THE POTENTIAL OF SPEED CONTROL

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Abstract

The effect of speed control when used as a single action to resolve aircraft conflicts is not well known in the ATM scientific world. Therefore, the objective of this study is to get some initial figures to evaluate its potential.

This paper introduces the use of speed control manoeuvres with a specific focus on automation. The Reorganised ATC Mathematical Simulator that served as a tool is described and especially the modifications for its resolution rules, the aircraft performance and uncertainty model. Then the simulation setup and the seven scenarios are analysed in more detail concerning traffic and conflict density. Next, the results from the simulations are shown with analysis of resolution rates, speed rates, encounter angles, and closest points of approach. Last, the results are discussed and further studies suggested.

Introduction

Speed Control and Automation

Speed control is one of the measures that air traffic controllers may apply to aircraft to keep them separated. However, clearances for speed are almost unused in European upper en-route sector control (<1%) [1], whereas transfers, level changes, direct routing and vectors are most commonly used.

Speed control has not been studied for the purpose of automation yet, or at least there is no significant literature. The literature that treats algorithms for automatic conflict resolution is mainly discussing horizontal vectors and, to a lesser extent, vertical resolutions, but no speed adjustments. Only some project documentation treats speed-manoeuvres, e.g. the CORA project [2].

Also, the operational concept of Airborne Separation Assistance (ASAS) is researching the possibility to chain and space aircraft in sequences for easier handling of (arrival) flows [3], so-called station keeping, with a consequence of similarities in speed of the targets, but is not explicitly giving speed instructions. Same applies to Miles-In-Trail (MIT), which, like the procedures over the Atlantic Ocean, spaces aircraft on in-trail sequences on similar speeds or with a specific radar separation buffer. The author has no quantified figures about these.

All Arrival Managers set time constraints on arrival fix points, and aircraft can accomplish the time contract amongst others with speed adaptations [4, 5]. This concept of metering fixes can further be propagated into the en-route domain, e.g. [6, 7]. Those flow organisers do not include a conflict resolution function using explicitly speed, at least this has not been found documented. The procedures of sequencing aircraft with speed, however, do differ from generic speed instructions, because they only use one dimension of the geometry (along-track conflicts). If, instead, speed-instructions are used for all kind of conflict resolutions, they will be used in all dimensions of the possible conflict geometries.

The Automated En-Route Air Traffic Control (AERA) concept [8] in its very early versions mentions speed restriction measures where the automation-system tags traffic that should not be touched by the controller and pilots, because it is recognised as not conflicting if nothing happens. This could be regarded as a “maintain speed and heading” clearance, hence a speed instruction that is given by the system.

J. Villiers [9] introduces the notion of speed adjustments as a means to make what he calls “subliminal” control, which could be considered as an automation system that creates “lucky traffic” so that controllers, who would still be part of the system, would not have to intervene on the traffic. The automation system would use speed adjustments for this, and the controllers would not see nor have to know about hidden automatic operations, because they would not perceive the speed changes.
This paper intends to analyse with the help of fast-time simulations to which extent speed adjustments could be used to resolve conflicts for en-route traffic.

**Simulation Setup**

The Reorganised ATC Mathematical Simulator (RAMS) was used in its version RAMS-Plus5.0 and 5.04. The scenario was reused from the 5 States Fast-Time Simulation [10] with an area extending from London/Paris in the west to Berlin/Prague/Vienna in the east and from Copenhagen/Malmö in the north to Lyon/Milan in the south. More than 140 sectors from 24 ATC Centres were simulated. The measured centres were limited to en route and to Karlsruhe, Maastricht and Reims, which corresponds to 36 en-route sectors above flight level 245. Three traffic samples were used, the baseline traffic of 12 Sep. 1997 containing 9171 flights, and then at 150% and 200% levels, which correspond roughly to year 2005 and 2010.

Figure 1 shows the distribution of flights over the day for the three measured centres for the 150%-2005 traffic sample.

**Conflict Detection**

RAMS includes a tool for conflict detection and resolution. The modelling of these influences the performance of the simulator and is briefly described here.

The detection of conflicts is not like normal medium-term conflict detection! Here, conflict detection is triggered upon sector-entry events. In the simulated setup, both the planning (PC) and tactical (TC) controllers were activated to apply detection and resolution. For each aircraft there is one event for sector entry for the planning controller, and one event for the tactical controller, making two events per aircraft per sector entry. The conflict detection is only successful if the other aircraft is in the “window” of the respective controller. That means that each conflicting aircraft pair can be detected twice, given that both sector controllers conduct conflict detection.

Figure 3 illustrates an example. If aircraft ac1 enters the PC window at time e1, and ac2 at e2, then e1 will not trigger a conflict, because the other aircraft is not yet in the scope of the PC, but e2 will do. Same applies then for the TC with events 3 and 4. The resolution time interval $\Delta R$ is a simulation setup parameter that can be set differently for each controller; however, in these simulations it was set to $\Delta R = 800$ seconds for both.
Figure 3. Events Triggering the Conflict Detection- and Resolution Algorithm

Resolution Rule Base

RAMS uses a data-driven, rule-base system as a resolution algorithm, which attempts to emulate real controllers’ behaviour. The performance of the rule base is entirely dependant on the way it is programmed, and the default rule base coming with the simulator is not running at optimum. Therefore, the rules have been modified for this study, following the logic illustrated in Figure 4.

Conflict Geometry Analysis

Which a/c to move?

Speed Reduction?

Speed Increase?

Set Resolution Constraints
New speed, times

Penalise:
1. requesting occupied stable FL
2. nearer to airport
3. inbound and second
4. inbound vs outbound
5. evolution vs stable
6. behind
7. below
8. in descent
9. significantly faster
10. about to leave cruise
11. still on ground

Reduce penalised
Increase penalised
Reduce favourite
Increase favourite

Set resolution start time
Set resolution stop time
Iterate speed

Figure 4. Logic of Rule-Base for Speed Manoeuvres

First, an analysis of the conflict geometry is undertaken with a categorisation of conflicts depending on the angles and attitudes of the aircraft involved, then the aircraft to be penalised is selected, then the manoeuvre is chosen, and finally additional constraints of the speed manoeuvre are set. The rule base that was created only moves one aircraft, which is very limiting - especially for speed - and where it would be more logical to increase one aircraft and reduce the other one. This subject will be covered in the discussion.

Uncertainty Emulated with Separation Minima

Uncertainty in trajectory prediction was approximated with the use of higher separation minima, as illustrated in Figure 3. Separation minima $\Delta S$ were set to different values for PC and TC: $\Delta S_{PC} = 7\text{NM}$; $\Delta S_{TC} = 5\text{NM}$; $\Delta S_{PC} = 10\text{NM}$ and $\Delta S_{TC} = 15\text{NM}$. To how much uncertainty would this correspond? Given a nominal cruise speed of 430 knots, 1% per hour would correspond to 4.3NM. An average look-ahead time of 20 minutes was assumed, the PC look-ahead parameter $\Delta L$ being set to $\Delta L_{PC} = 15\text{ minutes}$, and the sectors quite small. Then the 7NM separation compensates 2NM (at 5NM real minimal separation), which corresponds to 1.4% at the 20 minutes horizon. 15NM compensate 10NM and correspond to 10.5% uncertainty, and 10NM compensate 5NM correspond to 23% with only 5 minutes average look-ahead assumed for the TC. In other words, the scenarios that separate by 7NM and 5NM would require a highly reliable trajectory prediction with errors only around 1.4%, whereas the scenarios that separate by 15NM and 10NM are possibly too pessimistic allowing for more than 10% uncertainties in trajectory prediction.

Aircraft Performance Envelopes

The aircraft performance envelope plays a major role in the ability of the aircraft to speed up or to slow down at the specific flight levels and attitudes where the resolution manoeuvres are applied. Significant improvements have been introduced to use the aircraft performance as given in [12], including over 100 aircraft types. 20 aircraft types have precise speed envelopes, and all other types are mapped to a representative category, i.e.
heavy, medium or light. Nevertheless, the simulator was set up to allow for speed variances no higher than 10%, even if the performance profile of a specific aircraft type would allow for it.

Simulations Scenarios

About 35 simulations were run, each taking between 24 and 48 hours, and from which only the most significant seven are presented (see Table 1). One scenario covers one full day. The traffic baseline is taken from the 5 States simulation and 100% traffic corresponds to the 12 Sep. 1997. This was increased by 50%, 100% and 200%, which corresponds roughly to 2005, 2010 traffic and beyond. The radar separation $\Delta S$ was set to 7NM and 5NM and to 15NM and 10NM for the respective controllers. All scenarios set the lookup to $\Delta L_{PC}=15$ minutes and $\Delta L_{TC}=0$ minutes; and allowed a maximum implementation interval of $\Delta R=800$ seconds.

<table>
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<th>Exercise</th>
<th>Parameters</th>
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| 100      | 1997 traffic = 100%  
$\Delta S_{PC} = 7$NM, $\Delta S_{TC} = 5$NM  
$\Delta L_{PC} = 15$min, $\Delta L_{TC} = 0$min  
$\Delta R = 800$sec |
| 150      | 150% traffic ~ year 2005 |
| 200      | 200% traffic ~ year 2010 |
| 300      | 300% traffic ~ year 2010+ |
| 100 PC15-TC10 | $\Delta S_{PC} = 15$NM, $\Delta S_{TC} = 10$NM |
| 150 PC15-TC10 | 150% traffic |
| 200 PC15-TC10 | 200% traffic |

Simulation Results

Figure 5 depicts the percentage of resolutions relative to all resolutions, and presents the main results. The baseline simulation (100% traffic = 1997) generated 1365 conflicts in the three measured en-route centres and speed manoeuvres could resolve 81% of all conflicts, where 74% of conflicts could be resolved by the PC. Resolution rates hardly decreased with increasing traffic and conflict rates, but dropped with increasing separation minima!

Figure 6 indicates that about 65% of the resolved conflicts have been resolved by speed reduction, and hence 35% by speed increase. This is mainly due to the resolution rules that favour reduction, but also to aircraft performance envelopes.

![Figure 5. Resolution Rates and Number of Conflicts](image)

![Figure 6. Increase and Decrease of Speeds for the Manoeuvred Aircraft](image)

![Figure 7. Average Speed Increase and Decrease with Standard Deviations](image)
Figure 8 illustrates the speed ratio for resolved and unresolved (monitored) aircraft pair conflicts and their standard variation. All encounters have about 90%, which means that all encountering aircraft have similar speeds.

Figure 9 and Figure 10 show the encounter angles for unresolved and resolved conflicts, with different relations. The unresolved conflicts for a particular encounter angle are related to the total of unresolved conflicts, e.g. 40% of all unresolved conflicts are parallel-opposite-direction; whereas the resolved are related to their angles, e.g. 40% of all conflicts with parallel-opposite-direction could be resolved. It seems evident that parallel-opposite and parallel-same have more difficulties to be resolved, yet they may improve, because of the high number of attitude-cruise conflicts where speed-maneuoures can still have impact. It must be noted for the discussion that 50% of all unresolved conflicts could possibly be resolved with maneuvers other than speed, e.g. lateral offset.

Figure 11 and Figure 12 illustrate the resolutions to the Closest Point of Approach (CPA). Again, the unresolved for a particular CPA are related to all unresolved, e.g. 40% of all unresolved conflicts occur with a CPA smaller than 1NM, whereas the resolved relate to the category, e.g. 60% of conflicts with a CPA smaller than 1NM could be resolved.
Discussion

The main result is the astonishing high rate of speed resolutions, around 75% for the 2010 traffic, with very small changes in speed. Second is the high rate of PC speed resolutions – if discussed with the idea of subliminal control in mind, that result could be interpreted as a drastic reduction of TC workload, subject to further evaluation.

It can further be noted that more conservative separation minima strongly reduce resolution performance, but are still high (>50%); this parameter relates to uncertainty in the predicted trajectory (TP). Therefore it can be stated once again that accuracy of TP is highly correlated to the performance of the resolution and that it would be worthwhile to improve performance of TP.

In general, those conflicts with a small CPA are more difficult to resolve, which sounds normal. Simulation exercises with “low” resolution rates also had more difficulties with larger CPAs. In addition, simulation exercises with “low” resolution rates had more difficulties in resolving encounter angles other than opposite-direction types.

Conclusion

The study is an initial step in evaluating the potential of speed control. The Reorganised ATC Mathematical Simulator (RAMS) was used with modified resolution rules and improved aircraft performance models. The scenarios were only en route for the three measured centres Karlsruhe, Maastricht and Reims. The simulator was configured to let the planning controllers have a long look-ahead time of 15 minutes before sector entry, and no look-ahead time for the tactical controllers. The planning controllers used a separation minimum of 7NM and the tactical controllers 5NM, or 15NM and 10NM, respectively. Traffic baseline was one full day in the summer of 1997, which was increased to correspond roughly to 2005, 2010 and 2010+ traffic levels.

The results show the very high potential of speed manoeuvres, ranking from 50 to 80%, with very low speed adjustments. The “planning” function could execute 90% of all resolutions, which left only 10% for the more traditional tactical controller, and is an early indicator for workload reduction if this planning function is automated. Furthermore, larger separation minima lead to lower resolution rates. The causes for the non-resolutions are mainly the parallel-same- and parallel-opposite-direction encounters, which amount to about 40-50%. Other causes for non-resolutions could not be discerned.

The continuation should further evaluate traffic and conflict densities as well as resolution parameters such as the duration of implementation. The algorithm used in the simulator can largely be improved, e.g. manoeuvre both aircraft, set aircraft on a long parallel offset, etc. In addition, workload and economic performances should be studied.

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References


