E.02.39 EMERGIA D3.1 Report

Report on the proposed improvements to the A3G concept

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Abstract

This document describes the results of work package 3, task 3.2 of the EMERGIA project. It holds the results of the process that has been followed to identify potential modifications to the A3G concept to improve its performance on safety. Several brainstorm sessions and discussions with experts have been held. Each of the weak points of A3G, identified in T3.1 and described in D2.2 was assessed and expected impact on the emergent behaviour is provided.

Authoring & Approval

Prepared By – *Authors of the document.*		
Name & Company	Position & Title	Date
Dennis Nieuwenhuisen / NLR	WP3 leader	14/01/2015
Dennis Nieuwenhuisen / NLR	WP3 leader	10/02/2015
Dennis Nieuwenhuisen / NLR	WP3 leader	13/03/2015
Dennis Nieuwenhuisen / NLR	WP3 leader	01/04/2015

Reviewed By – *Reviewers internal to the project.*		
Name & Company	Position & Title	Date
Frank Bussink / NLR	Project member	15/01/2015
Bert Bakker / NLR	Project member	20/01/2015
Henk Blom / NLR	Project leader	20/01/2015
Bert Bakker / NLR	Project member	12/02/2015
Henk Blom / NLR	Project leader	12/02/2015
Henk Blom / NLR	Project leader	18/03.2015

Reviewed By – *Other SESAR projects, Airspace Users, staff association, military, Industrial Support, other organisations.*		
Name & Company	Position & Title	Date
Richard Irvine	Project Officer	30/03/2015

Approved for submission to the SJU By – *Representatives of the company involved in the project.*		
Name & Company	Position & Title	Date
Henk Blom / NLR	Project leader	19/03/2015

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Executive summary

This document describes the results of work package 3, task 3.2 of the EMERGIA project. In task 3.1, a comparison has been made of the emergent behaviours found for the A3G ConOps with A3. In task 3.2, for each of the differences found in emergent behaviour, options for potential improvements of the A3G ConOps are identified and described. This has mainly be done through discussions and consultation of experts by using brainstorm sessions.

1 Introduction

During large European research projects HYBRIDGE and iFly, innovative complexity science techniques have been developed and applied to airborne self-separation concepts of operations. In order to understand and improve the emergent behaviours of SESAR2020+ at multiple time scales, the EMERGIA project [7] will use these innovative complexity science techniques. This way EMERGIA aims to dramatically reduce the risks that negative emergent behaviours have to be repaired at a late stage, at huge operational costs, and will shorten the period needed to optimize the system architecture and design of SESAR2020+.

The most advanced airborne self-separation concept of operations studied within iFly, makes use of similar 4D planning and tactical layers as SESAR2020+, though fully airborne. This ConOps is referred to as the A3 model. Based on rare event Monte Carlo simulations of this A3 model, conducted within the iFly project, in [3][4][5][6] it is shown that in an advanced airborne-self separation TBO concept the 4D planning and tactical layers can work so well together that this leads to very powerful positive emergent behaviours, even beyond expectations of the concept developers. As a result of these powerful positive emergent behaviours, the advanced airborne self-separation concept considered can safely accommodate very high en-route traffic demands. This raises the question whether these powerful emergent behaviours can be maintained while moving the 4D planning layer and the tactical layer to the ground, as is the case with SESAR2020+. The objective of EMERGIA is to answer this research question.

1.1 Purpose of the document

This document describes the results of work package 3 of the EMERGIA project. In work package 2, the A3G concept, in which the 4D planning layer and the tactical layer were moved to the ground, was thoroughly evaluated through Monte Carlo simulations. In addition in work package 3.1 a comparison has been made with the original A3 concept. Results of this comparison have been described in Deliverable 2.2. In task 3.2 potential improvements are identified and recommendations are given to improve the A3G concept. This deliverable reports on the results of task 3.2.

The main question to be answered in the assessment is to identify points of improvement of the a3G concept such that safety levels are sufficient to accommodate high traffic demand.

1.2 Intended readership

This document is intended for those who are interested in the safety assessment of a ground based ATC concept. However, it cannot be read without a proper understanding of the A3G concept (and possibly the A3 concept) and a study of the results of work package 2.

1.3 Inputs from other projects

Not applicable.

1.4 Glossary of terms

Not applicable.

1.5 Acronyms and Terminology

Term	Definition
A3 concept	Autonomous Aircraft Advanced
A3G concept	Autonomous Aircraft Advanced Ground
ADS-B	Automatic Dependent Surveillance-Broadcast

Term	Definition
ATM	Air Traffic Management
ConOps	Concept of Operations
E-ATMS	European Air Traffic Management System
SESAR	Single European Sky ATM Research Programme
SJU	SESAR Joint Undertaking (Agency of the European Commission)
SJU Work Programme	The programme which addresses all activities of the SESAR Joint Undertaking Agency.
SESAR Programme	The programme which defines the Research and Development activities and Projects for the SJU.
TBO	Trajectory Based Operations

2 Introduction

2.1 Goal of WP3

The goal of work package 3 of EMERGIA is to identify potential points of improvement of the A3G concept based on the differences between emergent behaviour between A3G [1] and A3.

WP3 is organized through conducting two successive tasks.

1. Systematic comparison of the emergent behaviours found for A3G with that of A3. For each observed difference an explanation needs to be identified.
2. For each difference potential modifications of the A3G ConOps are proposed, together with their expected impacts on the emergent behaviours. Once this list of potential improvements has been identified, in work package 4, a sub set of those potential improvements will be implemented and successive Monte Carlo simulations will be run to assess the impact of those improvements.

2.2 Input documents

The main input for this document is [1].

2.3 Approach

Using the results of Deliverable 2.2 (which also contains the results of task 3.1) , in task 3.2 potential modifications of the A3G ConOps were identified. First the results of D2.2 were carefully studied and some discussions with work package 2 were held to clarify certain aspects. The discussions led to some additional simulations. A part of the results of those can be found in Chapter 4.

Next an initial internal brainstorm was held (21st of October 2014). Some preliminary results of this brainstorm were discussed at the subsequent gate meeting in Brussels (27th October 2014). Further internal discussions were held resulting in a final brainstorm with an SJU ATC expert and the EMERGIA project officer on the 13th of November 2014. Finally, some suggestions were generated during the progress meeting of the 4th of March in Brussels. Together these inputs formed the recommendations described in Section 4.2.

3 Overview of simulations performed

Work package 2 performed extensive tests of the A3G concept to investigate under which conditions it is possible to get A3G concept simulation results as good as the results obtained for A3 [1]. First, tests have been performed for a 2 aircraft scenario. Initial parameter values were called baseline parameter values. The test have been used to verify to which extent these parameters could be relaxed (selected parameter values) while still maintaining A3 performance.

The following table lists the parameters that were investigated and their influence on the performance of the A3G concept compared to A3 for the 2 aircraft encounter scenario.

Test ID	Description	Result
A	A3 with baseline parameter settings	
B	A3G with baseline parameter settings	
C	Global GNSS/GPS not working	No significant effect
D	Global ADS-B occupied	No significant effect
E	ATC uplink frequency occupied	Significant effect
F	Aircraft GPS receiver not working	Significant effect
G	Aircraft altimeter not working	No significant effect
H	Aircraft ADS-B transmitter not working	Significant effect
I	ATC ground system corrupted	Significant effect
J	ATC ground system not working	Significant effect
K	ATC ground ADS-B receiver not working	Significant effect
L	ATCo tactical response time	Significant effect
M	ATCo planning response time	No significant effect
N	ATC Uplink transmitter send time	Significant effect

After the 2 aircraft experiments, an 8 aircraft scenario was used. Tests have been performed with both the baseline and selected parameter values. Results showed that baseline parameter settings for the 8 aircraft scenario resulted in significant better performance than the selected parameter values, but there still was a major difference with the results obtained for A3. The most important reason for this lies in the transmission and pilot's delay when implementing an updated STCR. Because of this delay, a non-optimal solution may be implemented. Only when significantly lowering the pilot and transmission delay parameter values, results improve dramatically and are in line with A3. However, the pilot delay parameter had to be set at unrealistically low values to achieve this result. Two additional parameters have been identified that did not have a significant influence in the 2 aircraft scenario but in the 8 aircraft scenario these were significant. These are listed in the following table:

Test ID	Description	Result
M	ATCo planning response time	Significant effect
8	Pilot maximum response time	Significant effect

In addition, tests L and N have a more severe (bad) influence on the results when using the 8 aircraft scenario.

Finally, Monte Carlo simulations have been performed for a simulation of a large area using Periodic Boundary Condition. These simulations show the number of STCA and MTCR generated. When the amount of traffic is increased and/or when the wind prediction error increases, then the amount of STCR and MTCR activities also rises resulting in very challenging workloads for the ATCo's.

3.1 Selected relevant parameters

Using the results from D2.2, each parameter that had a significant effect on the results of the performance of the A3G concept was used as input for work package 3. For these parameters potential improvements in the concept were identified which will be presented in Chapter 4. In D2.2 it has been mentioned that the findings from tests E through K may be due to specific A3G model assumptions. Nevertheless to learn it is important to still assess those tests and to identify improvements.

3.1.1 Test E: ATC uplink frequency blocked

The ATC uplink frequency is used to send medium and short term resolution advices from ATC to the specific aircraft. When the frequency is blocked, such advices cannot be sent and as a result, these are not implemented by the aircraft. The baseline value of this parameter is that once in a million times, the frequency is blocked for 1 hour (mean duration).

3.1.2 Test F: Aircraft GPS receiver not working

When the on-board GPS is receiver is not working, an aircraft is not able to determine its position using satellites. The only position information available for the aircraft is then obtained using the inertial reference system.

3.1.3 Test H: Aircraft ADS-B transmitter not working

If the ADS-B transmitter of an aircraft is not working, it is not able to send its accurate position and intent to the ground. As a result, ATC is not able to verify the 4D trajectory plan. The 4D trajectory plan and the aircraft's position then become unreliable. The impact of such failure is larger in the A3G concept than in the A3 concept because in A3 such aircraft still has reliable state and intent information from all other aircraft and it can continue to resolve conflicts. In A3G all state and intent information is collected at a central point on the ground. If information about a specific aircraft lacks, then this is a potentially dangerous situation as no conflict detection nor resolution can be performed on this aircraft.

3.1.4 Test I: ATC ground system corrupted

If the ATC ground system is corrupted, then the system is unable to detect conflicts but is also unable to determine its corrupted state. If not conflicts are detected by the ground system, then no resolutions are generated. Each aircraft will continue its path along their trajectories.

3.1.5 Test J: ATC ground system failure

The impact of an ATC ground system failure is equal to that of Test I but in this case the system *is* able to determine its failure state. It is therefore able to show a failure indication. As there are no backup systems, the effect is the same as in Test I.

3.1.6 Test K: Ground ADS-B receiver not working

If the ground ADS-B receiver is not working, the ground system is unable to receive updates of the state and intent of the aircraft. In such case, old information is used leading to potentially dangerous situations.

3.1.7 Test L: ATCo-Tactical response time

In the A3G concept, two ATCo's are necessary: one for the tactical part and one for the planning part. The tactical ATCo is responsible for processing the short term conflicts. The role of the ATCo is to verify whether the resolution advice generated by the system is acceptable. In case of acceptance, the advice is uplinked to the aircraft. The necessary response of the ATCo, results in a delay of the uplink of the advice. In case of 8 a/c encounter the tactical ATCo response time is an important factor and even a small delay may affect safety.

3.1.8 Test M: ATCo-Planning maximum response time

The planning ATCo is responsible for the medium term conflicts and is verifies the medium term resolution advice generated by the system. If the controller accepts the advice, it is uplinked to the pilot. The longer the ATCo takes to accept the advice, the larger the delay in implementing the advice.

3.1.9 Test N: ATC uplink transmitter send time

The ATC uplink transmitter is part of the ATC ground system. It is responsible for sending the resolution advices that are generated by the ground system. The duration of sending is linear proportional to the number of waypoints in the resolution. In the A3G concept each waypoint takes 3 seconds to send.

3.1.10 Test 8: Pilot maximum response time

When an STCR or MTCR is accepted by either the tactical or planning ATCo, it is uplinked to the relevant aircraft. The advice is then presented to the pilot. It is then up to the pilot to implement or reject the advice. The time the pilot needs to decide to implement or reject is the maximum response time of the pilot. The longer the pilot takes to decide, the older the information on which the advice was based becomes.

4 Results

Each of the selected issues identified in the previous chapter have been addressed and potential solutions have been identified.

4.1 Additional simulations

When studying the results of Work Package 2, some questions arose that have been discussed within the team. The conclusion was to run some additional simulations to better understand the outcome of the influence of some parameters. Some of these results are presented in this subsection.

4.1.1 Test E: ATC uplink frequency blocked

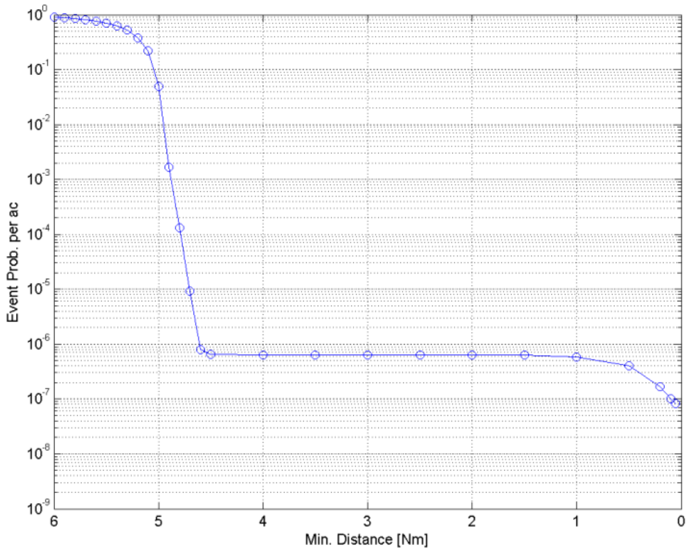

Figure 1: original result with a mean occupancy interval of 1 hour.

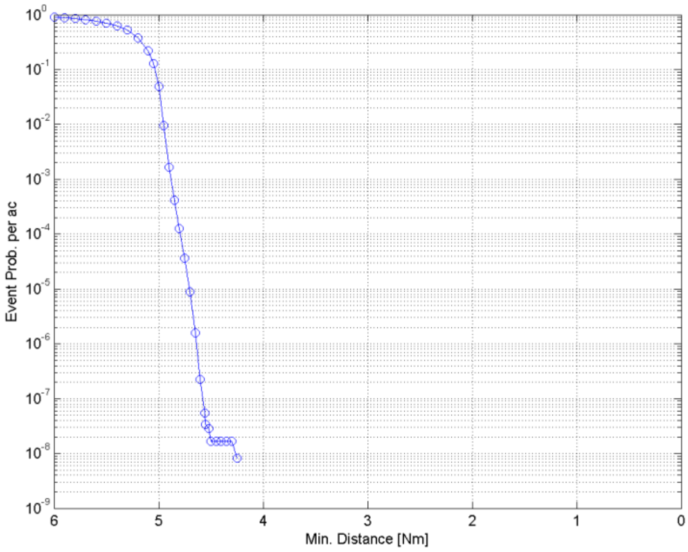

Figure 2: new result with a mean occupancy interval of 60 seconds.

The first issue was a parameter of the uplink being occupied. The (mean) duration of 1 hour seemed unrealistically large (see Figure 1). It is of interest to know the influence of a smaller occupancy interval on the results. An additional run has been performed with a duration of 1 minute (still with a probability of 1 per million runs). The results are shown in Figure 2. By comparing the two figures, the influence of the mean occupancy duration is clear. This suggests that the A3G concept is robust against short occupancies of the uplink frequency.

4.1.2 Test N: ATC uplink transmitter send time

The second issue that was addressed was the delay of the transmitter. It was unclear how such delay could result in the effect that was measured (a significant degradation of safety performance). By studying specific runs (all runs were saved) it became apparent that the result of the delay between generating a resolution and implementing it, results in the implementation of resolutions based on "old" information. As in the time between generation and implementation the aircraft continue to fly, the resolution may no longer be optimal at the moment of implementation. In specific cases the implementation may trigger another generation of a resolution that is also implemented with delay etc. In rare cases this may result in a series of contradicting advices to solve a conflict which is counterproductive. An example is shown in Figure 3 and Figure 4. First an STCR is generated by the ground system that requests the aircraft to turn right. Because of the transmission delay, a new (contradicting) STCR is already generated before the previous one is implemented. If this happens more than once, the aircraft will keep turning from left to right but never solve the conflict.

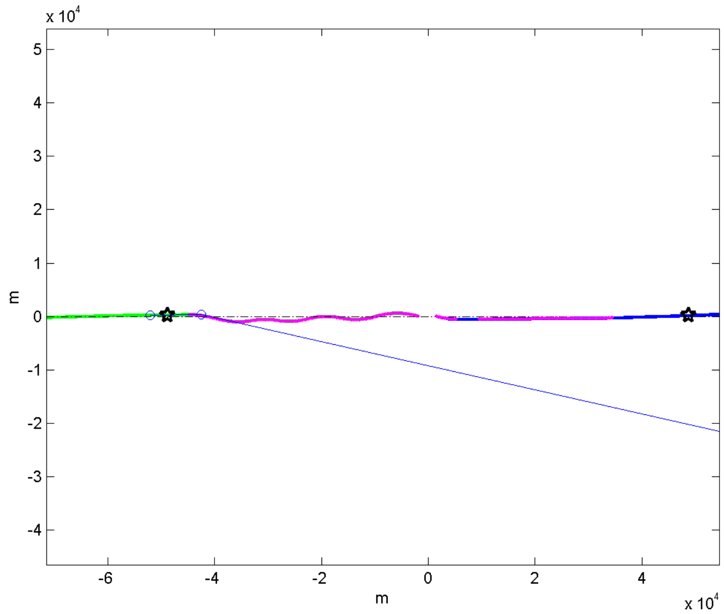

Figure 3: A two aircraft head on situation at t=452s. An STCR is generated by the ground system. The STCR request the aircraft to turn right.

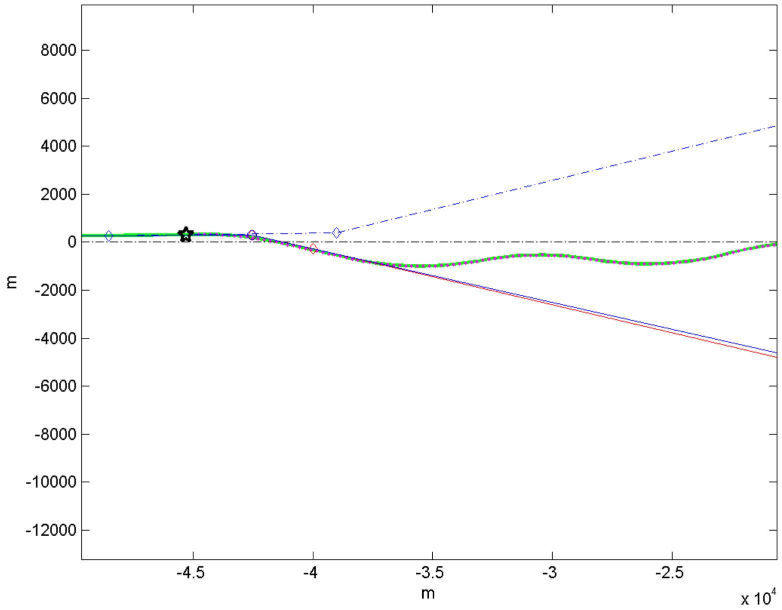

Figure 4: The same scenario at t=466. Before the 1st STCR is implemented a 2nd (contradicting) STCR is generated by the ground system to turn the aircraft left. The pilot implements the 1st as well as the 2nd STCR.

4.2 Points of improvement

For each of the selected parameters with a significant effect on the performance of the A3G concept the results of the brainstorm sessions will be discussed. For the A3G model, several assumptions have been made, which are listed below:

A1. In the A3G model all aircraft are identical and fly at the same level with the same speed.

A2. In the A3G model no emergency situations are modelled.

A3. In the A3G model no SSR radar data is assumed to be available to ATC.

A4. In the A3G model the 4D plan in Flight Data Processing System (FDPS) is considered to be unreliable when ADS-B messages about the RBT in the FMS are not received.

A5. In the A3G model no ground based navigation support is available, i.e. navigation is based on Global Navigation Satellite System (GNSS) and Inertial Reference System (IRS) only.

Although D2.2 already suggested that lifting these assumptions will resolve some performance problems (specifically those of tests E through K), this has not played a role in the brainstorm sessions.

4.2.1 Test E: ATC uplink frequency blocked

The blocking of a frequency can occur because the amount of data that needs to be sent over the frequency is larger than the capacity. In such case, it is possible that data is put in a queue and is sent with a delay; the larger the queue, the longer the delay. A solution around this is to prioritize messages. Important messages (i.e. conflict resolutions) will then have priority over other messages. In this case the delay of delivering the conflict resolutions will decrease.

It is also possible that, for some technical reason, the data uplink to the aircraft cannot be used at all. In such case no communication with the aircraft using the data uplink is possible. Contingency procedures for the pilots will reduce the probability of a conflict occurring. Such procedures could be to continue on the intended 4D trajectory or, if an aircraft is not on a 4D trajectory, to continue on the present heading. As these trajectories have been de-conflicted before (up to a certain horizon), this strategy will ensure a certain level of safety for a limited amount of time.

Finally, it is advisable to have a backup procedure to communicate with the pilots. Such backup could be an R/T option as is practise today, when in total blackout ATC is able to safely separate aircraft using contingency procedures and R/T only. It could also be possible to have an alternative data-link, using different hardware and a different frequency.

4.2.2 Test F: Aircraft GPS receiver not working

If the on-board GPS receiver is not working, the aircrafts navigation is not functioning optimally. While navigation accuracy will be reduced, position and intent will still be provide through other on-board systems (e.g. IRS, FMS) However, this may lead to deviations in the intended flight path of the aircraft and potential dangerous situations. Two different cases can be distinguished: either the aircraft is aware of the GPS malfunction, or it is not. In the first case, the malfunction can be communicated to the ground system which may anticipate this situation. If the 4D trajectory of the aircraft is extrapolated through time, then a good estimate of the aircrafts position may be obtained. If the aircraft is also aware of the malfunction, it should (as a contingency measure) continue its most up-to-date 4D trajectory. If the position of the aircraft is based on the fusion of multiple sources (e.g. ADS-B and secondary surveillance radar), then it is possible to leave out the ADS-B in the sensor fusion process. Although this will lead to a less precise position, it prevents errors in the data. To further mitigate risks, the ground system could increase separation around the affected aircraft by utilizing a larger protected zone

In the second case, when the ground system is not aware of the malfunction, integrity algorithms could be of use. Such algorithm is able to detect uncommon behaviour and is able to conclude when there is a malfunction. If the conclusion has been drawn that there is a malfunction, the mitigation measures of the first case apply.

4.2.3 Test H: Aircraft ADS-B transmitter not working

The ADS-B transmitter is used to send intent information from the aircraft to the ground system. If the transmitter fails, updates of the intent will not be received on the ground. The position of the aircraft may still be available through secondary surveillance radar updates. The longer this situation lasts, the less reliable the intent information on the ground becomes. The mitigation measures are equal to those of the previous section.

4.2.4 Test I: ATC ground system corrupted

All de-confliction calculations and communications are performed from a single ground system. Failure of this ground system may lead to a significant impact on the safety of the total system; resolutions will no longer be generated. The longer this situation persists, the larger the probability of a conflict. As the system itself does not provide an indication of failure, aircraft will assume that they are safe and continue on their trajectories, even though those are no longer safe.

However, aircraft do not have to be completely dependent on the ground system. TCAS may be used as a fall back system. In addition, there should be no single point of failure. The ground system can be duplicated at a different location and operate in a shadow mode. A monitoring function should be designed that constantly checks if the two systems provide the same output. If an inconsistency between the two systems is detected, this is an indication of failure of one of the systems and appropriate action should be taken. In case of failure, the backup system is able to immediately take over from the primary ground system.

4.2.5 Test J: ATC ground system failure

The ground system fails, but *does* provide an indication of failure; the contingency measures are the same as in the previous section.

4.2.6 Test K: Ground ADS-B receiver not working

Failure of the receiver leads to the use of old information on which to base the resolutions on. The longer the failure lasts, the less reliable the resolutions get. Extrapolation (in time) of the trajectories will ensure a proper estimate of the positions of the aircraft. This will mainly be of use for short failures. To mitigate longer failures, it is necessary to add redundancy to the system. This redundancy could consist of a backup ADS-B receiver or the combination of ADS-B with secondary surveillance radar. Even primary radar could be of use.

4.2.7 Test L: ATCo-Tactical response time

The air traffic controller is also part of the loop that communicates the resolution advice to the FMS. Most solutions that were proposed in the previous sections also apply to this issue. In addition to decrease the ATCo response time it is possible to provide the controller with automated support. Such support could consist of automatically generated resolution suggestions that are in line with how a controller would approach the problem. Such resolutions that follow the same line of reasoning as the controller are called to have a “shared mental model”. A shared mental model means that the automation uses the same lines of reasoning as a controller. In [2] one such approach is investigated.

Resolutions that are generated as a result of a shared mental model require less time to be interpreted by a controller and as such the controller is able to decide faster.

Another solution is to automatically uplink a resolution to the aircraft. This bypasses the controller, saving valuable time. The philosophy behind this is that human remains in the loop in the form of the pilot who can sees the proposed resolution presented on a HMI in the cockpit for approval/rejection. Only upon pilot approval, the proposed resolution is implemented in the aircraft.

A final solution is to increase the number of air traffic controllers in busy sectors to decrease the average response time.

4.2.8 Test M: ATCo-Planning response time

Although the ATCO-Planner operates in a different horizon than the ATCo-Tactical, they both have a similar task: check if the resolution advice generated by the ATC system is acceptable or not. If accepted, then the resolution is uplinked. The type of solutions is the same as for the ATCo-tactical: use automation support to lower the response time.

Also for the planner task, it is an option to add more controllers in busy sectors to decrease the average response time.

4.2.9 Test N: ATC uplink transmitter send time

The time to get the appropriate resolution information in the aircraft FMS is an important factor of the safety of the system. A (relatively long) delay in this process will result in the use of relatively old information once a resolution is deployed. In the meantime (time between generation and execution of the resolution) the world has changed and the resolution may not be optimal anymore. Implementing such resolution may trigger the generation of another resolution that contradicts the first one. A number of mitigating actions have been identified to counter this effect.

First, the delay that occurs between calculation and implementation can be estimated. This opens the possibility to estimate the world state of the aircraft at the moment the resolution will be implemented. Using these estimates instead of the current state will improve the quality of the resolution when implemented. There is a parallel with current day practise here. For example, when turning an aircraft, an air traffic controller takes into account the delay between clearing the aircraft for the turn and the actual start of the turn. Note that some predictive behaviour is already present in the A3G model.

Second, to prevent a cascade of contradicting resolution advices, it is useful that, when generating a resolution, a previously communicated resolution for the same conflict is taken into account. This will ensure that subsequent resolutions all reside in the same “class”. For example, if a first resolution for a conflict directs an aircraft to turn to the right, then a second resolution for that same conflict should also turn the aircraft to the right. Because of increased urgency, the amount of heading change to the left may increase with the second resolution, but the direction remains the same. This will prevent aircraft from receiving a series of left, right, left, right etc. clearances. Off course, in extreme cases it may be necessary to change the class of the resolution. In any case, the “rules-of-the-air” may provide a proper guideline for the resolution generation process.

Third, a monitoring function could be added to the system that detects “strange” advices (for example a series of three advices to solve the same conflict could be classified as strange). In such case, the controller could be taken in the loop to judge the situation. The definition of strange advices is important and care should be taken in designing it. Too many false positives or false negatives could undermine the trust in such system. The exact definition (and parameters) of a strange advice should be established with the cooperation of actual controllers possibly in a real-time simulation as they may be dependent on the actual traffic situation. However, without defining the exact parameters, several cases that could be classified as strange are listed below.

- An advice that contradicts a previous advice for the same aircraft.
- Several advices for the same aircraft in a short period.

- A large deviation from the intended flight path.
- A very complex resolution (e.g. consisting of more than 4 segments).
- A large deviation from the intended flight direction (e.g. a 180 degree turn).

In case the ATCo agrees with the system (that the advice is strange), the advice should not be implemented and is thus not uplinked to the pilot.

Fourth, for conflicts that are far away, a delay in the transmission time is of less importance than an urgent conflict. A distinction could be made in the method used to transmit the resolution to such conflict. If there is a very urgent conflict, R/T may be a better option to use as it provides immediate feedback from the flight deck. Solutions communicated using R/T should off course be in line with previously communicated solutions using data uplink.

Finally, an airborne backup system for when the ground system fails to solve a conflict could be used. Such system could be an ACAS based system. Its advices could even be implemented automatically by using, for example, auto TCAS. Note that TCAS is already part of the A3G ConOps.

4.2.10 Test 8: Pilot response time

When a resolution is generated, it is obviously based on the most recent information available (i.e. aircraft state vectors) at the time of the calculation. In the time between *calculation* of the resolution and the *implementation* of the resolution, time progresses and the state vectors of the aircraft change. As a result, the quality of a resolution degrades as long as it has not been implemented. The results of this degradation depend on the circumstances and can vary between no influence to a counterproductive resolution.

The response time of the pilot is an important factor in the time between calculation and implementation. The longer the pilot needs to respond, the larger the degradation of the resolution quality. To mitigate, it is important to have a very good cockpit HMI such that the pilot is able to quickly decide.

A more drastic resolution is to generate short term advices on-board without the ground in the loop. This would imply a fundamental change to the A3G concept and it would convert A3G into a *hybrid* solution which operates partially on the ground and partially in the air. However, this is not a desired solution for a true ground-based concept. To show the full potential for a ground-based concept, using a hybrid solution will make the simulation results difficult to interpret as the distinction between air and ground has become fuzzy. To learn as much as possible from A3G it is better to strive to maximize the results of a ground-only solution.

4.3 Additional suggestions

The discussion of the results of the previous section with work package 2 resulted in further insight in the details of the simulation and subsequently some additional points of improvement were identified. These are described below.

4.3.1 MTCR and STCR ground iteration loop

To ensure a fair comparison between the results of A3 and A3G, the amount of changes when transferring A3 into A3G was kept as little as possible. In both concepts the idea of prioritized planning is embraced. Prioritized planning reduced the planning problem from one multi aircraft planning problem to a series of single aircraft planning problems (in each of these problems the other aircraft are seen as moving obstacles). This means that each aircraft has a (distinct) priority. If a conflict is detected, this conflict is solved taking into account only the aircraft with a higher priority. A solution may therefore result in a new conflict (involving a lower priority aircraft). The resolution loop is repeated for each aircraft (from highest to lowest priority) until all conflicts have been solved.

In A3, if an aircraft detects a conflict with another aircraft, it generates a solution (on-board), taking into account aircraft with higher priorities only. In case this results in a new conflict with an aircraft with a lower priority, it is the task of this lower priority aircraft to solve this new conflict etc. As each aircraft operates individually for this monitoring and resolution generation task, results are generated efficiently and stability of the process is high.

In A3G the MTCR and STCR resolutions are generated by the ground system and the results are uplinked to the involved aircraft. Next, the ground checks the conformance of the resolution with *existing* 4D trajectories. In case of a (new) conflict, a resolution for the next aircraft is generated etc. For each resolution, the involved aircraft is contacted and the resolution is shared. Because of the uplink delay, a cycle of resolutions may take a lot of time and may play a role in the bad performance of A3G in multi aircraft conflicts. Accepted resolutions do not lead to an immediate update of the 4D trajectory in the ground system. This design decision has been made to maximize the similarities between A3 and A3G. As a result, a newly generated resolution may interfere with a previous one. This may, in worst case, lead to a long series of continuous resolution updates, each causing a new conflict.

Adapting the methodology slightly, such that the whole iteration loop is executed on the ground may result in a significant improvement. In this case, the ground system starts by freezing all state vectors. Next a first resolution is generated for the conflicting aircraft with the highest priority. This resolution then leads to an immediate update of the corresponding 4D trajectory in the ground system. Next the other aircraft are processed in the order of decreasing priority. At the end of the cycle a stable conflict free set of trajectories is created. Each trajectory that has been altered is then subsequently uplinked to the aircraft. The maximum amount of uplinks in this algorithm is equal to the number of aircraft which is a vast improvement to the current implementation.

4.3.2 Reduction of 4D plan conformance threshold

Two parameters that play an important role in the conformance monitor function of the ground system could be relaxed to reduce the number of STCR's. First, because of navigation imprecision an aircraft may deviate slightly from its intended 4D trajectory. Usually this is corrected by the on-board navigation. However, a brief deviation may lead to a (very small) undershoot of minimum separation. This leads to a STCR generation by the ground system. Because the aircraft would have corrected this, the STCR was unnecessary. By increasing the minimum separation marginally, the aircraft is able to correct *before* an STCR is generated, leading to less STCR's. In theory, larger separation minima lead to less airspace capacity, but in practise, such small changes are hardly measurable.

The conformance monitor function of the ground system continuously verifies whether aircraft fly in conformance with their intended 4D trajectory. This function is in place to detect deviations between planned and actual 4D trajectory. Small deviations are often caused by navigation errors (e.g. cause by imprecision of navigation equipment) and are often automatically corrected by the FMS. On the ground system, a threshold is in place to determine non-conformance. A small increase of this threshold could lead to a lower non-conformance count.

5 Conclusions and recommendations

At first glance the performance of the A3G concept is much worse than the A3 concept. Work package 2 showed that, with some changes to the parameter settings, the performance of A3G can be comparable to that of A3. Unfortunately the necessary parameter settings had to be set at unrealistic values.

It can be concluded that the A3G in its present form is not able to accommodate very high traffic demand sufficiently safe. It is therefore not recommended that this concept (in its present form) will be implemented.

The main difference between A3 and A3G is the position where the resolution advices are generated. Instead of a distributed system in which each aircraft calculates its own resolution advices, in A3G this is all concentrated on a single system on the ground. Although this obviously has advantages (overview and easier sharing of information), it also introduces the inherent weakness of a single point of failure. In addition, overhead is introduced in the transmission of information, introducing delays and additional single points of failure. These two properties of A3G, “single point of failure” and “transmission delay” are the main causes of the bad performance of A3G compared to A3 and many suggestions for improvement address one of these properties.

5.1 Recommendations

In Chapter 4, for each of the significant parameters, potential improvements have been identified. The list of potential improvements is large and is summarized in the table below. The predicted effect on the performance of A3G is also presented.

#	ID	Description	Predicted effect
1	E	Prioritize messages to prevent delay of high priority messages.	Less delay in important messages.
2	E	Implement contingency procedures for pilots in case uplink fails.	Less deviation in 4D path and therefore a smaller probability of the introduction of a conflict.
3	E	Implement (R/T) backup procedure for uplink failure.	Less advices that are not received (on time) by the pilot.
4	F	If aware of GPS failure: communicate this to ground system so that ground can anticipate (e.g. extrapolation of trajectory). In addition, aircraft should continue its 4D trajectory using IRS.	Less deviation in 4D path and therefore a smaller probability of the introduction of a conflict.
5	F	In case of multiple sensors (e.g. MODE-S and ADS-B), ground can leave GPS out of the sensor fusion process.	Ground still has a (more or less) accurate position of the aircraft, and is able to assist aircraft.
6	F	If not aware of GPS failure: use ground based integrity algorithms to detect uncommon behaviour.	Unnoticed GPS failure occurs for a shorter period leading to smaller deviations.
7	H	Use SSR as a backup system for aircraft position.	In case of aircraft ADS-B transmitter failure, ground still has a (more or less) accurate position of the aircraft.

8	I	Use TCAS as fall back system.	Aircraft has TCAS if ground does not provide STCA or MTCA.
9	I	Duplicate ground system and add health monitoring.	Probability of ground failure is much smaller.
10	K	Use trajectory extrapolation in case of GPS ground receiver failure.	This will provide ground with a better estimation of aircraft positions leading to fewer conflicts.
11	K	Add backup ground ADS-B or SSR or primary radar.	ADS-B ground failure will have no effect on the quality of operation anymore. In case of fall-back on SSR, position information may become less accurate.
12	L	Provide ATCo-Tactical with (better) automated support.	ATCo-Tactical response time will decrease.
13	L	Automatically uplink the resolution to the aircraft	Time will be saved in the uplink cycle.
14	L	Add more controllers in busy sectors	Will decrease the average response time.
15	M	Provide ATCo-Planner with (better) automated support.	ATCo-Planner response time will decrease.
16	M	Add more controllers in busy sectors	Will decrease the average response time.
17	N	Use better estimates of future position of aircraft that take into account the delay of the communication loop.	Estimating future aircraft state (trajectory prediction) is a complex process. Although in the A3G model there is already a trajectory predictor implemented, it could be further refined to result in more accurate results.
18	N	Prevent contradicting advices in a short period.	This will prevent the behaviour described in Section 4.1.2.
19	N	Add monitoring function to prevent strange advices.	In current A3G no effect is expected because the simulation does not generate strange advices.
20	N	Prevent strange advices by taking the “rules-of-the-air” as a starting point of the calculations.	In current A3G no effect is expected because the simulation does not generate strange advices.
21	N	Use different transmission means for (very) urgent advices (e.g. R/T).	More STCA’s will be implemented on time. This will prevent generation of a second STCA for the same conflict. In addition, as STCA’s are implemented earlier, the conflicts will be less severe.
22	N	Use (auto) TCAS as an airborne backup system.	This provides a backup system independent of the ground systems. Normal TCAS is already present A3G.
23	N		

24	**8**	Provide pilot with a better HMI.	Will lead to a quicker decision by the pilot.
		Additional suggestions (section 4.3)	
25	**8**	STCR iteration on the ground	Communication with the aircraft during resolution generation process is less extensive resulting in better performance.
26	**8**	MTCR iteration on the ground	Communication with the aircraft during resolution generation process is less extensive resulting in better performance.
27	**8**	Relax the 4D resolution buffer parameter	Less STCR because of navigation imprecision.
28	**8**	Relax the 4D plan conformance parameter	Less STCR because of lower non-conformance count.

The predicted effect on the emergent behaviour will need to be verified in additional experiments. From suggestion 19 no effect is expected as because currently there are no advices generated that can be categorized as “strange”. In an actual system in which the environment is constantly changing this could be the case and such system could be of use.

One of the assumptions from D2.2 states that SSR is not implemented in the A3G model. Although some performance degradation could be expected in advance (as stated in D2.2) because of this design choice, a backup for each part of the ATC system is considered so important that suggestions 7 and 11 still address this issue.

Suggestions 8 and 22 contradict each other. The first states to have TCAS if ground does not provide STCA or MTCA, while suggestion 22 states to always have TCAS. A choice will have to be made between the two solutions.

6 References

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