[EN-A-024] From Perfect to Possible: Two Trajectory Based Operation Concepts for Future Terminal Manoeuvring Areas Workshop on ATM/CNS 2017

(EIWAC 2017)

[+] Juergen Rataj*, Marco-Michael Temme*

* Institute of Flight Guidance,
German Aerospace Center (DLR)
Braunschweig, Germany
juergen.rataj@dlr.de
marco.temme@dlr.de

Abstract: In the last two decades, the approaches to improve the Air Traffic Management (ATM) system changes from a technology-push to a technology-pull principle, like the following ICAO Global Air Traffic Management Operational Concept citation shows. "…it was later recognized that technology was not an end in itself and that a comprehensive concept of an integrated and global ATM system, based on clearly established operational requirements, was needed." This sentence from the foreword of ICAO Document 9854 (AN/458) defines the new way and determines the independence between technology and operating concept as the following quote emphases as well. „A key point to note is that the operational concept, to the greatest extent possible, is independent of technology; that is, it recognizes that within a planning horizon of more than twenty years, much of the technology that exists or is in development today may change or cease to exist." To implement this approach, the document identifies significant changes as the ATM system migrates towards the concept vision. One such change is the introduction of Trajectory Based Operations (TBO) with an adapted operational concept and at least new technologies as an enabler. To choose supporting technologies, the different flight phases and boundary conditions have to be taken into account for a structured approach.

Critical flight segments for a new concept are the arrival and departure phases and hence, the implementation of the concept in the vicinity of airports. In the TMA, especially at hub airports, the airspace is limited and the boundary conditions for arrivals and departures are high. For example, this includes the space for a transition structure considering different kinds of aircraft with different abilities based on different equipage up to airport specific noise abatement procedures.

To avoid to lose oneself during the design of a new TMA airspace and procedures for TBO in all these constraints and to stay as close as possible with a "perfect" concept, only a few constraints were taken into account in the design. Core principle of the low limits design approach is that the routes between airports or merging points for the finals are all great cycle arc routes connecting the airports to minimize the flown distances. Hence, only nearly direct arrival and departure routes appear. The TMA itself is designed as small as reasonable to avoid additional flight distances in any kind of path stretching areas. Secondly, continuous descents operations should be possible. The questions on how the traffic can be guided by controllers and which tools they need were not addressed. In the paper such a design, including an evaluation with logged real traffic flows is presented and the requirements concerning a time-based guidance of the aircrafts are shown.

Away from "make a dream come true" and facing the real world, in the second design, shown in the paper, the perfect low limits design is "ruined" to be able to deal with more constraints found in the near future in the air traffic management. The process of "ruining" the low limits design is done in way to minimize the required changes to take necessary constraints into account. In this near future design, the TMA provides a transition to deal with higher target time uncertainties, takes different aircraft equipage into account, and considers restricted areas. Furthermore, tools and HMIs were developed which are necessary to guide the aircraft through such an airspace design by the controller. Especially, this airspace design is able to deal with a mixed traffic situation, allowing better equipped aircraft to fly continuous descent profiles on negotiated trajectories while lower equipped aircraft have to conduct conventional approaches. The concepts were evaluated in different projects with varying traffic scenarios running in automated fast-time and real-time as well as human-in-the-loop simulations.

Keywords: Trajectory based operation; Time based flight guidance; Airspace design; Terminal maneuvering area

1. INTRODUCTION

In the last two decades, the approaches to improve the Air Traffic Management (ATM) system changes from a technology-push or bottom up to a technology-pull or top down principle. At least ICAO pushes this kind of approach like the citation in ICAO Global Air Traffic Management Operational Concept shows. "…it was later recognized that technology was not an end in itself and that a comprehensive concept of an integrated and global ATM system, based on clearly established operational requirements, was needed." This sentence from the foreword of ICAO Document 9854 (AN/458) [1] defines the new way and determines the independence between technology and operating concept. Based on past experience it turned out that technology driven developments in long development cycles, like in aviation, tent to rely on outdated technologies. As a consequence in the same document it is pointed out that „A key point to note is that the operational concept, to the greatest extent possible, is independent of technology; that is, it recognizes that within a planning horizon of more than twenty years, much of the technology that exists or is in development today may change or cease to exist." To implement this new approach, the document identifies significant changes concerning the provision of services by concept components as the ATM system migrates towards the concept vision. The seven concept components are a mean to decompose the ATM-system to enable to understand the complex interrelationship. The concept components consists of the airspace organization and management, aerodrome operations, the demand/capacity balancing, traffic synchronization, conflict management, airspace user operations and ATM service delivery management. In the Guiding Principles is state that "The description of the Concept Components is based on realistic expectations of human capabilities and the ATM infrastructure at any particular time in the evolution to the ATM system described by this operational concept and is independent of reference to any specific technology."

To implement such a concept all components have to share a central mean to work on, the trajectories of the aircraft in different levels of detail according to time horizon until to aircraft intent. Hence, trajectory based operations (TBO) are introduced which lead to major changes in the ATM system. Under significant changes is stated that: "Air traffic management (ATM) considers the trajectory of a manned or unmanned vehicle during all phases of flight and manages the interaction of that trajectory with other trajectories or hazards to achieve the optimum system outcome, with minimal deviation from the user-requested flight trajectory, whenever possible. The TBO allows a continuing increase in the level of detail of the use trajectory for the different services in a close and consistent working environment. To introduce TBO an adapted operational concept is necessary as well as appropriate technologies as enabler. To develop and choose appropriate technologies requirements for the technologies have to be determined for all flight phases. Concerning en-route a new trajectory based concept is under exploration in SESAR, the "flight centric ATC" [2]. In this trajectory based en-route concept the controller guides several aircraft in a wide area without sectors. Other controllers guide the other aircraft in the same area. In the case of a conflict rules and tools exist to support the controllers to solve the conflict. According to the other flight phases, the concepts using TBO are not so advanced. Concerning the surface DLR have developed a surface management tool, TRACC (Taxi Routing for Aircraft: Creation and Controlling), which is able to create and guide aircrafts along "4D" trajectories on the ground [3]. Concerning the approach, in the paper two concepts are described to deal with arrivals and departures, differing in the time horizon in which it can be implemented.

The described work is done in the DLR flexiGuide project which focuses on the creation and introduction of more individual and flexible approach procedures to reduce environment impacts.

The next chapter describes the method used to derive the designs. The "low limit airspace" with some requirements is described in chapter 3. The result of pushing the "low limit airspace" into reality is shown in chapter 4. Chapter 5 summarizes the paper and gives an outlook.

2. METHODS FOR AIRSPACE DESIGN

To choose supporting technologies, the different flight phases and boundary conditions have to be taken into account for a structured approach. In particular critical flight phases for a new concept are the arrival and departure phases and hence, the implementation of the concept in the vicinity of airports. In the TMA, especially at hub airports, the airspace is limited and the boundary conditions for arrivals and departures are high. For example, it includes the space for a transition structure considering different kinds of aircraft with different abilities and different equipage up to airport specific noise abatement procedures. According to the view of an airport operator and ATC every (big) airport is unique. Furthermore new concepts concerning the en-route phase requiring also new TMA designs to fully use their capabilities.

To avoid to lose oneself during the design of a new TMA airspace and procedures for innovative TBO concepts in all these constraints and to stay as close as possible with a "perfect" concept, only a few constraints were taken into account in the design. Core principle of the "low limits design" approach is to minimize everything to the lowest possible. Take only physics into account. Only consider constrains which will surely exist in 2050, i.e. the durable components. To know what surely exist in 2050 it has to be "borne" today, has a high endurance and a high resistant against alteration. A high resistance against alteration mostly depends on high investments and partly on public opposition. Hence, the concrete of an airport will mainly exist in 2050. This accounts also for many parts of the CNS (Communication, Navigation, and Surveillance) infrastructure on the ground. Another endurable component is the aircraft performance schema of today. The medium time for retirement for aircrafts is around 25 years. To launch a new aircraft type need more than 10 years. In the internet, numbers can be found for aircraft programs concerning a major upgrade of an existing type of approx. 9 years from announcement to until the first flight. Taking a total new aircraft design concept, like blended wing body, into account it will take even longer. To simplify the task of the airspace design for a new TBO concept, only runway configurations of single or independent parallel runway system are taken into account.

Away from "make dreams come true" and facing the real world, in the second airspace design, shown in the paper, the perfect "low limits design" is "ruined" to be able to deal with more constraints found in the nearer future in the air traffic management. The process of "ruining" the low limits design is done in way to minimize the required changes based on necessary constraints concerning the nearer future. Necessary constrains are the remaining constrains taking the developments in SESAR, NextGen and CARATS program into account. Namely, these are e.g. flexible use of airspace, extended horizon arrival management, and precise 4D-trajectory negotiation. Furthermore, this design has to be able to deal with changes, which will occur to reach the final stage of the TBO concept.

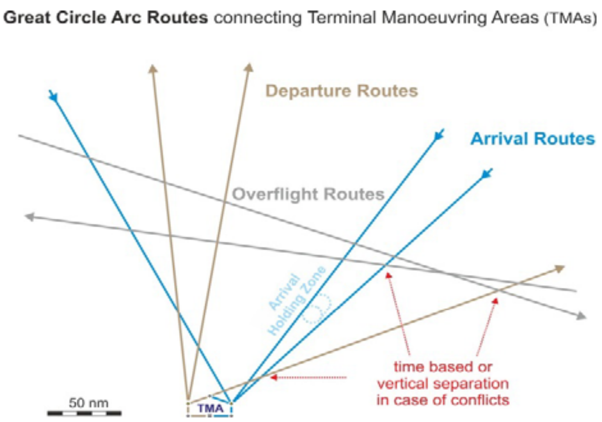

Figure 1 En-route design.

3. LOW LIMITS DESIGN

The chapter low limits design is split in two parts. The first part describes the considerations concerning the airspace design. The practicability of these considerations is tested in a simulation scenario. The results of the simulation are presented in the second part, the chapter simulation results.

3.1 Airspace Design

For the low limit design, the first design principle is to reach as near as possible the minimum of resource consumption of a flight. This minimum depends on the cost index set in the Flight Management System (FMS) of an aircraft [4]. To drive everything to the minimum, flying on great cycle between two airports is mandatory. This approach has been studied extensively for the en-route part of a flight. For optimizing the procedurally separated in- and outbound traffic flows, most of the relevant studies assume flow control procedures and the extended TMA concept, which will be consider here as well. In the ICAO concept, this part is assigned to the component "Traffic Synchronization". The following simulation results will give advices for the necessary precision concerning the flow control. Flying only on great cycles further will be supported by a "flight centric ATC" approach in en-route. Hence, only nearly direct arrival and departure routes appear, see Fig. 1.

To keep the flown distance at an absolute minimum any kind of detour has to be avoided. Especially two kinds of detours are taken into account in the paper. Because the runway have a certain direction and a minimum of spacing procedure is necessary a TMA, which is as small as reasonable, have to be introduced. The size of the detour according to the runway direction depends on the conflict solution between arriving and departing aircrafts. The detailed design is discussed afterwards.

The second kind of detours occurs from conflicts between the trajectories. To avoid these detours every conflict has to be solved by time based or vertical separation. The feasibility of this approach was tested using a fast time simulation based on real world traffic demand data.

To keep the fuel consumption theoretically on its minimum in descent the aircraft has to glide without engines from the top of descent to the runway. In this case, only the potential and kinetic energy at the top of descent is use to land. Hence, the concept has to be able to deal with the continuous descent approach (CDA) or optimized profile descent (OPD). A major problem for CDA nowadays is the reduction of the capacity of the airport based on the increased separation. Because the aircrafts are flying their own specific trajectory with own speeds and altitudes the separation between the aircrafts need to be much higher compared to the case that all are flying with similar speeds.

For an optimal climb the best procedure is a continues climb procedure (CCP) with individual speed and altitude profile. Here the same problem occurs like at the descent with higher separations have to be used which reduces the airport capacity.

The core element for an airspace, which is able to deal with the requirements described above, is the late merging point concept (LMP) [5]. This concept bases on a time contract at a “late merging point” at which the aircrafts are merged to one traffic flow for one runway. The time contract with every aircraft is, to be at a certain time at the late merging point. In this way, the necessary landing sequence is implemented.

For this concept, all aircrafts should be equipped with an advanced 4D-FMS and are able to exchange information with the appropriate concept component in accordance with the TBO concept.

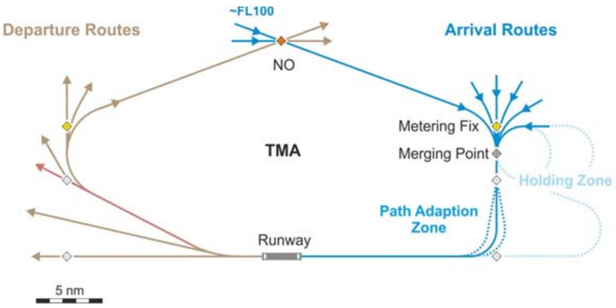

Figure 2 Generic structure of the TMA.

An advanced 4D-FMS is a flight management system, which is able to negotiate with the concept component “traffic synchronization” to be at a certain time at a certain place. Furthermore, this kind of FMS is also able to control the aircraft in a way that the required time will be reached within a deviation of ±5 sec.

To create the necessary ATC-separation at the merging point the ground component for traffic synchronization, especially in this case is an arrival manger (AMAN) which negotiate with all arriving aircrafts a required time of arrival (RTA) at the merging point.

In Fig. 2 only the north part of the new airspace structure is depict. The south part is the mirror picture of the north part. All aircraft fly directly to the merging point, except the aircrafts directly from the west. From this direction the aircrafts have to made a small detour flying to the waypoint NO to reduce the amount and the complexity of conflicts with the departing traffic. Hence, aircraft flying with a high probability on individual routes, and because the flow to the late merging point is controlled it can be expected that the separation problems for CDO are minor or completely solved. At least the controllability of target times by speed variation is limited by the flight envelope of civil aircraft, which creates a requirement because controlling delays by detours are not permitted in the concept. As an example for the reduced controllability, the flight times in a horizon of 200 nm before runway threshold can be varied by approximately 4 minutes using the high/nominal/low speed profiles of an Airbus A320 based on calculations using BADA 3.9 model data.

According to the departures, the same account for CCP in nearly the same way. To reduce the probability of conflicts all departing aircrafts flying to the east have to take first the orange heading, then flying to the metering fix and at least to NO. The next waypoint then is the first waypoint at the destination. The position of the used waypoints are the mirrored one to a line from NO the middle of the runway. Hence, changing the runway direction results in exact the same procedures.

The highest probability for conflicts within this airspace design exists between departures and arrivals. To solve this problem the following procedure is proposed. The departures are scheduled between the arrivals according to a runway separation matrix supported by an arrival departure coordinator as a part of the traffic synchronization component. Directly after take-off a departing aircraft should send its trajectory update based on the actual take-off time to the conflict management concept component. The conflict management component checks the departure trajectory for conflicts against arrival trajectories.

If a conflict is detected, the conflict management component has to create a level segment or an altitude constraint to keep the departure below the conflicting arrival. The constraint is transmitted to the departing aircraft, which includes the constraint in its trajectory. The new departure trajectory is transmitted to the conflict management component, which checks trajectory against follow-on conflicts. If a follow-on conflict appears, the conflict management component inserts an additional altitude constraint as long as all conflicts are solved. It could be expected that this procedure solve nearly all departure arrival conflicts.

The questions on how the traffic can be guided by controllers and which tools they need to do so were not addressed in the work. Hence, it is not clear if this concept can be implemented. This work is left for a follow on project.

3.2 Simulation results

The aim of the simulation trials is to test the proposed design according to its feasibility. Feasibility is given in the case that it would be possible to solve all conflicts in the intended way in a heavy traffic scenario based on an existing day for an airport with 2 independent parallel runways.

To prove the concept, fast time simulation trials are conducted based on a real world traffic demand (origin/destination pairs and times, aircraft types, CFL) taken from the EUROCONTROL Demand Data Repository [6] representing the traffic structure of an airport in terms of aircraft mix as well as spatial and temporal distribution of arrivals and departures. The used data set comprises the flight plans of a whole day. Based on this set, using a specifically designed scenario generator RouGe [7] and taking into account the new generic runway and TMA structure, appropriate test data sets are created as runway-to-runway flight plans. This data set represents user preferred flight plans because it did not consider any other intent of flights. The used tool for the trials is the TrafficSim, a proprietary DLR tool [8]. The tool uses BADA as performance model. It is assumed that the trajectories are of a high quality, i.e. close to the one of a FMS. To emulate the flow control for the runway a runway sequence was implemented based on a runway capacity model [9]. The implemented model takes care on five wake vortex categories and their speed performance. The sequence is established well before top-of-descent and gaps in the arrival sequence are foreseen for departures. In the trials, it is assumed that always a departure is available for every gap. One result is shown in Fig. 3.

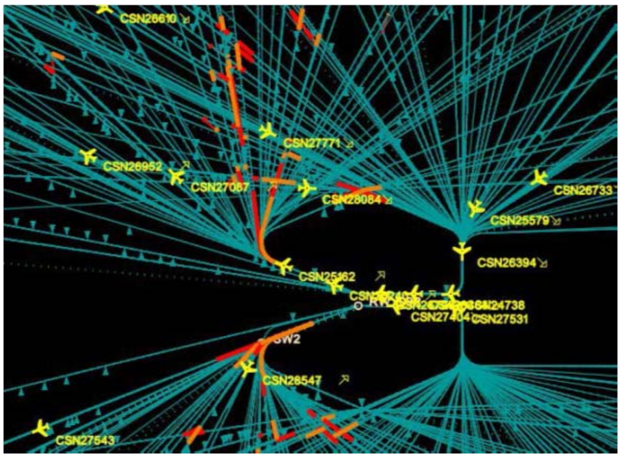

Figure 3 Typical conflict situations in a trial.

This complete day scenario comprises 1274 flights. For the conflict detection limits of 3000 ft vertical and 3 nm longitudinal especially for approaches were introduced. Conflicts on en-route level are disregarded because these conflicts are addressed in the flight centric concept. Departure/departure conflicts can be simply solved by changing the departure sequence [10]. The remaining conflicts are between arriving and departing flights creates more effort for its solution. Compared to the total number of flights in the scenario the remaining 52 arrival/departure conflicts, can be consider as less with 4% of all flights. The minimum altitude for the departure/arrival conflicts are found at 11500 ft, the maximum at 31000 ft and the median value at 18650 ft. These values result from the basic route structure of the TMA, which provides free airspace below the departure trajectory to implement a vertical conflict solution maneuvers.

To not disturb the arrivals, the conflict resolution is done by the departing flights. These flights have enough time left to compensate the gathered delay effectively by i.e. speed control. Furthermore, departing aircrafts are always able to perform a level segment during climb. In this way it was possible to solve all conflicts in the test scenarios and the feasibility of the new airspace design is exemplarily proven. For more details and additional scenarios, see [10].

4. RUINED LOW LIMIT DESIGN

Real world constraints like other traffic of surrounding airports, airspace sectors, restricted areas, and weather mean that controllers have to guide aircraft on routes deviating from the optimal origin to destination trajectory. In this near future design, the TMA design provides individual negotiated and optimized 4d-trajectories as far as to the threshold and considers different aircraft equipages and temporarily restricted areas.

4.1 Approach separation

Using direct approaches from origin to destination airport reduces the possibilities of route variations to meet target times at waypoints and the threshold. Alternatively, linear holdings are available in which speed adjustments can be made without changing the route to adjust target times at waypoints. Due to the relatively small speed range within aircraft can be varied during cruise flight, the possible temporal adjustments are only a few minutes even when adjustment starts an hour before the target waypoint. Longer delays must therefore be started very early, preferably at the departure airport or at the beginning of the flight, which may means that pilots cannot achieve the cost index dictated by the airlines. When executing direct flights along the great circle up to the final of the destination airport, a precise 4d-trajectory must therefore be defined and met, which has to be coordinated with the remaining traffic, especially in the TMA at the destination airport. For this, an Extended Terminal Manoeuvring Area (E-TMA) was defined, which is much bigger then classic TMAs (Figure 4). The E-TMA is a sector overlapping planning area, representing the calculation horizon of newest Extended or Cross Boarder Arrival Manager (EMAN and XMAN). The size was chosen to deliver pilots with negotiated and committed 4d-trajectories all needed clearances from the top of descent down to the threshold at once to comply with the optimized descent profile. An additional benefit of the extended planning horizon is the possibility to take restricted military areas and severe weather like thunderstorms even for the arrival scheduling into account (red and black areas in Fig. 4).

However, the accuracy of optimized CDA-trajectories depends very much on the quality of the weather forecast, which can show noticeable deviations over several hours forecast time. Therefore, the possibility for a small path stretching before reaching the final was introduced for the implementation of direct approaches, which at least allows target time adjustments by a few minutes. This path stretching area was inspired by a fan pattern and defined for all arrival areas in the TMA and their surrounding sectors through side-by-side FMS waypoints. These new defined points got the name Aircraft Separation Points (ASP) (Fig. 4).

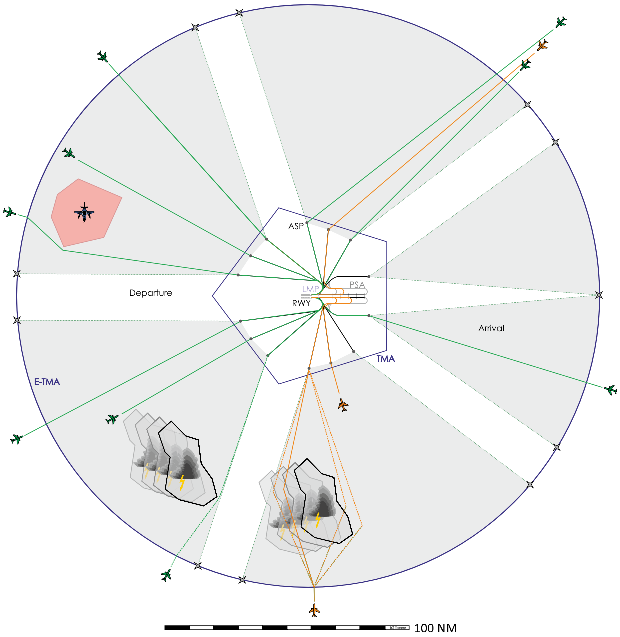

Figure 4 Schematic representation of the presented airspace structure with Extended Terminal Maneuvering Area (E-TMA), Aircraft Separation Points (ASP), and Late Merging Points (LMP) for each runway (RWY). Green lines represent individual negotiated and optimized approach routes, orange lines standard routes.

The possibilities of the aircraft to meet a 4d-trajectory regarding navigational and timely precision depends on its individual Flight Management System (FMS) equipage. Different FMS reach different Required Times of Arrival (RTA) precision at specific waypoints or the runway, which are essential for a precalculated and optimized air traffic. For a global optimization of arriving and departing traffic at an airport, a minimum precision in meeting negotiated 4d-trajectories is required. Looking at the FMS-equipage of today's aircraft, not all will meet the desired precision [11]. To introduce negotiated and individual optimized 4d-flight and arrival trajectories today at an airport, aircraft have to be clearly separated during final approach phase on discrete approach routes. This route separation takes place at the Aircraft Separation Points. All aircraft with Advanced Flight Management Systems (A-FMS) meeting their RTAs with a deviation of around ±5 seconds at any desired waypoint get the possibility to follow great circle routes through the TMA until the final [12].

Aircraft with older and not so precise FMS are guided over a classical path stretching area like a trombone, which allows an easy adjustment of approach separations on downwind, base, and final.

4.2 Late Merging

Now the challenge of approach guidance is the integration of aircraft with negotiated 4d-trajectories and therefore target times at all waypoints on the approach route down to the runway on the one side, and the standard approaches guided manually through radiotelephony using standard phraseologies according to International Civil Aviation Organization specifications [13] on the other side.

From a scheduling point of view, the CDAs have to be integrated into the manual guided stream of the trombone flying aircraft, because these aircraft are already on the centre line, when the direct approaches reaching the final. However, from a technical point of view the CDAs with their optimized approach profile have negotiated target times for all waypoints, which include the Final Approach Point (FAP) and the threshold. These target times cannot be modified to adjust aircraft separations on the final without destroying their optimized descent profile. Therefore, all manual guided aircraft have to be integrated into the stream of CDAs. To reduce the influence on each other, the waypoint, where CDAs and standard approaches meet on final should be as late as possible. For this reason, a Late Merging Point (LMP) is positioned on each final around six Nautical Miles before threshold where the CDAs, all separated among each other, and the standard approaches, also separated among each other, ICAO-conform merge (Fig. 4).

To achieve this goal, a number of conditions have to be accomplished. First, the CDA-trajectory negotiation and scheduling have to be done in this way, that all scheduled target times between the approaches for the LMP and the RWY have to be minimal with an additional airport specific safety margin [14]. A particular challenge is the crossing of arrival routes of CDAs and standard approaches using the trombone pattern in the TMA. The negotiated CDAs can fly nearly direct routes from their destination airport over the ASPs until the LMP on the final. The other aircraft, guided onto the trombone from different approach directions, have to transect the direct routes safely without separation violations (in Figure 4 green and orange lines north and south of the LMPs). In the TMA, the required vertical separation for crossing aircraft are 300 ft., but usually aircraft controller prefer one and a half times space for a safe approach guidance. For this reason, all approach routes crossing each other in the TMA where evaluated automatically regarding their average flight altitude and therefore their average vertical spacing by a software program to guarantee sufficient separations even with the additional safety clearance requested by controllers. For direct approaches conducting Continuous Descent Operations (CDO), the route length from the ASPs to the LMPs is significant shorter than for the trombone approaches. For this reason, the directs have to decrease their flight altitude earlier than the standard approaches and so they fly at all crossings underneath the trombone flights (green routes in Fig. 5 are direct approaches and the orange lines represents standard approaches). Additionally, the downwind flight altitude is set a little higher than usually to 8000 ft. That way the average altitude clearance between direct and the standard approaches increases to 2200 ft. and 4400 ft. (670 m – 1340 m) and thus it is safe in all traffic situations.

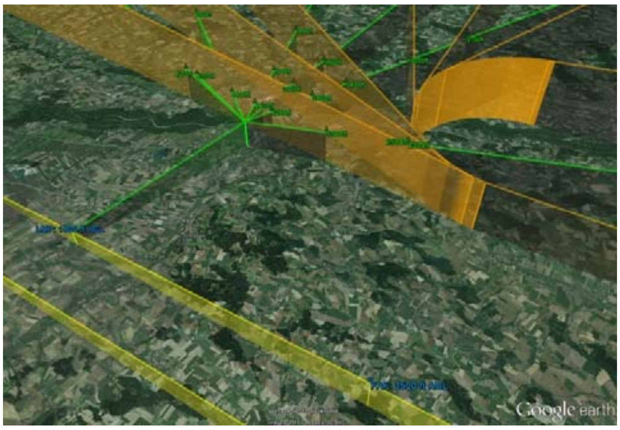

Figure 5 3D model of the standard arrival routes for CDA (green) and conventionally equipped (orange) aircraft with average separation values (green triangles), final approach depicted in yellow [12].

A disadvantage of the raised downwind altitude and therefore the trombone and the ILS intercept altitude is the extension of the downwind and the according trombone length (Fig. 6). Due to their approach speed and glide ratio modern aircraft need longer distances to reduce their speed and altitude. Going higher on the downwind, they need longer ways to cut down the altitude with simultaneous speed reduction.

In other words, the higher the downwind, the longer the minimum trombone pullout. Consequently, the shortest possible way from downwind onto final may be for some aircraft types in the presented airspace a few miles longer than with now commonplace 4000 ft. or 5000 ft. intercept altitude. On the other hand, direct approaches with negotiated target times save the downwind stretch and the biggest part of the final. The overall benefit in flight time and distance reduction depends on many factors like the airport topology and the position of the LMPs.

For this reason, the ratio between direct approaches with negotiated target times and conventional ones at which the procedure is worthwhile depends on the airport and its individual operational procedures. First trials indicated that a percentage of 20% A-FMS equipped aircraft already shows benefits in overall fuel consumption [15].

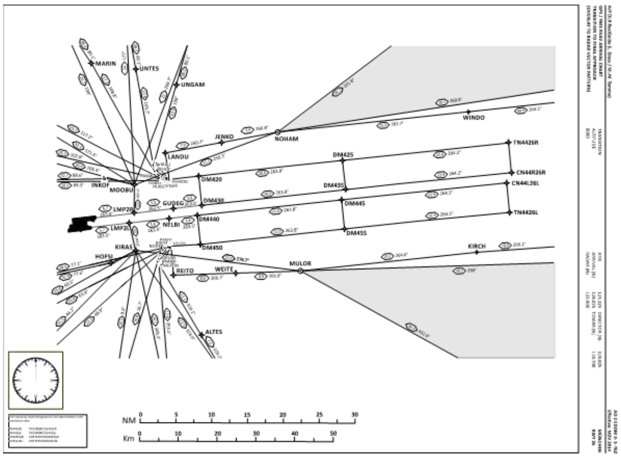

Figure 6 Airspace structure with LMPs, trombone path stretching area and finals as airspace map.

4.3 Inbound Stream Coordination

At the LMPs, new guidance challenges result for approach controller. On the final, manually guided and separated aircraft approaching the runway. At the LMP, the CDA performing aircraft with negotiated target times for the LMP and the threshold intercept the final, too. Because of their fixed times and relating thereto clearances for the final approach, the CDA aircraft should not be influenced by the feeder or the tower controller, both responsible for parts of the final. With this airspace structure, feeder controller have to separate the manually guided inbounds on the final in this way, that at the times, when a CDA aircraft approaching the final from the side at the LMP, no manually guided aircraft is allowed to fly in the vicinity of this waypoint. To achieve a fluent inbound stream without lavish space between the two inbound streams, controllers need dedicated support to turn their aircraft timely precise on the base and further on the final. This can be realized with an AMAN support system with sophisticated algorithms for trajectory-negotiation and -coordination and an additional graphical radar display support [12]. Beside a semi-automated trajectory negotiation, optical support functions like Ghosting, TargetWindows, and Trawl-Nets may help air traffic controllers staggering and merging the inbound traffic. On runways with mixed traffic, the coordinated cooperation between an Arrival and a Departure Manager ensure instantaneous traffic movements even with a high percentage of CDO executing approaches [16][5].

5. Summary and Conclusions

Starting with a perfect direct route from origin to destination airport, constraints like other airports, airspace sectors, restricted areas, and weather force pilots and the air traffic control to guide aircraft on routes deviating from the optimal trajectory. This means aircraft have to extend their flight distance, lengthen the flight time, increasing the fuel consumption and the environmental impact. With our approach, we propose an airspace concept only with minor restrictions for controllers and pilots to implement great circle routes at least for aircraft with technical equipment, which should be available for nearly all modern civil aircraft types over the next view years. The early scheduling of arrivals with the help of data link and a trajectory based AMAN, discrete approach routes which allow for separation of aircraft with different FMS equipage, and the late merging on the final provide aircraft to follow its individual optimized descent profile. Furthermore, with tools and HMIs developed to guide aircraft through such an airspace design, optimized descent approaches on individual arrival routes are possible. Especially, this airspace design is able to deal with a mixed traffic situation, allowing better equipped aircraft to fly continuous descent profiles on negotiated trajectories while lower equipped aircraft have to conduct conventional approaches. The concepts were evaluated in different projects with varying traffic scenarios running in automated fast-time and real-time as well as human-in-the-loop simulations.

6. REFERENCES

[1] ICAO (2015). Global Air Traffic Management Operational Concept, Doc 9854 AN/458, International Civil Aviation Organization (ICAO).

[2] Birkmeier, B., S. Tittel, and B. Korn (2016). Controller Team Possibilities for Sectorless Air Traffic Management. Integrated Communications Navigation and Surveillance (ICNS) Conference. Herndon, VA, USA

[3] Gerdes, I. and A. Temme (2012). Taxi routing for aircraft: Creation and Controlling: Ground movements with time constraints. Second SESAR Innovation Days, Braunschweig, Germany

[4] Cook, A., G. Tanner, V. Williams, and G. Meise (2007). Dynamic Cost Indexing. 6th EUROCONTROL Innovative Research Workshops & Exhibition,. Brétigny sur Orge, France

[5] Oberheid, H., B. Weber, M.-M. Temme, and A. Kuenz (2009). Visual Assistance to Support Late Merging Operations in 4D Trajectory-Based Arrival Management. 28th Digital Avionics Systems Conference (DASC), Orlando, Florida, USA

[6] Eurocontrol Demand Data Repository, http://www.eurocontrol.int/ddr

[7] Luchkova, T., A. R. Schmitt, A. Temme, M. Schultz, and A. Lau (2016). ATM Evaluation of Volcanic Ash Optimized Trajectories in Europe. SESAR Innovation Days (SID). Delft, The Netherlands

[8] Edinger, C. and A. R. Schmitt (2012). Rapid Prototyping for ATM Operational Concept Development. Deutscher Luft- und Raumfahrtkongress 2012, Berlin

[9] Karbowy, A. (2008). Schätzung und Optimierung der Kapazität eines Flughafens auf der Grundlage von empirischen oder simulierten Verkehrsdaten, DLR-IB 112-2008/42

[10] Schwoch, G., F. Knabe, and R. Stump (2012). Estimating Requirements and Costs of 4D ATM in High Density Terminal Areas. Integrated Communications, Navigation and Surveillance Conference (ICNS). Washington, USA

[11] De Smedt, D. (2012). Aircraft Systems and 4D Trajectory Management, EUROCONTROL

[12] Sinapius, P. B. and M.-M. Temme (2015). flexiGuide - Flexible Air Traffic Management in the Extended TMA to Reduce Environmental Impacts. DASC. Prag, Czech Republic

[13] ICAO (2007), ATM (Air Traffic Management): Procedures for Air Navigation Services, DOC 4444 ATM/501, International Civil Aviation Organization (ICAO)

[14] Hanses, C., F. Knabe, and B. Korn (2015). Designing and Evaluating Advanced Approach Procedures for the Concept of Segmented Independent Parallel Approaches. 15th AIAA Aviation Technology, Integration, and Operations Conference Dallas, Texas, USA

[15] Kuenz, A. and C. Edinger (2010). Green Approaches Without Trade-off: Final Results From The FAGI-Project. 29th Digital Avionics Systems Conference (DASC), Salt Lake City, UT, USA

[16] Böhme, D., R. Brucherseifer, and L. Christoffels (2007). Coordinated Arrival Departure Management. 7th USA/Europe ATM 2007 R&D Seminar, Barcelona, Spain

7. COPYRIGHT