MERGING ARRIVAL FLOWS WITHOUT HEADING INSTRUCTIONS

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Abstract

This paper presents a method to merge arrival flows of aircraft without using heading instructions. The principle is to achieve the aircraft sequence on a point with conventional direct-to instructions, using predefined legs at iso-distance to this point for path shortening or stretching. A series of small-scale experiments was conducted with air traffic controllers to assess benefits and limits of the method. The method was found comfortable, safe and accurate, even under high traffic load, although less flexible than today with heading instructions. Predictability was increased, workload and communications were reduced. Even under high traffic load, the inter-aircraft spacing on final was as accurate as today (runway throughput maintained), while descent profiles were improved (continuous descent from flight level 100). As heading instructions were no longer used, aircraft remained on lateral navigation. The flow of traffic was more orderly with a contained and predefined dispersion of trajectories. All these elements should contribute to improving safety.

Introduction

In most terminal areas, the merging of aircraft flows essentially relies on the use of open loop radar vectors (heading instructions). Although this method is efficient and flexible, it is highly demanding for air and ground sides under high traffic load conditions, as it imposes rapid decisions for the controller and time-critical execution by the flight crew. Typical consequences are peaks of workload, high frequency occupancy, lack of anticipation, difficulty to optimise vertical profiles and to contain the dispersion of trajectories.

The introduction of area navigation (RNAV, P-RNAV) allowed defining new route structures to revisit the merging of arrival flows[1,2,3,4,5,6]. Specific P-RNAV routes are being used, mainly in the form of “trombones”, each composed of multiple waypoints[8,11,12]. With this type of route structure, the merging of arrival flows relies on route modifications, which does not provide enough flexibility in case of high traffic load. Indeed, “In recent times, P-RNAV applications in the terminal area have not realised all the anticipated benefits of reduced cost, improved environment and increased capacity. PRNAV procedures can be integrated with conventional procedures and can bring environmental, financial and operational benefits in light and medium traffic loads. However, at high traffic loads, the controllers inevitably revert to radar vectoring in order to maximise capacity.”[7] The key difficulty lies in maintaining some form of flexibility as the merging of arrival flows may require expediting or delaying aircraft, typically through path shortening or path stretching. Other limitations have been identified[10]: difficulty with waypoint manipulation for air and ground, cluttering of charts and limitation in Flight Management System navigation database.

A new method of path stretching has been proposed to overcome these disadvantages, based on a new set of instructions[9,10] (“path objects”). It requires however significant modifications in terms of phraseology and FMS. Path stretching methods with P-RNAV routes have been also investigated in the context of four-dimensional flight management with required time of arrival at waypoints. These methods assume new FMS capabilities and the execution by the flight deck. Recent studies also investigated the case of automation support for merging traffic in the context of terminal P-RNAV routes[13,14].

At the EUROCONTROL Experimental Centre, when investigating the use of airborne spacing in the terminal area (in which the flight deck is tasked to maintain the spacing to a preceding aircraft), a specific method for merging arrival flows has been defined, along with its associated route structure[15,16,17]. This method was found also usable without airborne spacing. It enables merging flows in the terminal area through systematic procedures without using heading instructions. The principle is to achieve the aircraft sequence on a point (with conventional direct-to instructions) using predefined legs at iso-distance to this point for path shortening or path stretching. Except P-RNAV capabilities, no specific airborne functions or ground tools are required.

A series of small-scale experiments has been conducted in 2006 to perform an initial assessment of the benefits and limits of this method. The paper discusses the main findings. It is organised as follows: the next section gives the background, the following one describes the experiment design and setup, and the last one presents the results.

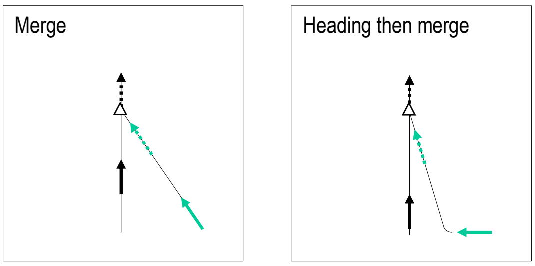
Background

The work performed in the CoSpace project has allowed the development and refinement of a set of spacing instructions for sequencing and merging arrival flows of aircraft. With these instructions, the controller has the ability to task the flight crew to achieve then maintain a given spacing along predefined routes with respect to the preceding aircraft. Two of these instructions were used to merge aircraft flows on a point and then maintain spacing (Figure 1). They were initially developed for enroute arrival sectors having a spacing constraint at a given point (e.g. 8NM at the initial approach fix). However, these instructions were not directly usable in the type of terminal areas considered due to the absence of routes and merge point. For that purpose, we defined a specific route structure consisting of a merge point and segments tangent to a circle centred on this point ("sequencing legs"), along with the possibility of sending aircraft direct to this point at any time (Figure 2). This enables expediting or delaying aircraft while staying on lateral navigation mode. It was shown that the association of the spacing instructions and the route structure brings high benefits in the terminal area[16]: increased controller anticipation, drastic reduction in number of instructions, more expeditious and orderly flow of traffic (slight increase of throughput, reduced dispersion at low altitude). These findings raised two questions:

- What are the contributions to the benefits of this new route structure?
- How to implement two changes (route structure and airborne spacing) at the same time?

It was thus decided to investigate the sole use of the new route structure. The motivation was twofold:

- To propose an intermediate step between today operations (open loop radar vectors) and airborne spacing.
- To get initial trends on the possible benefits brought by the route structure compared to today operations.



To maintain a predicted spacing at a waypoint by speed adjustments

To achieve then maintain a predicted spacing at a waypoint by a heading then a direct then speed adjustments

Figure 1. Spacing instructions for sequencing and merging

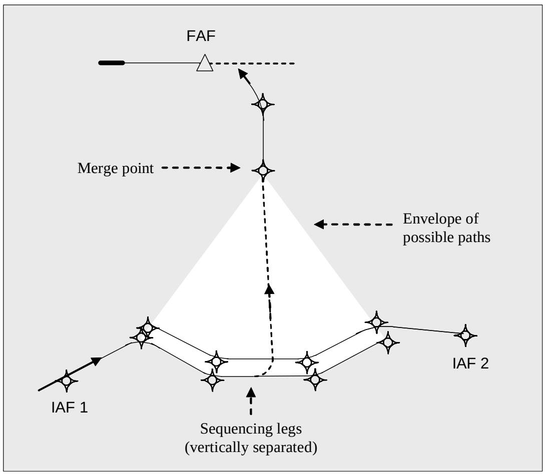


Figure 2. Route structure for the terminal area

How to use the route structure without spacing instructions? In following the same principles, but with the controller in charge of the tasks previously allocated to the flight deck. In other words, the sequence is still achieved on the merge point using the sequencing legs to delay aircraft. The controller has to issue the speed instructions and the direct-to instruction. No specific tool was developed to assist the controller.

Experiment design and setup

Objective and organisation

The objective of the series of small-scale experiments was to investigate the new working method and to perform an initial assessment of its benefits and limits. The first three experiments were used to refine the method and assess its feasibility under various conditions (moderate and strong wind) and configurations (two or three entry points, legs of same or opposite direction, legs parallel or non parallel). The next one was dedicated to data collection with the today method as baseline. The following ones (not discussed in the paper) further explored the method by considering new types of legs (segments approximating concentric arcs, intermediate points) and configurations with four entry points feeding one or two runways. Each small-scale experiment lasted two or three days and involved the same three approach controllers.

The paper will mainly discuss the findings from the data collection experiment. The two conditions were:

- Today's working method with heading instructions for integration on an axis ('baseline').
- Working method with direct-to instructions for integration on a point ('point merge').

This experiment consisted of six runs, three in both conditions. Due to this limited sample of runs, the results presented hereafter should only be considered as initial trends.

Simulated environment

The simulated airspace consisted of a TMA with two entry points (IAFs) and a single landing runway. The TMA had two arrival positions (frequencies): approach controller (APC) and final director (FIN). The APC handled the traffic received from enroute arrival sectors (e.g. via IAF) and then transferred it to the FIN. Today, he/she is typically in charge of stack management and initial vectoring to delay traffic or create gaps between flows. This position is often referred to as "pick-up" or in the US as "feeder". The FIN handled the traffic received from APC and then transferred it to the tower. Today, he/she is typically in charge of integration onto final approach and axis interception. This position is often referred to as "feeder" or in the US as "final". The third controller was acting as a planning controller for the APC.

For the baseline, the TMA had a radar vectoring area with two initial magnetic routes (after MOTAR and SIMON) as shown in Figure 3, top. For 'point merge', the TMA had two parallel sequencing legs (SIMON-TOLAD and MOTAR-NADOR) and a merge point (LOTAM) as shown in Figure 3, bottom. The legs were vertically separated by 2000ft to provide a spare level in case of unexpected event. The flight level constraints at IAFs were identical in both conditions. Although no departure traffic was simulated, an altitude constraint was applied (FL100 at SIMON) in both conditions to strategically segregate arrivals on the downwind leg from departures to the South. Traffic samples with 40 arrivals per hour (including 20% of "heavy" aircraft) were used. Each team of controllers played the same traffic in both conditions. A complete phraseology was used including announcement of ILS, indication of atmospheric pressure value (QNH). The analysis period was 45 minutes from the first aircraft reaching the FAF.

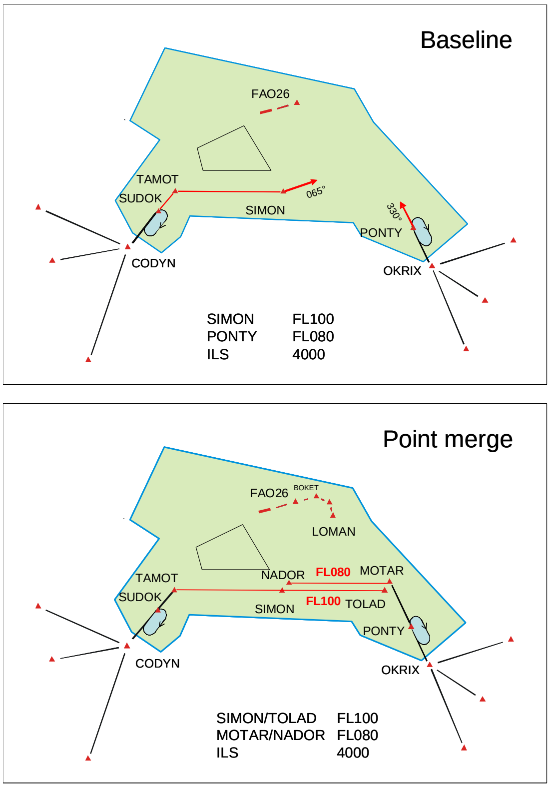


Figure 3. Simulated terminal area

Results

The main results are presented in five parts: human factors, controller activity, effectiveness, quality of service and safety.

Human factors

In the baseline, the APC prepared the sequence which was then achieved by the FIN. The FIN had to issue many time critical instructions (heading and speed) to sequence the aircraft close to the ILS and to the sector boundary (in the real environment, there is another airport located North). The workload was reported as high.

With 'point merge', the working method was found totally feasible and not more difficult than today's method. Even under strong wind conditions (35kt on the ground, 50kt at FL100, parallel or perpendicular to the sequencing legs), it was found not more difficult than today with similar wind. The method is however considered as less flexible than today's method: the sequence order has to be decided earlier and, when the integration is performed (i.e. when on direct course to the merge point), only speed adjustments should be used to maintain the sequence[1]. Controllers reported a

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[1] The method is considered more flexible than with airborne spacing as the choice of the sequence order is less constrained (no aircraft linked and no need to define the sequence order in advance).

reduction of workload (especially for FIN), fewer messages than today and no saturation in spite of a complete phraseology. The working method allows a clear and better tasks distribution between APC and FIN. Compared to the baseline, the workload were better distributed between both positions and provided more availability, hence better anticipation and monitoring.

With 'point merge', the task of the APC essentially consisted in achieving homogeneous speeds when aircraft join the sequencing legs (e.g. 220kt), refining the sequence order (proposed by the planning controller), handling the integration with a direct route to LOMAN (with the support of concentric circles displayed on the radar screen to estimate the spacing), and transferring the aircraft to the FIN. The task of the FIN consisted in giving the descent while maintaining spacing with speed instructions, and transferring the aircraft to the tower once established on ILS.

Typical situations are shown in Figure 4.

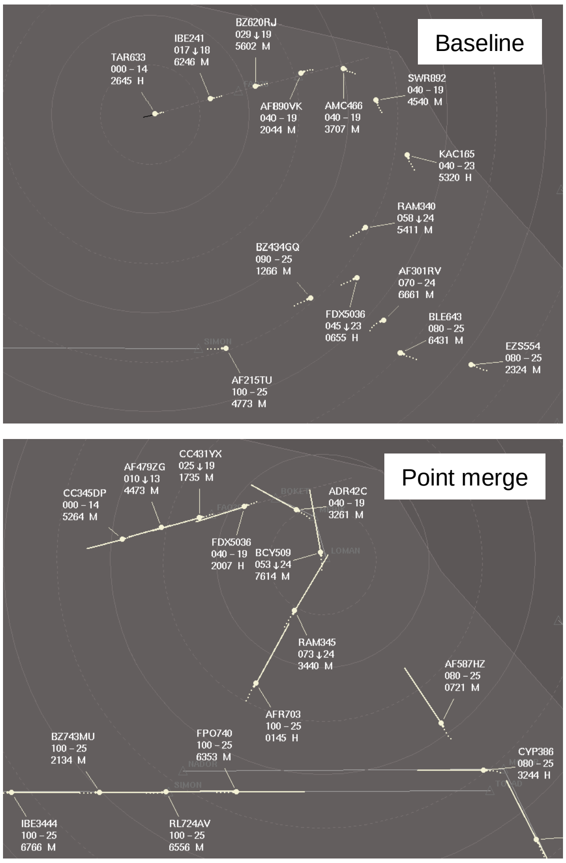

Figure 4. Typical situations

In the baseline, because the aircraft were flying on various headings, the speed vectors were not displayed as not really useful and cluttering the radar screen. In contrast, with 'point merge', the speed vectors were helpful to monitor the spacing for aircraft on the same leg as well as when converging to the merge point, and did not cluttered the display as the route structure induced an orderly traffic. The concentric circles were centred on the airport in the baseline, and on the merge point with 'point merge'.

Controller activity

The controller sequencing activity was assessed essentially through the analysis of manoeuvre instructions. With 'point merge', a decrease in the number of instructions can be observed (Figure 5), more important for FIN than for APC (respectively 57% and 29%). This is in line with controller feedback. For the APC, the reduction came from a drastic reduction in number of level instructions. In the baseline, the APC sometimes gave an intermediate level to facilitate integration by the FIN. This was no longer necessary with 'point merge' as the integration was performed by the APC at predefined flight levels. For FIN, the reduction is due to a reduction of level instructions (no need to give intermediate flight levels to provide separation) and almost the disappearing[2] of heading instructions (aircraft were already on direct course to the merge point).

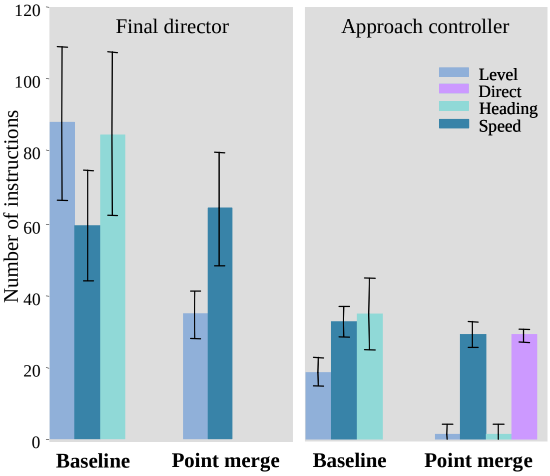

Figure 5. Repartition of manoeuvre instructions

The analysis of the frequency occupancy is consistent with the analysis of the number of instructions and with controller feedback. It confirms the reduction for APC and FIN (more important for FIN) with 'point merge'. It also confirms the better task distribution between APC and FIN (Figure 6). Whereas the frequency occupancy was similar for APC and FIN with 'point merge' (approximately 45%), FIN had a higher occupancy than APC in the baseline (80% compared to 50%).

The analysis of the geographical distribution of manoeuvre instructions provides an objective

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[2] Heading instructions may still be used to recover from a direct-to not correctly executed (e.g. pilot mistake).

assessment of the impact of the condition on the sequencing activity (Figure 7). In the baseline, the majority of the instructions were given in the second part of the TMA near the ILS (from 30 to 10NM to the FAF). This reflects the late integration performed on the axis by the FIN. The speed and heading instructions given in the first part of the TMA (from entry until approximately 45/40NM) correspond to the preparation of the integration by the APC. In contrast, with ‘point merge’, the task repartition was clearly defined and can be inferred from the type of instructions used: the APC performs an early integration with direct-to instructions at around 35/40NM to the FAF. Then, from 25NM until transfer to the tower, the FIN was giving the descent and maintaining spacing with speed instructions.

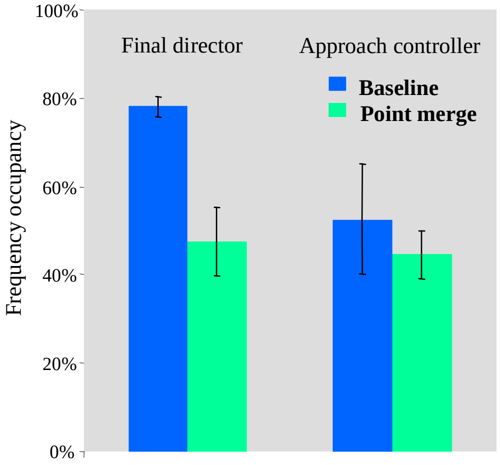

Figure 6. Frequency occupancy

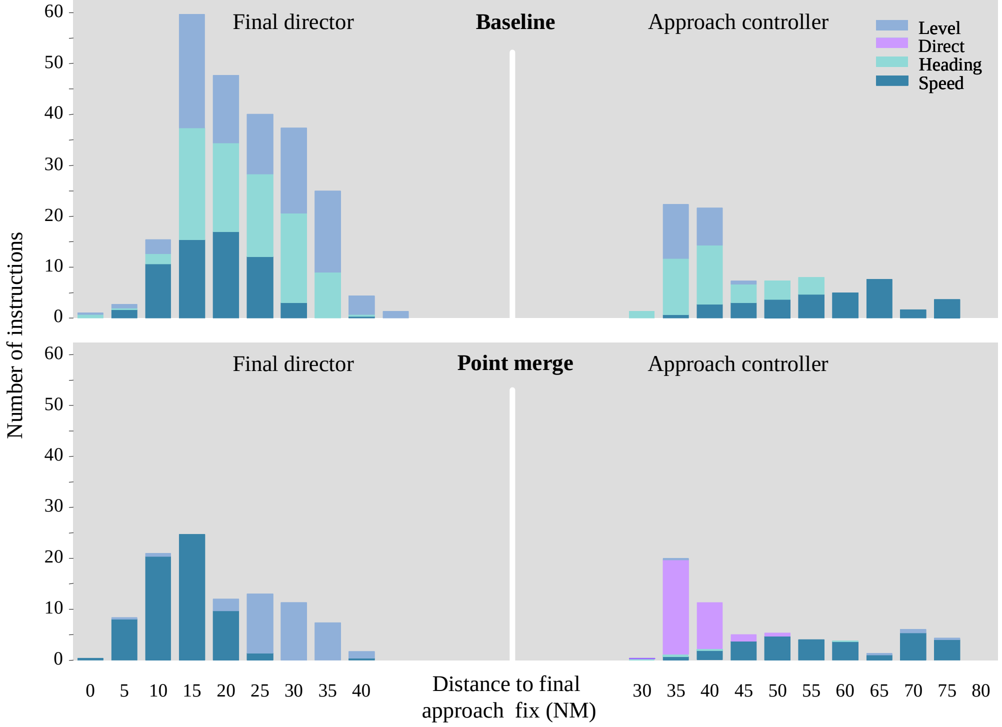

Figure 7. Geographical distribution of manoeuvre instructions

Effectiveness

The effectiveness was assessed in terms of inter-aircraft spacing. The objective was to achieve 4.5NM at final approach fix between aircraft at 180kt (or 6NM for a medium behind a heavy). The spacing accuracy was similar in both conditions when looking at average and standard deviations as shown in Figure 8 (for a required spacing of 6NM, the value was normalised at 4.5NM). Minimum values revealed some tight situations in the baseline that might have resulted in a go-around.

Quality of service

According to previous results, ‘point merge’ provided a global reduction of the number of instructions. We analysed the number of instructions per aircraft to assess whether the reduction was equally shared among the aircraft. Whereas the first result corresponds to a controller perspective, this one corresponds to a pilot perspective. A reduction can be observed (Figure 9): on average, every aircraft received more than 10 instructions in the baseline, compared to slightly less than 6 instructions with ‘point merge’. Moreover, the larger standard deviation observed in the baseline shows that some aircraft received more than 12 instructions in the TMA. In the baseline, each aircraft received on average three heading, three speed and three level instructions. With ‘point merge’, each aircraft still received three speed instructions, but only one level instruction (4000ft) and exactly one direct-to instruction.

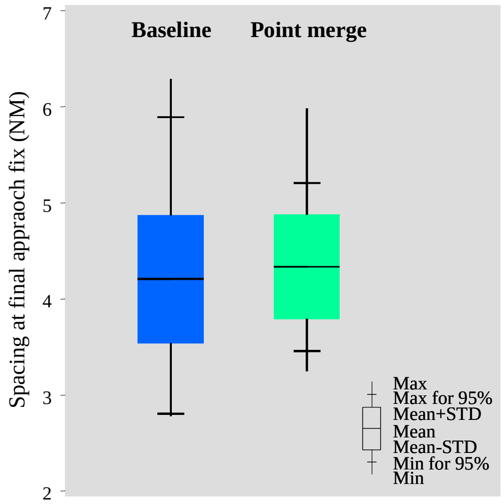

Figure 8. Inter-aircraft spacing at final approach fix

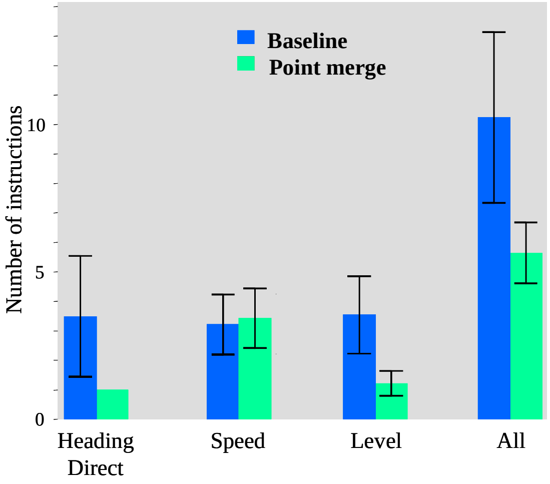

Figure 9. Instructions per aircraft

As anticipated, the analysis of trajectories shows a clear impact of the condition (Figure 10). In the baseline, the dispersion area is close to the ILS and to the adjacent sector. With ‘point merge’, the dispersion is contained within a pre-defined triangle located upstream of the ILS. Although the flown trajectories are completely different in both conditions, distance and time flown are very similar: aircraft flew 70NM during 18 minutes on average in the TMA.

The analysis of descent profiles shows an impact of the condition (Figure 11). With ‘point merge’, aircraft remained slightly higher in the final part, when leaving the legs at about 25NM until FAF. This is due to a better predictability of aircraft trajectories (same ‘distance to go’ when leaving the legs) and an increased availability of the FIN to give the descent at appropriate time. Knowing the ‘distance to go’ would give the opportunity to the flight crew to better manage his/her descent, which should benefit to environment (noise and fuel consumption). Furthermore, controllers mentioned that the route structure could be improved with higher altitudes on the legs. The routes have been redesigned to optimize both climb and descent profiles, which would allow aircraft to perform a continuous descent from FL100 or FL120 until the ILS. This was explored during subsequent experiments.

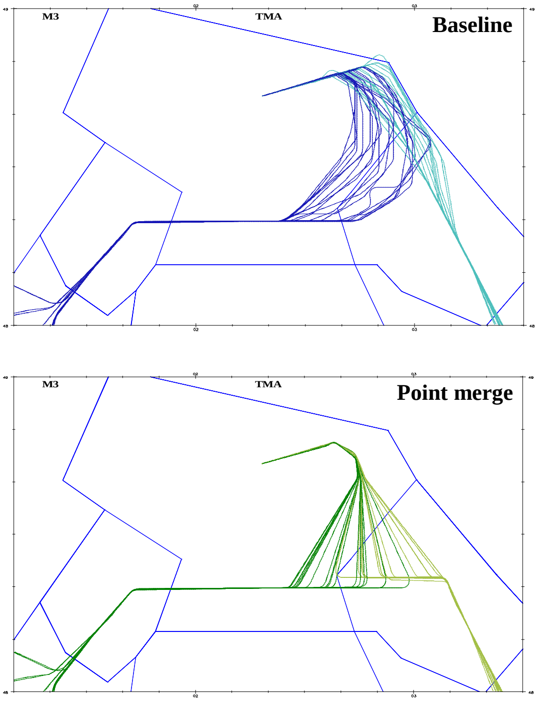

Figure 10. Example of the trajectories flown

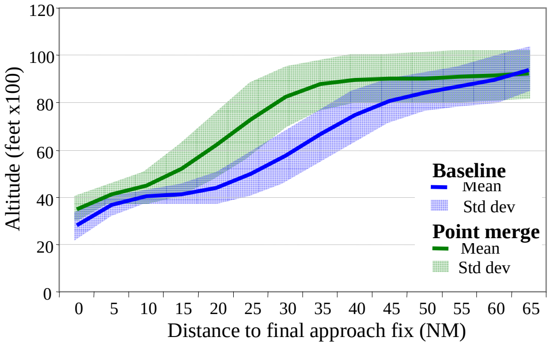

Figure 11. Descent profiles

Safety

The overall feeling on safety was an improvement in particular by providing more anticipation, decreasing workload and reducing the risks of misunderstanding (less communications). The dispersion of trajectories was more structured, which should contribute to safety in reducing the number of potential conflict and de-cluttering the approach area. From a controller perspective, this should contribute to improve situation awareness, better predictability of aircraft path, better monitoring. From a pilot perspective, as aircraft remain on lateral navigation, situation awareness should also be improved. The analysis of number of losses of separation shows that out of the 264 aircraft controlled, the two losses of separation occurred in the baseline.

Conclusion

The initial assessment of the benefits and limits of the proposed method is very positive. The method was found comfortable, safe and accurate, even under high traffic load, although less flexible than today with heading instructions. From a controller perspective, compared to today, it provided a reduction of workload and communications, more predictability and anticipation, a clear and better tasks repartition between controllers. Under strong wind conditions, the method was found totally feasible and not more difficult than today with similar wind.

From a pilot perspective, in addition to the reduction of communications, aircraft remained on lateral navigation as heading instructions were no longer used. Even under high traffic load, the inter-aircraft spacing on final was as accurate as today (runway throughput maintained), while descent profiles were improved with a potential for continuous descent from FL100. The flow of traffic was more orderly with a contained and predefined dispersion of trajectories. All these elements should contribute to improving safety. Except P-RNAV capabilities, no specific airborne functions or ground tools are required.

The benefit airborne spacing brings compared to the sole of the route structure is a more accurate inter-aircraft spacing on final, which could lead to an increase of runway throughput. A secondary benefit is a further reduction of controller workload, to be balanced with the introduction of a new task for the flight crew.

The method and the associated route structure could not only be seen as a preliminary step to prepare the implementation of airborne spacing, but also as a transition towards an extensive use of P-RNAV, and as a sound foundation to support further developments such as continuous descent (CDA) and target time of arrival (4D).

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Acronyms

APC = Approach Controller
ASAS = Airborne Separation Assistance System
CDA = Continuous Descent Approach
FAF = Final Approach Fix
FIN = Final Director
FMS = Flight Management System
IAF = Initial Approach Fix
ILS = Instrument Landing System
P-RNAV = Precision Area Navigation
RNAV = Area Navigation
STD = Standard Deviation
TMA = Terminal Control Area (Terminal Manoeuvring Area)