals'[9]) will be important considerations for algorithm development. Some controllers in some ACCs derived extensive resolutions, not merely moving the two conflict a/c, but also several context a/c, either manoeuvring them or locking them on headings. A significant consideration for CORA will be whether the algorithm tries to do such a comprehensive job, or focuses on the minimal manoeuvres to achieve

[9] Non-nominals are a/c not behaving normally or correctly, or can also be a/c given unwise clearances, or the result of poor co-ordinations, etc. Several of these were simulated in the investigation, and they took up a lot of the controllers thinking time when deliberating resolutions.

safety, perhaps leaving other fine-tuning aspects up to the controller. This is not a decision to be taken lightly, as the computational complexity of dealing with all context a/c will increase dramatically. Secondly there is a potential situation awareness paradox here. If CORA manoeuvres conflict and context a/c, the controller may not understand why some a/c have been removed. Alternatively, if CORA moves only the conflict a/c, the controller, being somewhat 'out of the loop', may see less easily which context a/c also need to be moved to 'fine-tune' the situation. Probably, as suggested later (5.3), the ideal is to keep CORA simple, probably not affecting the context a/c. This

Figure 8: Conflict Resolution Selection Process (Incorporating Workload Management)



would mean the controller still had the job of optimising traffic, and would not be placed in the difficult and possibly untenable position of having to accept complex and 'opaque' resolutions, yet still be responsible for them. It would also draw the controller 'back into the loop' to an extent. This would be advantageous from a system safety and reliability viewpoint.

Look-ahead time - although CORA is primarily intended as a planner tool, some of the time-frames used in the investigation were more 'tactical'. There were a number of comments on the 'ideal' look ahead time, which seemed to range from 5 – 10 minutes from controllers' perspectives. One salient point however, is that some resolutions will 'expire' after a certain 'time-to-conflict' point has been passed, and others may arise as the traffic evolves. A critical decision for CORA will therefore be when to present resolutions – at the earliest opportunity? And as new ones arise, or original ones 'expire', how should these events be signalled to the controller? This is probably an area where some dynamic simulation study will be required.

Global versus pairwise resolving processes - in multiple conflict situations (i.e. more than one conflict), there are essentially two conflict resolution approaches. The first would take the most serious conflict and offer resolutions for it. Once a resolution for that conflict had been implemented, a resolution for the second conflict would be produced, etc. This is a 'pairwise' approach. An alternative and more ambitious approach is to consider the global situation (all conflicts). This approach looks for the best resolution for all the conflicts and surrounding a/c. Sometimes, the global approach can result in less manoeuvres, as there may be certain actions that resolve both (or more) conflicts, which would not be found with a pairwise approach.

In the study, controllers were asked during the solving of scenarios 7 and 8 if they were resolving them globally or pairwise. Also, the analyst observed their resolution process, as most controllers talked aloud during this process. It appeared that most controllers considered a/c pairwise, and in sequence, and then tried to consider whether they had introduced secondary conflicts or problems, or made later conflicts more severe or difficult to resolve. A few controllers did indeed consider the situation globally, and produce resolutions that were in some cases more 'efficient' (less manoeuvred a/c), but this was not the norm. This remains a question for the developers of CORA, and is probably an item best discussed further with controllers and algorithm developers, to consider the advantages and disadvantages of these two approaches.

'Controller-informed' versus 'controller-bound' optimisation - during the investigation it was notable that some controller principles were not always optimal. For example, a commonly expressed principle was to leave over-flights alone, so that if a climbing a/c had a conflict with an over-flight, then the climbing a/c (who 'wanted something') should be the one that is manoeuvred. In a simple single conflict pair scenario, this principle was indeed adhered to by most controllers. However, in more complex scenarios, adherence to such a principle sometimes led to complex solutions, and ignored much simpler ones that violated this principle. Controllers who 'violated' this principle saw the higher level benefits of this approach, and acted accordingly. The question is therefore one of the degree to which CORA resolutions should be bound by operational expertise. It is likely that the algorithm should not be bound in this manner, at least for complex scenarios, else it may not achieve its global aim of reducing workload and enhancing capacity. This is something that should be discussed more fully with controllers. It was also noticeable that En Route controllers with more of a TMA or Approach background, appeared more ready to violate such principles. In TMA type environments, such principles are not viable, and the a/c pilots also accept that they may have to make significant manoeuvres, more so than when they are in cruising phases of flight. Better global optimisation of air traffic may need a small cultural change on the part of some controllers, and even pilots (via the airlines), to be more accepting of deviations in En Route phases, even when such deviations do not appear to relate to that particular a/c's situation.

Emergencies - scenario 6b contained an a/c that had a medical emergency onboard. Most (but not all) controllers gave this a/c priority. This led to resolutions which were not optimised, but which prioritised this a/c above all others. This is something the algorithm developers will need to consider. Furthermore, it was suggested that a better emergency to consider (from a conflict resolution perspective) would be an a/c depressurisation, which would entail dropping through many vertical levels at a very fast rate. More generally therefore, the resolution algorithm needs to consider the conditions under which resolutions should stop attempting to optimise, and should only maximise safety. This is clearly something controllers would relate to and value.

Algorithmic usage of the data – the exact usage of the data provided by this study will be determined by the next stage of the CORA project. However, it is useful to indicate by way of an example how the data could be used. Therefore, Table 10 illustrates the use of the data for a hypothetical expert system-type approach that converts the rules, factors, principles and no-no's into an algorithmic construction for deriving a resolution in a Head-on conflict situation between a/c A and B.

Table 10: Hypothetical algorithmic usage of controller-derived information

IF <conflict> is <pair-only> AND <category Head-On> AND <T =10+ mins> THEN IF <centre> is <level-favoured> AND <no turbulence at level> AND <levels above available> THEN [OPERATION: Determine ODL a/c = A] THEN IF <A not recently taken off> AND <a/c performance category = ok/FL> THEN

CLIMB A 1000 feet

ELSE IF <A recently taken off> OR <A performance inadequate> OR <turbulence> OR <no levels available above> AND <levels available below> THEN

DESCEND A 1000 feet

ELSE IF <B far from destination> AND <B climb performance ok?FL> AND <levels available above> AND <no turbulence> THEN

CLIMB B 1000 feet

ELSE IF <no FIR boundaries nearby> AND <no context a/c left/right> AND <wind = negligible> THEN [OPERATION: Determine non-ODL's destination short-cut = Right} THEN

TURN BOTH A/C RIGHT 10 DEGREES

Etc.

5.3 General controller comments on CORA

In individual and group sessions, controllers were asked their thoughts about having a CORA-type of system available in the future. This question led to a number of comments, which are summarised below:

- (Maastricht) - CORA is not the most urgent need – a medium term conflict detection system is needed. CORA may be needed later.
- (Italy) - A system such as CORA would be useful if extensively tested and validated – CORA might also be more needed with RVSM & increasing traffic levels.
- (Lisbon) – They believe it could be useful for their airspace.
- (NERC) – Any conflict resolution system needs to be simple, quick and straightforward.

- (Athis Mons) – Look ahead time will be a key factor. For their airspace 5 – 7 minutes would be optimal. There was also concern over the loss of skills, and they were not generally sure that CORA was applicable to Athis Mons operations, but in any case CORA should have a small number of choices, and not generate complex instructions.
- (Gothenburg) – Gothenburg TMA is too tactical an environment for CORA. For En Route it would be useful if it could enable the controllers to see ahead >10 mins.
- (Shannon) – At Shannon, controllers use speed control a lot, but for fine tuning, not for conflict resolution. CORA was seen as a very challenging project, but they were significantly interested in it if it could work. Such a tool would be particularly useful for Shannon because of the large number of aircraft coming and going periodically during the day, and especially for traffic cutting across the prevailing traffic flows. CORA could ease the workload of the tactical controller, but then if it looked ahead too far, it could overload the planner.
- (Malmo) – The development of CORA will be very challenging – the sequence of resolutions will be important in multiple conflict scenarios. A computerised tool could make one lose the picture – therefore need to assess situation awareness impacts with CORA. CORA should not be a tactical tool.

The above are the main comments gained from controllers about the desirability of a conflict resolution assistant tool. They range from a cautious interest (though not in TMA or TMA-style environments) to a clearly expressed need, if the tool can be shown to work and not have adverse effects on controller situation awareness. All controllers believed, however, that the project would be challenging. The next stage of CORA development will indeed aim to meet that challenge, by developing a controller-informed algorithm for conflict resolution.

6. CONCLUSIONS

The study has successfully elicited rules, principles and factors that affect conflict resolution performance. This information will be used to inform the CORA algorithm, to lead to the development of a controller-informed approach to conflict resolution assistance. A key insight gained is that practices in different locations do vary considerably, and it may be that CORA will need to be tailored to fit different regions. Nevertheless, the information gained, and the degree of convergence, suggest that the CORA approach is feasible, and the next stage will be to develop the conflict resolution algorithm itself, building on the data gained in this study.

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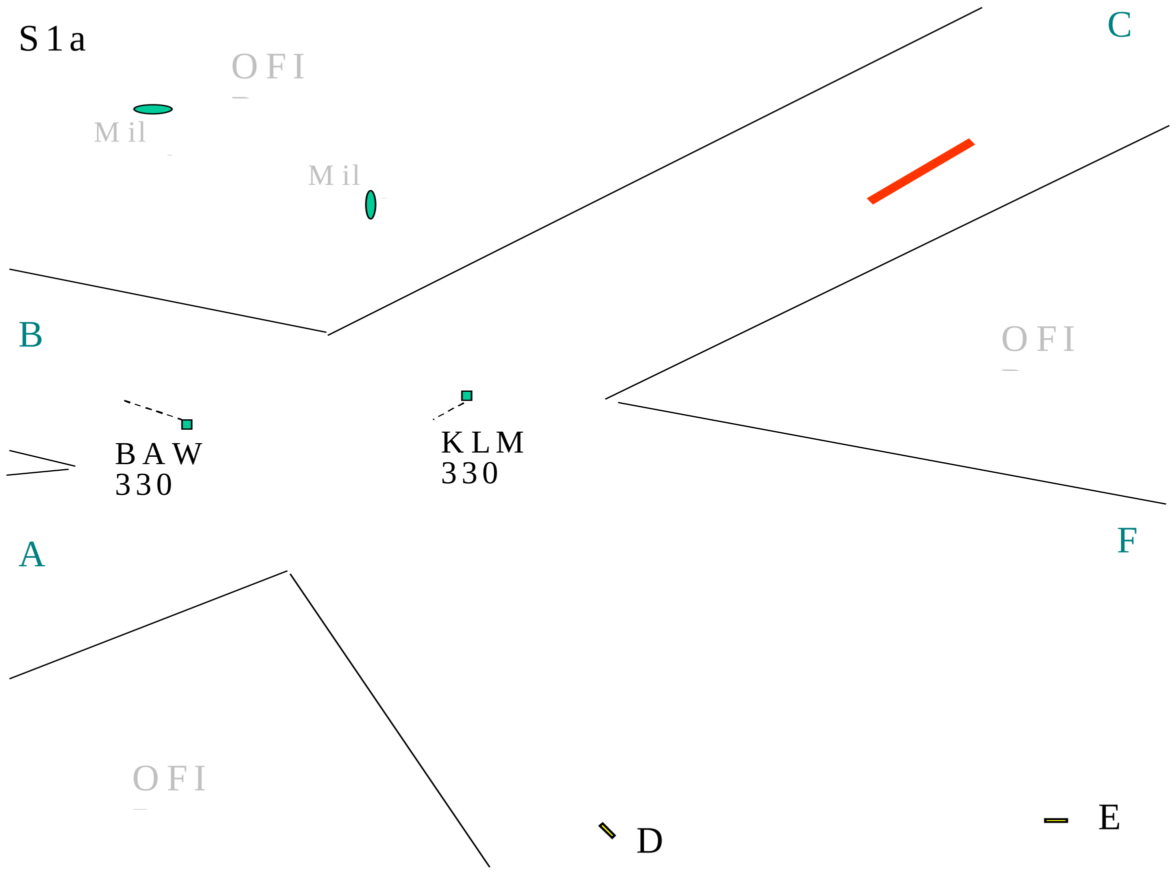
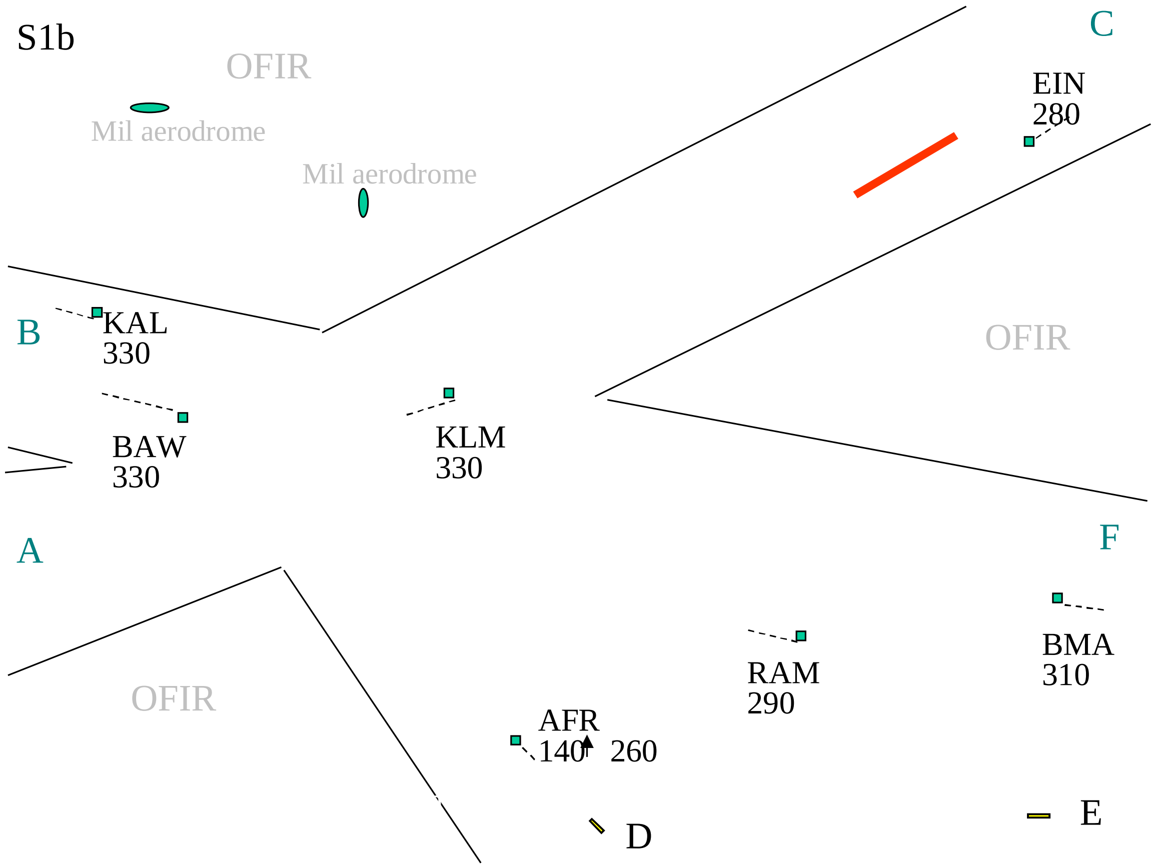
Acronyms

A/c	Aircraft
ACC	Area Control Centre
AERA	Automated En Route ATC
ATM	Air Traffic Management
CORA	Conflict resolution Assistant
EEC	Eurocontrol Experimental Centre
FIR	Flight Information Region
MTCD	Medium Term Conflict Detection
Nm	Nautical miles (nmi in the US)
NATS	National Air Traffic Services
NERC	New En Route Centre (UK)
ODL	Opposite Direction Level
PARR	Problem Analysis, Resolution and Ranking
RHEA	Role of the Human in European ATM
RT	Radio-Telephony
RVSM	Reduced Vertical Separation Monitoring
STCA	Short Term Conflict Alert
TCAS	Traffic Alert and Collision Avoidance System
TMA	Terminal Manoeuvring Area
UK	United Kingdom

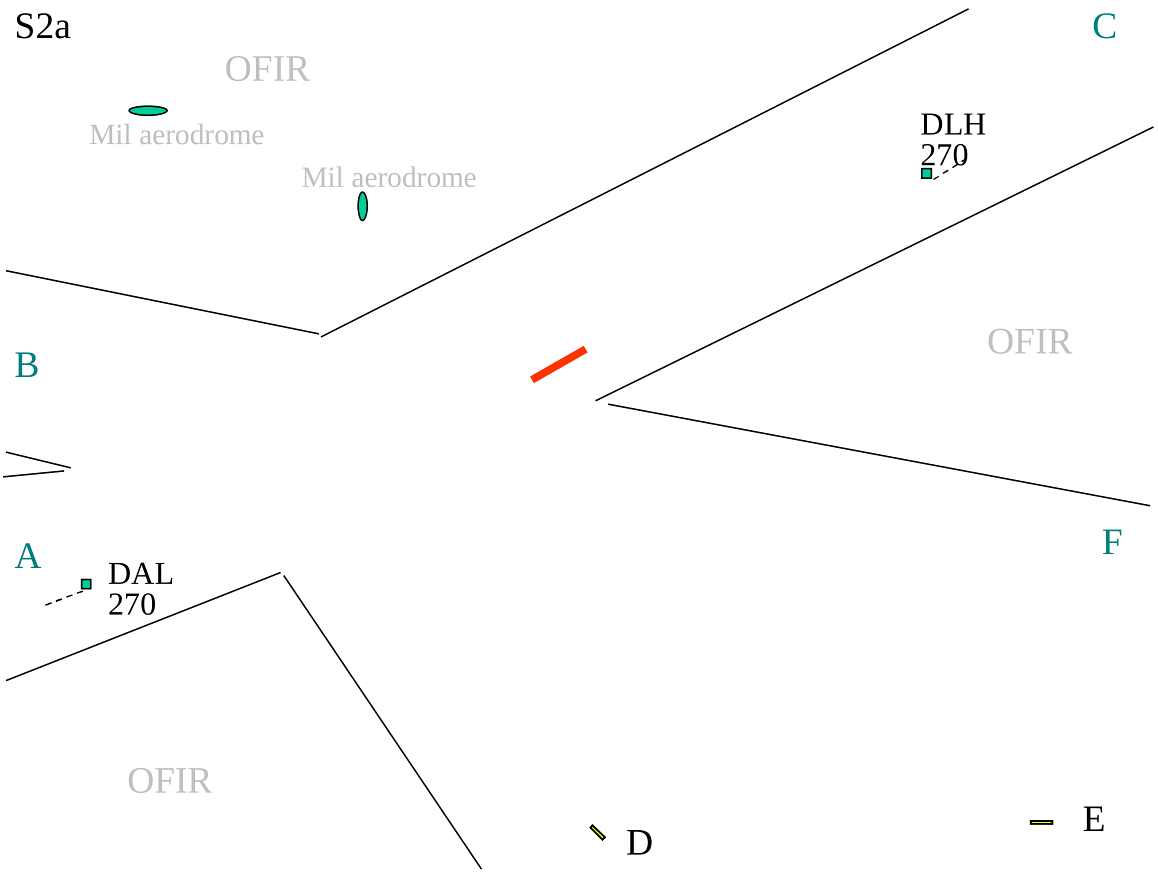
APPENDIX 1 – SCENARIO DESCRIPTIONS



Catch-up
BAW 123 is a 747 and is flying >100kts faster than KLM 234, a 737. Neither a/c can fly much faster than their current speeds today. They are both headed for the same airport 200 miles away in C. Top of sector is unlimited. Trail dots represent 30 seconds
Conflict is approximately 8 - 10 minutes away
Both a/c are transiting through my sector to exit at C at 33000 feet though there is not a rigorous standing agreement to that effect (i.e. they can exit at other acceptable altitudes according to the semi-circular rule).
None of the adjacent sectors is international, and a/c can be accepted on parallel headings. After sector A and B there is oceanic airspace. Traffic heading through these sectors are eithre bound for the USA or Southern Isles such as Canary Isles, West Africa, or Ireland, depending on their a/c type. ODLs (Opposite Direction Levels) are negotiable.
RVSM is not in place.Airways A, B and C are approximately 15 miles wide.
Length of trail-dots indicates relative speed.
The A and B exit points are towards the Atlantic sector. A/c leaving at these points are unlikely to be landing in the next sector. A/c leaving at C and F may be landing in the next sector. E is a large airport, D a smaller one.
Semi-circular rule: (above FL245): Eastbound: 250; 260; 290; 330; 370; 410
Westbound: 260; 280; 310; 350; 390; 430. Reverse may be true in France/Italy.



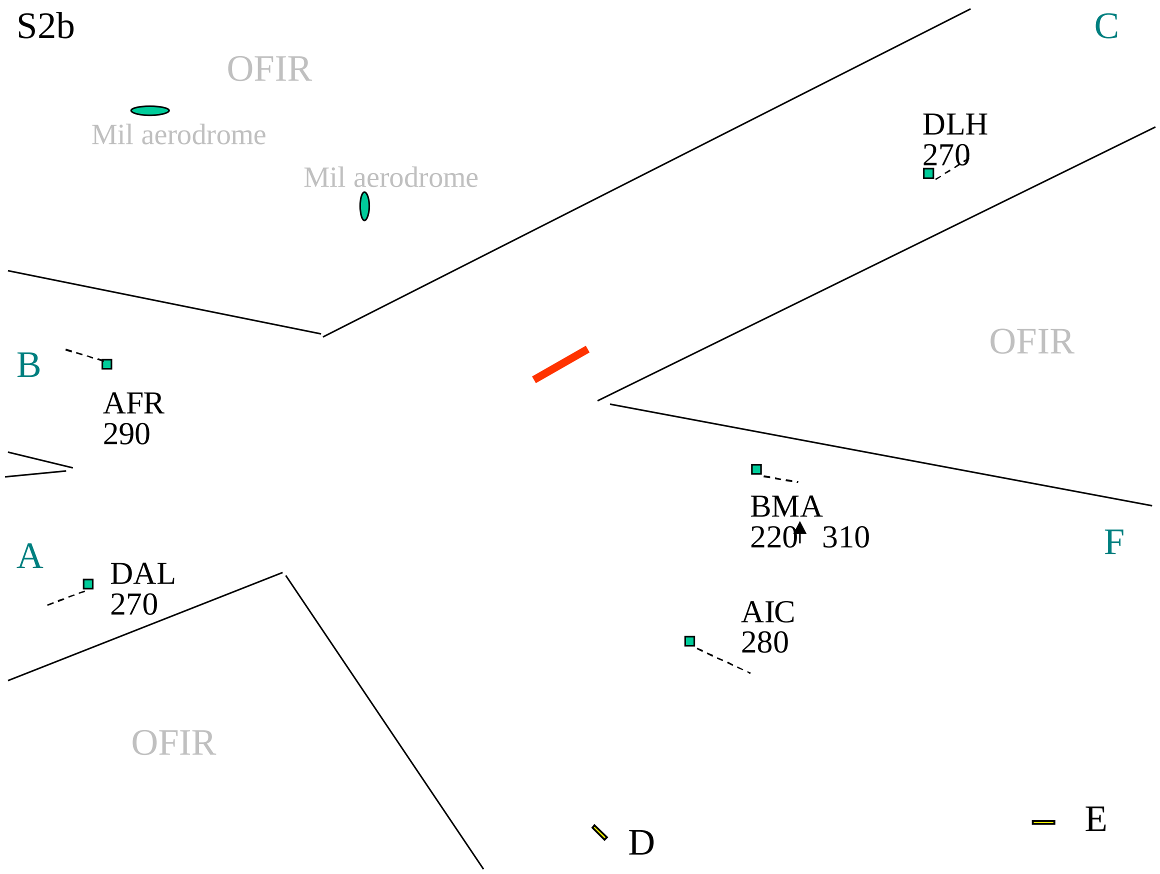
KAL 567 is an airbus A320.
EIN 536 is a 757
The BMA and AFR a/c are 737s, the RAM is an A320
Currently the BAW will pass in front of the KAL 567, with > 6-7 miles separation predicted.



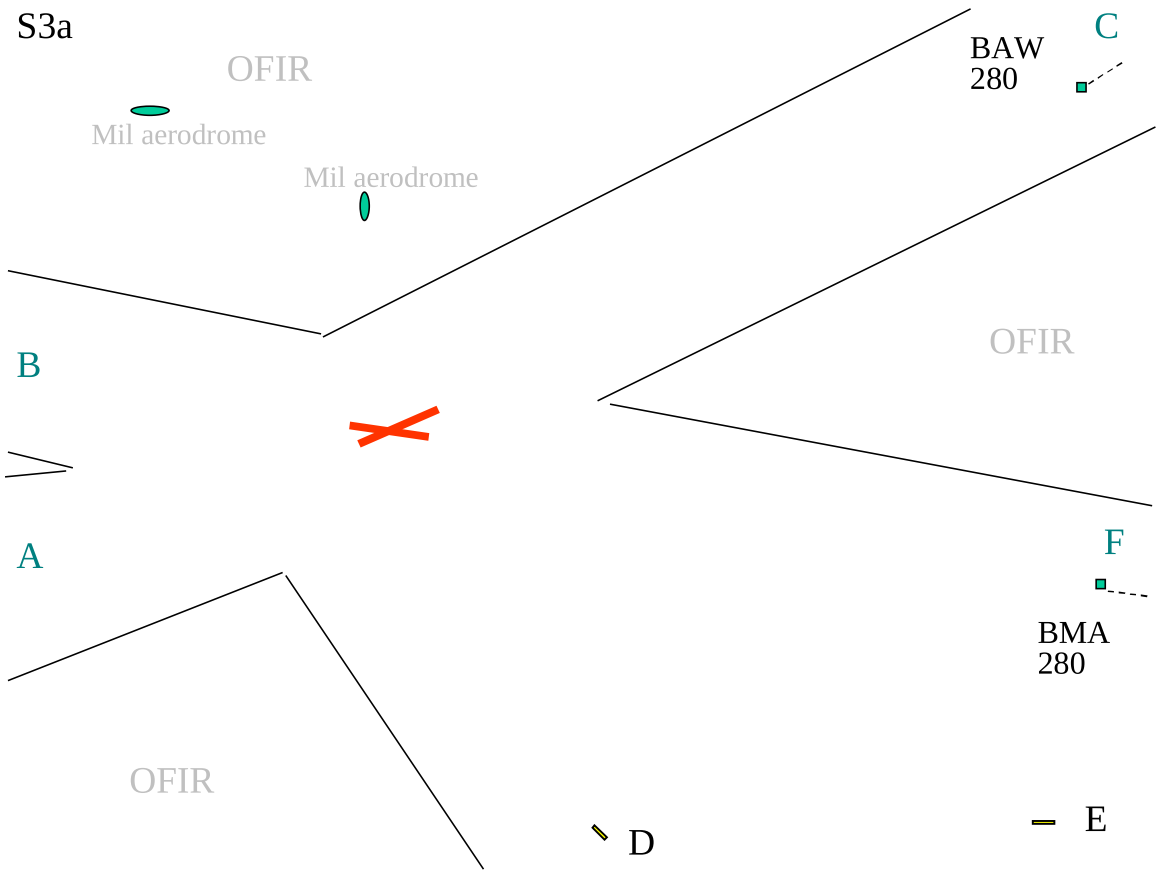
Head-on

DAL275 is a 737. It is not landing in the next sector.

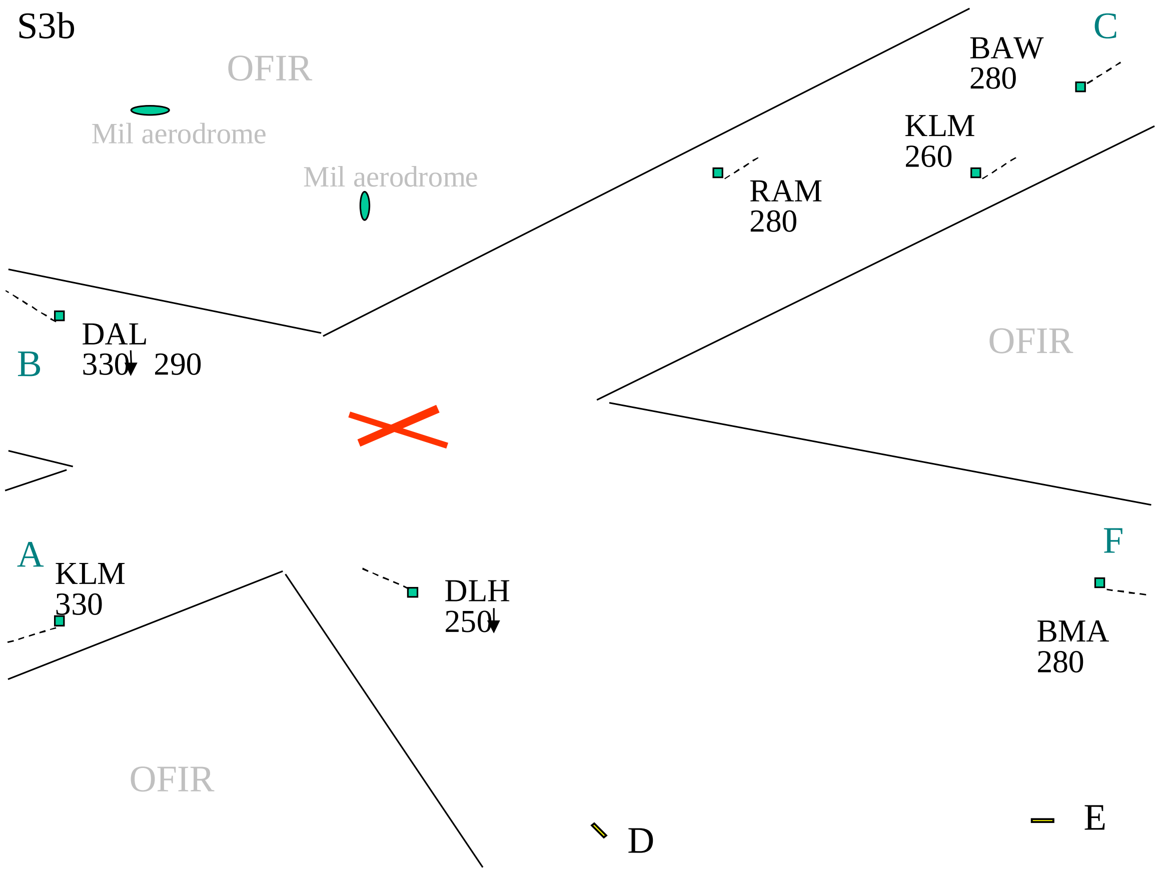
DLH 473 is a 747, heavy, which later will cross the Atlantic at 330. It is at an ODL due to a conflict in the previous sector at the sector boundary. The desired XFL at A for DLH is 280.



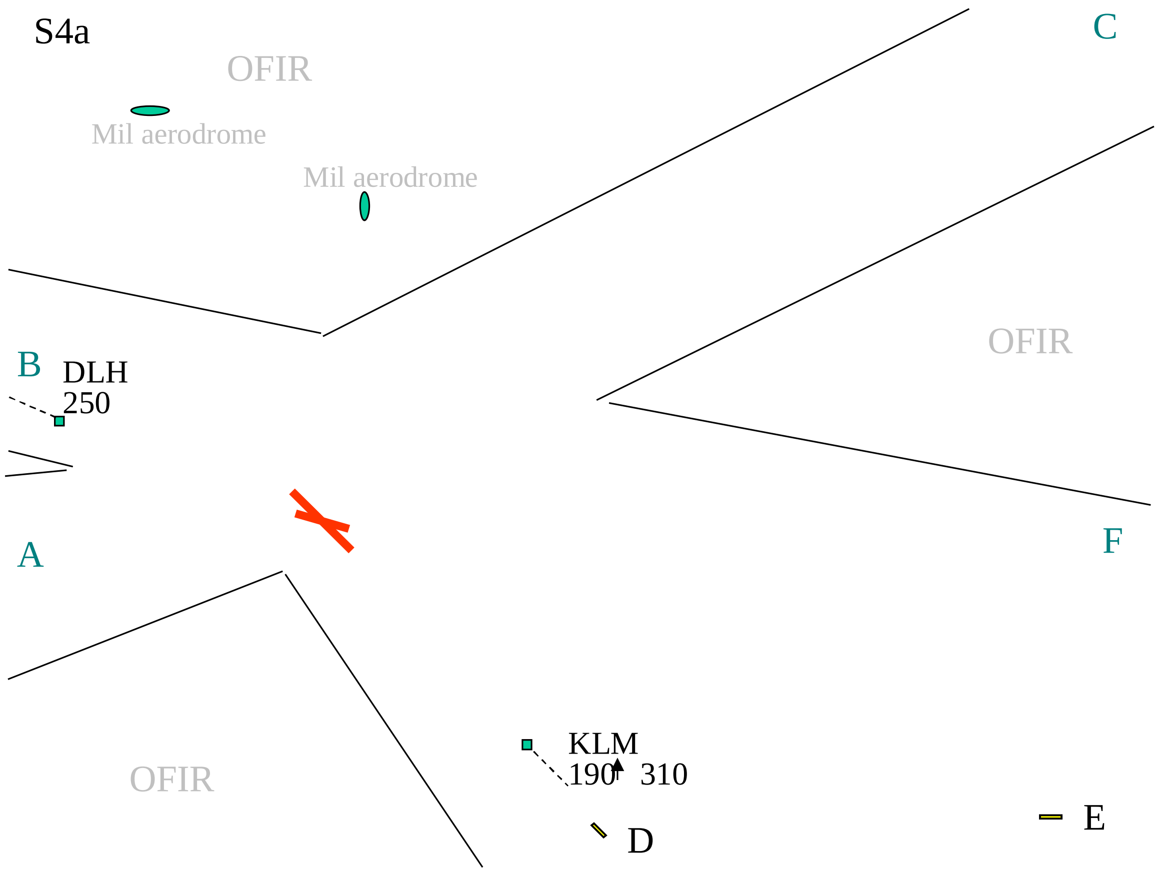
The exit FL at A is 280
AFR is a 757, BMA is a 737, AIA is an A340
BMA is a heavy slow climber
Turbulence is moderate.
AIC routes to middle of airways and then turns South to A.



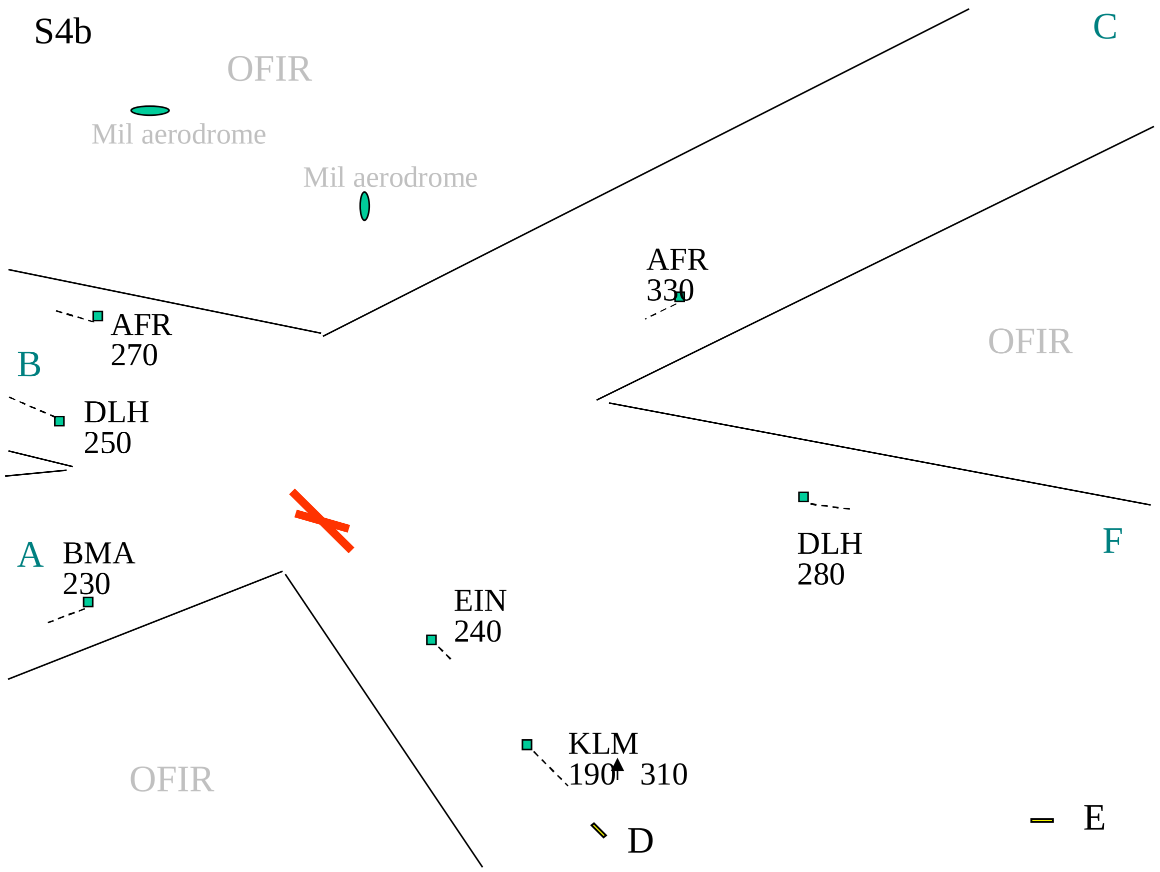
Acute angle crossing
BAW 362 is a A320
BMA 332 is a 777 (and can therefore go faster)



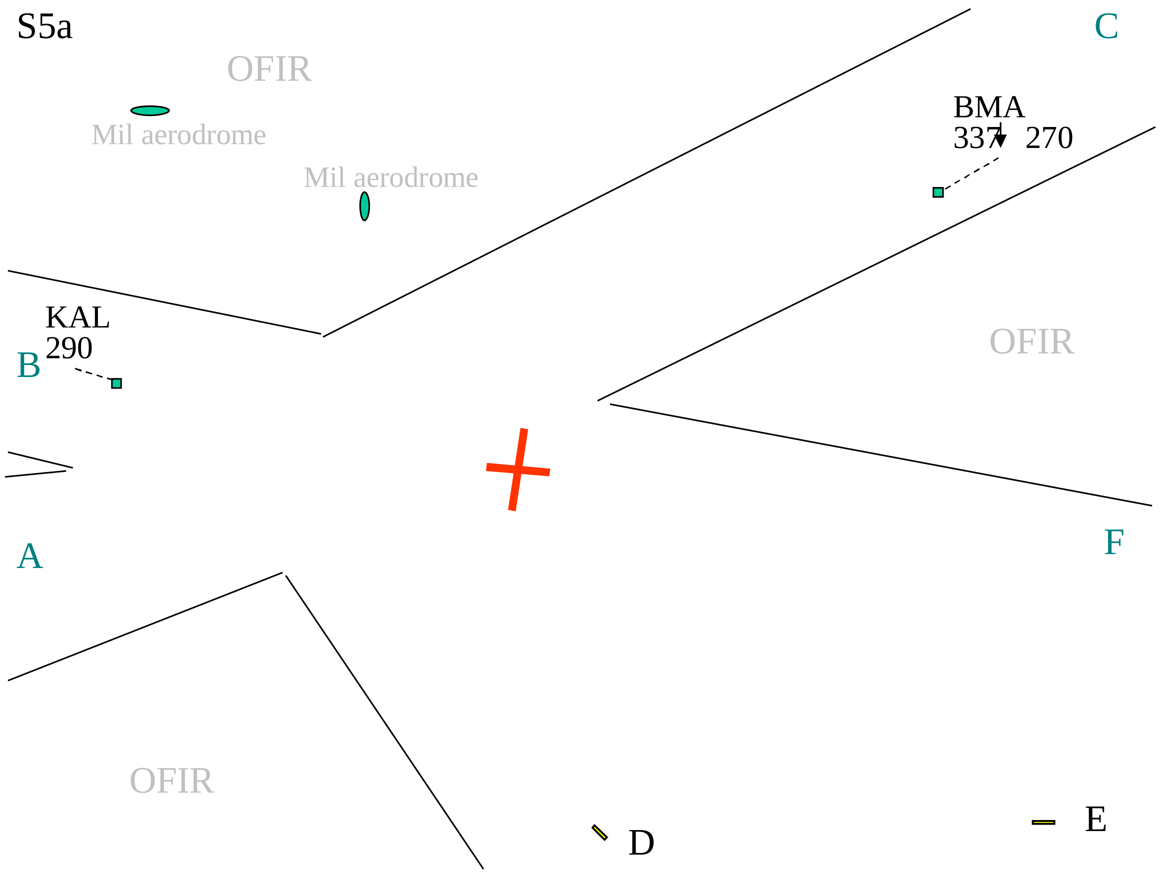
KLM324 is a 757
RAM 312 is a 737, and is the same speed as the BAW.
DAL 352 is a 767. It is routing South of the conflict area and will be below it (i.e. vertically separated).
KLM 732 is a 757 - it is >5miles ahead of BAW362 at present, but is slower
DLH 251 is an airbus A321



Climb-through
DLH 231 is a 747
KLM 261 is a Lear jet

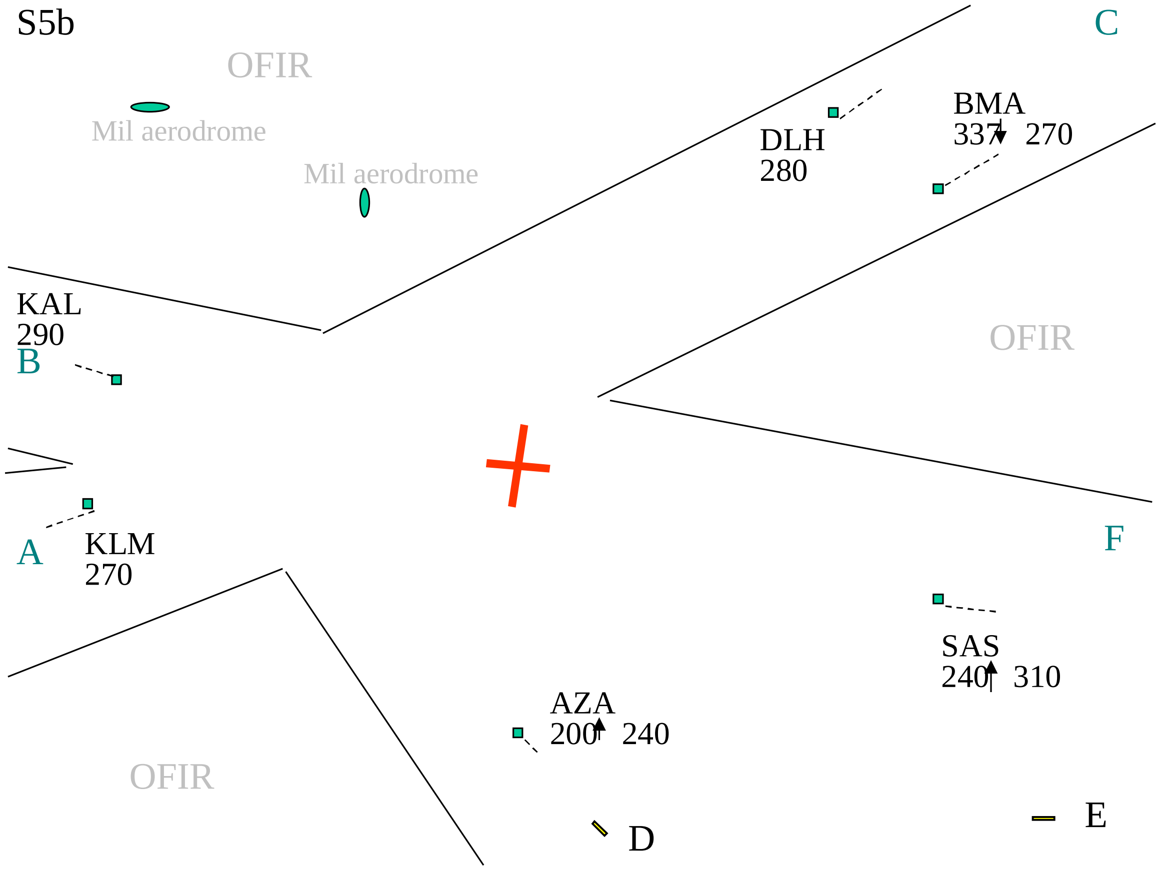


AFR 213 is an A320, as is AFR 251
BMA 512 is a 757
EIN 230 is an ATR (overflight)
DLH 317 is a 767

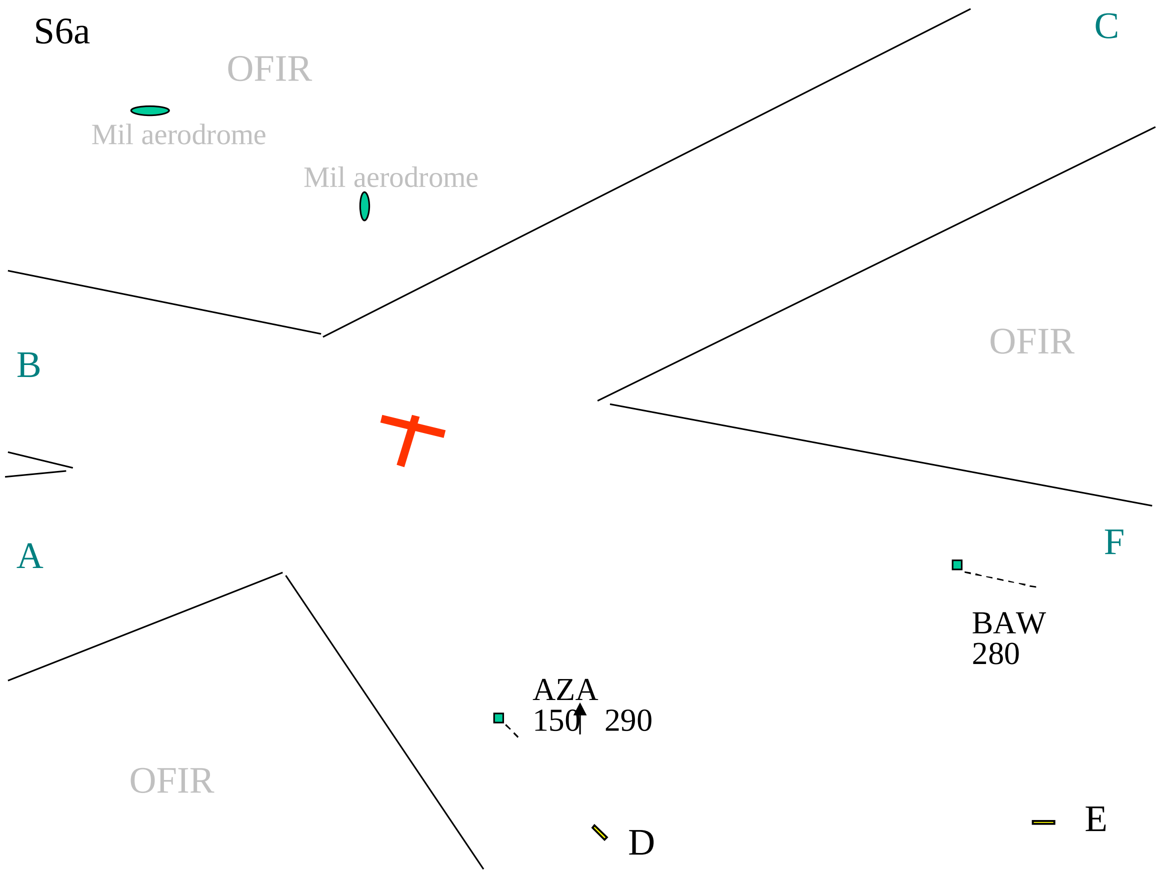


Descend-through
KAL 361 - 777
BMA is a Lear jet.
To gain more solutions than simply ‘expedite descent’, suggest that there may be a tailwind (Northerly) preventing the BMA getting down quickly

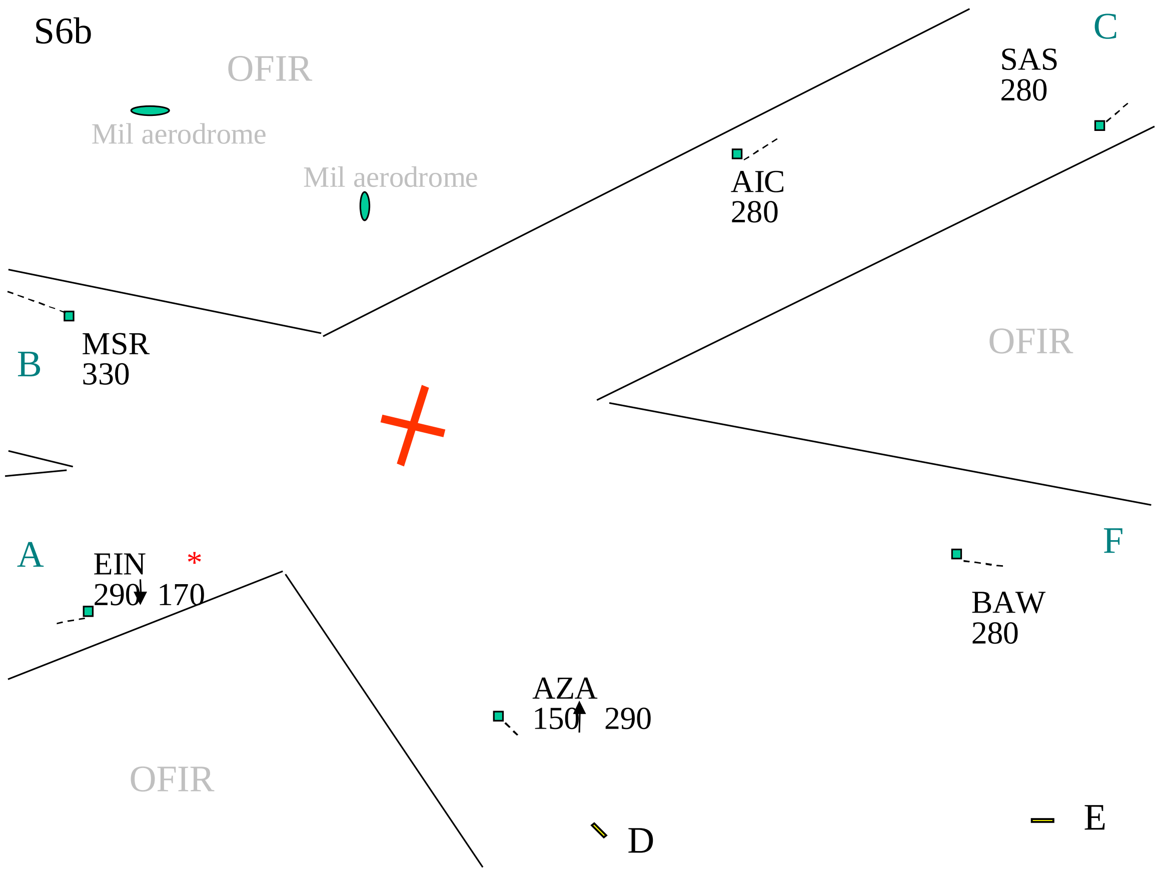
S5b



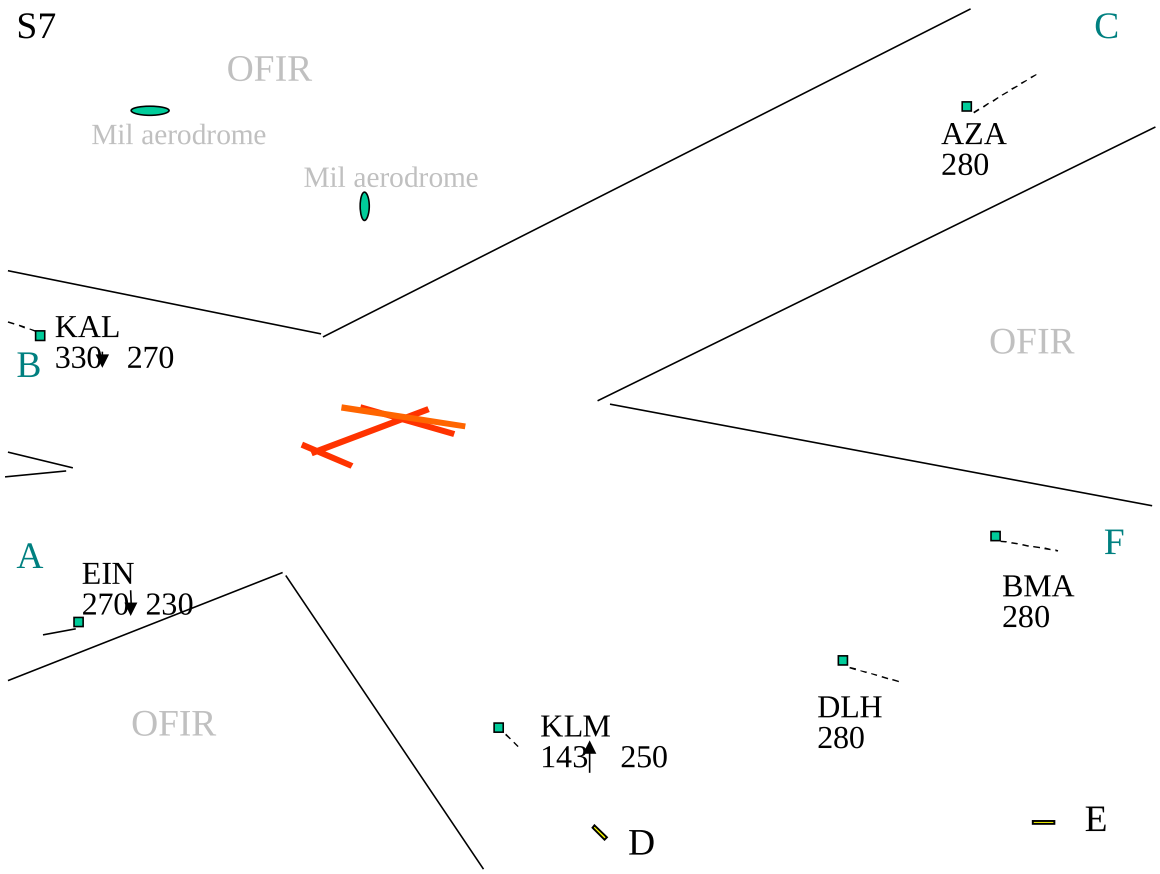
KLM is a 737
AZA is an ATR
SAS is a MD80 - probably given this clearance in error
DLH is an A320



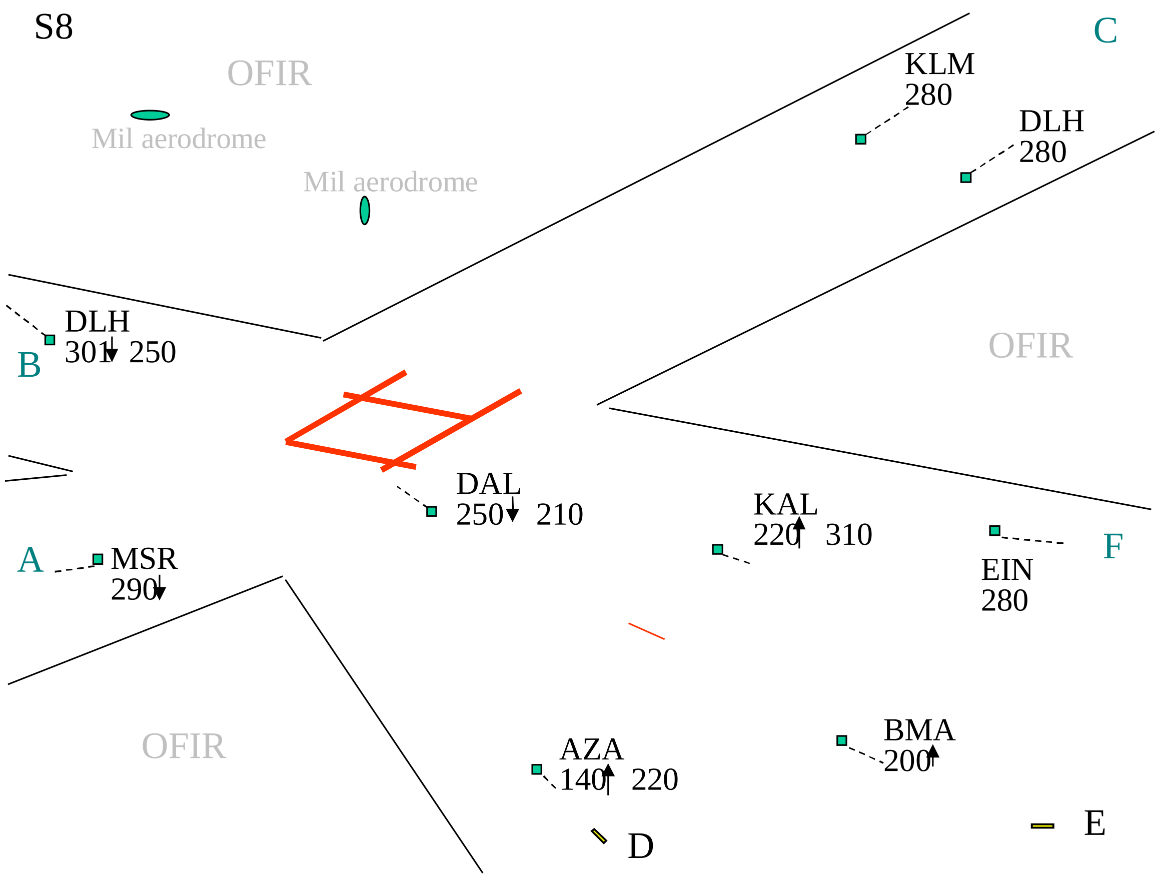
Right angle crossing and turning climb-through
AZA 236 is a 737
BAW 721 is a 777, a heavy heading for the Atlantic



SAS and AIC are 747s
MSR is an A320 that wants to descend soon
EIN 473 is a 747 a medical emergency, a passenger heart attack - D is too small for a 747at the moment, the SAS will pass behind the speedbird (BAW)



Multiple successive conflict
AZA is a 757
KAL is a 777
EIN is a 737
KLM is a 757
DLH is a A320
BMA is a 747
DLH and BMA will not conflict in my sector, but will conflict at the edge of B.



Global vs. Pairwise conflict resolution
KLM621 and DLH 237 are on parallel headings and are 757s
All conflicts take place at 280
Conflict 1 is between BMA 729 and DAL004 (A320 and 777)
Conflict 2 and 3 is between KLM621 and EIN478 (a 737) and DLH237 and EIN 478
Conflict 4 and 5 is between the KLM and DLH and KAL723
DLH 339 does not conflict with anything as it dips below the other a/c, unless a descent solution is offered.
MSR is an A320. AZA is a Fokker 80. These a/c do not conflict at present.