Integrating Aircraft Flows in the Terminal Area with no Radar Vectoring

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This paper reports on a series of small-scale experiments conducted with air traffic controllers. The objective was to assess benefits and limits of a method to integrate aircraft flows in the terminal area. 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. Open loop radar vectors (heading instructions) were no longer used and aircraft remained on lateral navigation mode. The method was found feasible, comfortable, safe and accurate although less flexible than today. Predictability was increased, workload and communications were reduced. The inter-aircraft spacing on final was as accurate as today, while descent profiles were improved. The flow of traffic was more orderly with a contained and predefined dispersion of trajectories. All these elements should contribute to improving safety.

Acronyms

ASAS = Airborne Separation Assistance System
FAF = Final Approach Fix
FMS = Flight Management System
IAF = Initial Approach Fix
INI = Initial Approach Controller
ITM = Intermediate Approach Controller
ILS = Instrument Landing System
RNAV = Area Navigation
TMA = Terminal Control Area (Terminal Manoeuvring Area)

I. Introduction

In most terminal areas, the integration 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. In such conditions, typical consequences are peaks of workload, high frequency occupancy, lack of anticipation and, beyond, difficulty to optimise vertical profiles and to contain the dispersion of trajectories. The introduction of area navigation (RNAV) capabilities allows defining new route structures to revisit this mode of operations. One of the key difficulties lies in maintaining some form of flexibility as the integration of aircraft flows may require expediting or delaying aircraft, typically through path shortening or path stretching.

The concept of RNAV has been widely studied, allowing the definition of the basis of RNAV route design taking into account performance requirements, and the identification of best practices of TMA organisation7,8,9,10,11
Specific RNAV routes are operated, mainly in the form of “trombones”, each composed of multiple waypoints7,8,9,10,11
This route structure enables path stretching by issuing direct instructions to appropriate waypoints, at appropriate moment. However, the method has some disadvantages9: difficulty with waypoint manipulation for air and ground, cluttering of charts, limitation in Flight Management System navigation database. These disadvantages often cause cancellations of the RNAV procedure, hence reversion to open loop radar vectors. A new method of path stretching has been introduced to overcome these disadvantages, based on a new set of instructions8,9 (“path objects”).

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requires however significant modifications in terms of phraseology and FMS. Path stretching methods with 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 RNAV routes\textsuperscript{12,13}.

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 has been identified, along with its associated route structure. This method was found also usable without airborne spacing. It enables integrating flows in the terminal area through systematic procedures without relying on open loop radar vectoring. 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 RNAV capabilities, no specific airborne functions or ground tools are required.

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

II. Background

The work performed in the project has allowed the development and refinement of a set of spacing instructions for sequencing and merging arrival flows of aircraft\textsuperscript{14,15}. 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 integrate 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 applicable in the type of terminal areas considered due to the absence of routes and merge point\textsuperscript{16}. The solution lies on the introduction of 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: 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).

![Figure 1. Spacing instructions for sequencing and merging.](image1)

![Figure 2. Route structure for the terminal area.](image2)
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 spacing instructions) 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 the use of spacing instructions.
- To get initial trends on the possible benefits brought by the route structure compared to today operations.

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.

### III. Experiment Design and Setup

#### A. Objective and Organization

The overall 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 working method and assess its feasibility under various conditions (moderate and strong wind) and configurations (2 or 3 entry points, legs of same or opposite direction, legs parallel or non parallel). The following one was dedicated to data collection with the today method as baseline. The last two ones (not discussed in the present paper) were used to further explore the method, in particular by introducing new types of legs (segments approximating concentric arcs, intermediate points). 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, denoted “vectors”\(^\dagger\).
- Working method with direct-to instructions for integration on a point, denoted “triangle”\(^\S\).

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.

#### B. Simulated Environment

The simulated airspace consisted of a TMA with two entry points (IAFs) and a single landing runway. The TMA had two arrivals positions (frequencies): initial (INI) and intermediate (ITM) with one executive controller on each position. The INI handled the traffic received from enroute arrival sectors (e.g. via IAF) and then transferred it to the ITM. 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 ITM handled the traffic received from INI 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 INI.

In vectors condition, the TMA had a radar vectoring area with two initial magnetic routes (after MOTAR and SIMON) as shown in Figure 3, left. In triangle condition, the TMA had two parallel sequencing legs (SIMON-TOLAD and MOTAR-NADOR) and a merge point (LOTAM) as shown in Figure 3, right. 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.

\(^\dagger\) In the following, the term “vectors” only refers to “open loop vectors” (heading instructions) and excludes “closed loop vectors” (direct-to instructions).

\(^\S\) To refer to the geometry obtained with the sequencing legs and the merge point.
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. Terminal area in vectors (left) and triangle (right) conditions.

IV. Main Findings

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

A. Human Factors

In vectors condition (Figure 4), the INI prepared the sequence which was then achieved by the ITM. The ITM 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.

In triangle condition (Figure 5), 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 totally feasible and 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**. Controllers reported a reduction of workload (especially for ITM), fewer messages than today and no saturation in spite of a complete phraseology. The working method allows a clear and better tasks distribution between INI and ITM. Compared to the vector condition, the workload were better distributed between both positions and provided more availability, hence better anticipation and monitoring.

The task of the INI essentially consisted in achieving homogeneous speeds (e.g. 220kt) when aircraft join the sequencing legs, refining the sequence order (proposed by the planning controller), handling the integration with a direct route to LOMAN, and transferring the aircraft to the ITM. The task of the ITM consisted in giving the descent while maintaining spacing with speed instructions, and transferring the aircraft to the tower once established on ILS.

In vectors condition, 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, in triangle condition, 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 range rings were centred on the merge point.

** The method is considered more flexible than with spacing instructions as the choice of the sequence order is less constrained (no aircraft linked and no need to define the sequence order in advance).
B. Controller Activity

The controller sequencing activity was assessed essentially through the analysis of manoeuvre instructions. In triangle condition, a decrease in the number of instructions can be observed (Figure 6), more important for ITM than for INI (respectively 57% and 29%). This is in line with controller feedback. For the INI, the reduction came from a drastic reduction in number of level instructions. In vectors condition, the INI sometimes gave an intermediate level to facilitate integration by the ITM. This was no longer necessary with sequencing triangle as the integration was
performed by the INI at predefined flight levels. For ITM, the reduction is due to a reduction of level instructions (no need to give intermediate flight levels to provide separation) and almost the disappearing\footnote{Heading instructions may still be used to recover from a direct-to not correctly executed (e.g. pilot mistake).} of heading/direct instructions (aircraft were already on direct course to the merge point).

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 INI and ITM (more important for ITM) in triangle condition. It also confirms the better task distribution between INI and ITM (Figure 7). Whereas the frequency occupancy was similar for INI and ITM in triangle condition (approximately 45%), ITM had a higher occupancy than INI in vectors condition (80% compared to 50%).

The analysis of the geographical distribution of manoeuvre instructions provides an objective assessment of the impact of the different working methods on the sequencing activity (Figure 8). In vectors condition, 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 ITM. 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 INI. In contrast, in triangle condition, the task repartition was clearly defined and can be inferred from the type of instructions used: the INI performs an early integration with direct-to instructions at around 35/40NM to the FAF. Then, from 25NM until transfer to the tower, the ITM was giving the descent and maintaining spacing with speed instructions.
C. Effectiveness

The performances were assessed in terms of inter-aircraft spacing. The objective was to achieve 4.5NM on final between aircraft at 180kt (or 6NM for a medium behind a heavy). The level of accuracy was similar in both conditions when looking at average and standard deviations as shown in Figure 9 (on the figures, for an objective of 6NM, the spacing was normalised at 4.5NM). However, the analysis of extreme values (min and min at 95%) revealed some tight situations in vectors condition that may have resulted in a go-around.

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The use of spacing instruction is expected to improve the spacing accuracy.
D. Quality of Service

According to previous results, in triangle condition, there was a global reduction of the number of instructions. We assessed whether the reduction was equally shared among the aircraft by analysing the number of instructions per aircraft. Whereas the first result corresponds to a controller perspective, this one corresponds to a pilot perspective. A reduction can be observed (Figure 10): on average, every aircraft received more than 10 instructions in vectors condition, compared to slightly less than 6 instructions in triangle condition. Moreover, the larger standard deviation observed in vectors condition shows that some aircraft received more than 12 instructions in the TMA. In vectors condition, each aircraft received on average 3 heading, 3 speed and 3 level instructions. In triangle condition, each aircraft still received 3 speed instructions, but 1 level instruction (4000ft) and exactly 1 direct-to instruction (to the merge point).

![Figure 10. Number of instructions per aircraft.](image)

As anticipated, the analysis of trajectories shows a clear impact of the condition (Figure 11). In vectors condition, the dispersion area is close to the ILS and to the adjacent sector. In triangle condition, 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 (Figure 12). Aircraft flew 70NM during 18 minutes on average in the TMA.

![Figure 11. Example of the trajectories flown in vectors (left) and in triangle (right) conditions.](image)
The analysis of altitude and airspeed profiles shows an impact of the condition (Figure 13**). In triangle condition, aircraft remained slightly higher and faster (although this happened during a too short period to be reflected on time flown) in the final part, from 25NM to FAF. This is due to an increased availability of the ITM to better arrange descent and speed. This would give the opportunity to let the flight crew better manage his/her descent, which should benefit to environment (noise and fuel consumption). In addition, controllers mentioned that the route structure could be improved with higher altitudes on the legs. This was explored during the two last experiments. 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.

** The small altitude increase around 25NM (green dots) is caused by the computation of the along track distance in triangle condition. In the simulation, aircraft were stable at this distance (dotted lines).

E. 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 mode, 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 when using radar vectors.
V. Conclusion

The initial assessment of the benefits and limits of the proposed method is positive. The method was found feasible, comfortable, safe and accurate although less flexible than today’s method. From a controller perspective, compared to today’s method (open loop radar vectors), it provided a reduction of workload and of 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’s with similar wind. From a pilot perspective, in addition to the reduction of communications, aircraft remained on lateral navigation mode as open loop vectors were no longer used. In terms of performances and quality of service, the inter-aircraft spacing on final was as accurate as today, the distance and time flown were similar, while descent profiles were improved. This method led to more orderly flow of traffic with a contained and predefined dispersion of trajectories. All these elements should contribute to improving safety. Furthermore, the method offers the potential for continuous descent from FL100 until final approach fix. Except RNAV capabilities, no specific airborne functions or ground tools are required. As a conclusion, the method and the associated route structure could not only be seen as a preliminary step before the introduction of spacing instructions, but also as a goal in itself.

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