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Approach and Landing Procedures for Airports "Nikola Tesla" and "Batajnica" Using RNP AR APCH and Baro-VNAV

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Abstract

An idea of introducing civil operations at military airport "Batajnica" near Belgrade, Serbia has been conceived recently as an answer to the latest challenges of the air transport market. In that case, the situation in the terminal airspace of both "Nikola Tesla" (LYBE) and "Batajnica" (LYBT) airports would change completely and therefore the new circumstances need to be considered and terminal airspace optimized accordingly. An important part of the optimization process is design of approach and landing procedures, as well as strategical separation of inbound flows. Some of the most advanced concepts and solutions in civil aviation have been applied in design of the proposed procedures: *Performance-Based Navigation, Baro-VNAV* and *CDA* which are already being implemented very successfully worldwide.

Keywords: RNP, Baro-VNAV, CDA, procedures, approach, Batajnica, Belgrade, terminal airspace, STAR, design

1. Introduction

Fluctuations on the global market, increase in population and other factors cause practically constant increase in demand for air transport worldwide while continuing to demand high cost-effectiveness and uncompromised safety. On certain routes, it is possible to meet the increased demand by introducing larger aircraft, but there is also a vast number of routes where such solution would be far from cost-effective. Large aircraft are an ideal solution for long-haul flights between major hubs, whereas for regional routes smaller aircraft are needed. An important characteristic of regional air traffic and transport is that there are usually less passengers per flight (independently of load factor), but frequencies could be rather high which depends on a specific market. In order to satisfy demand of a specific market for regional air transport, bearing in mind destinations network, number of passengers, preferable time of departure etc. more flights are needed to transport the same number of passengers than it would be the case if they were transported by a larger aircraft. Furthermore, an increased number of flights induce increased traffic load and complexity in terminal airspaces around the departure and arrival airports. Overload of airspace could lead to a large number of problems among which probably the most important would be:

- jeopardizing of safety due to potential violation of separation minima
- decrease in airport capacity due to poorly organized terminal airspace and potential limitations caused by the airport position
- long delays and flight schedule disruptions caused by holdings in approach or departure
- enormous costs for all stakeholders (airlines, airports, passengers, air navigation service providers) caused by the previously mentioned factors.

The basic principles upon which modern air traffic control is based are: safety, regularity and expedition. Meeting those principles in conditions of noticeably increased traffic requires constant improving and application of advanced solutions in air traffic management and aviation generally. Currently, one of the most advanced solutions is the new concept of air navigation based upon navigation performances - *Performance-Based Navigation (PBN).* Its numerous advantages compared to conventional navigation have made it possible to reorganize even the most congested terminal airspaces in the world and increase accessibility to the airports in the most remote and delicate places (caused by obstacles, climate or inadequate equipment for a precision approach).

An idea of introducing civil operations at military airport “Batajnica” near Belgrade, Serbia (LYBT) has been conceived recently as an answer to the latest challenges of the air transport market. According to the idea, it is expected that the newly opened airport would be used mostly by low-cost carriers encouraged by lower taxes than at the nearby “Nikola Tesla” airport (LYBE). Civil cargo operations are also expected at “Batajnica”. On one side of the two parallel runways there would be a military complex, and on the other side, civil passenger and cargo terminal, apron and other structures. Runway 12L/30R would be used for civil operations. It is still not known whether and when the airport “Batajnica” would be opened for civil operations although some plans do exist, but there is certainly very much to be done before that happens.

Opening of “Batajnica” airport for civil operations would completely change the situation in Serbian airspace, especially in the terminal airspaces in the region of Belgrade and therefore it needs to be assessed thoroughly. Currently, both of the airports have their own terminal airspace: “Beograd” and “Batajnica for LYBE and LYBT respectively. Those two terminal airspaces were assessed together because of their interdependence caused inter alia by relative geographical closeness of the two airports (approximately 14 km in straight line between the ARPs). In this paper, the proposed approach and landing procedures for airports “Nikola Tesla” and “Batajnica” are designed applying probably several of the most and increasingly popular concepts: RNP AR APCH (*Required Navigation Performance Authorization Required Approach)*, Baro-VNAV (*Barometric Vertical Navigation)* and CDA (*Continuous Descent Approach).* The goal of the proposed solution is strategic flow separation and optimization of flows and airspace according to the following criteria:

- safety
- minimisation of costs for all stakeholders in air transport and traffic
- minimization of negative influence on the environment
- accessibility: maximization of number of aircraft that could fly the proposed procedures
- flexibility

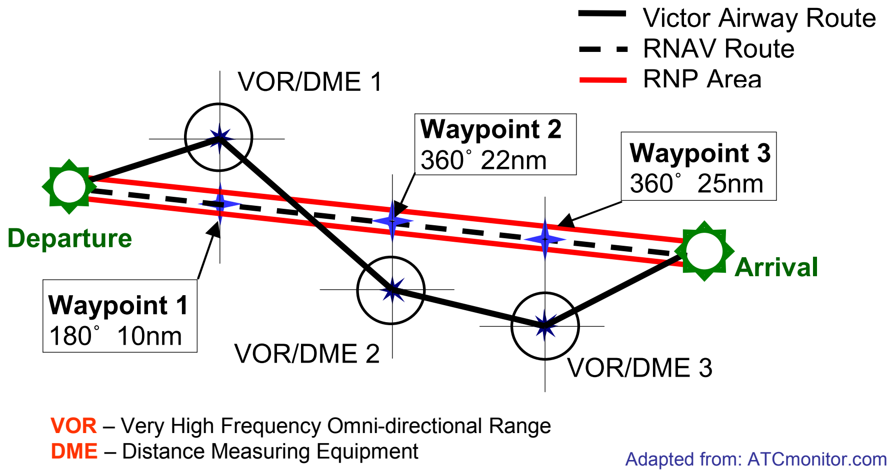
RNP AR APCH and Baro-VNAV are still so new that aviation experts around the world are still working on standardization of some details. This paper is based on currently available and the most recent documents which are naturally susceptible to future updates, such as ICAO Doc. 9613 Final Working Draft 5.1: *Performance Based Navigation Manual* and ICAO *Required Navigation Performance Authorization Required Procedure Design Manual*, Final Draft ver. 1.0, November, 29 2007. The fact that world’s leading airlines, airports, procedure design companies, as well as ICAO, FAA and EUROCONTROL focus increasingly more attention and efforts on standardization and implementation of RNP worldwide represents a significant encouragement. Bearing in mind the efforts and already achieved results in RNP implementation, it may be freely said that RNP represents the future of air navigation. Probably the best illustration of that is the fact that the most wanted type of avionics upgrade in the recent period has been the upgrades to the standards that enable RNP operations.

2. The concept of Performance-Based Navigation

According to ICAO Doc. 9613, the concept of Performance-Based Navigation is based upon idea that international aviation authorities specify navigation performance requirements instead of specifying required technologies or avionics. This new navigation concept (PBN) includes: *Area Navigation (RNAV)* and *Required Navigation Performance (RNP).*

Contrary to conventional navigation which relies on navigation signals from ground navaids (i.e. VOR, NDB), PBN is predominantly based upon satellite navigation - GNSS *(Global Navigation Satellite System).* Now, instead of overflying ground-based navaids, waypoints could be defined anywhere in the airspace covered by appropriate navigational signal. Airborne navigation computer determines the current position of the aircraft, position of the waypoints and all parameters of flight according to received navigation signals, and the computed parameters (for example: bearing, ETA etc.) can be shown relative to waypoints independently of the position of used navaids. RNP also provides monitoring of actually achieved navigational performances and navigation containment.

A simplified illustration of PBN concept is depicted in figure1.



VOR – Very High Frequency Omni-directional Range
DME – Distance Measuring Equipment

Adapted from: ATCmonitor.com

Figure 1: Comparison of conventional navigation, RNAV and RNP

3. RNP - Required Navigation Performance

According to ICAO 9613, RNP is defined as a set of standards which specify required navigation performance accuracy of an aircraft in certain airspace, along a certain route or approach etc. Lateral deviation from the nominal flight path must not exceed ±1RNP during at least 95% of flight time on an RNP route, in a certain airspace etc. or ±2RNP during 99% of flight time. RNP containment area is defined as linear and only as primary.

The key functions of RNP navigation system are:

- navigation according to predefined criteria including navigation containment
- monitoring of achieved navigation performances
- alerting the crew when the required navigation performance could not be met

One of fairly used RNP types is RNP AR APCH *(RNP Authorization Required Approach)* according to which the procedures in this paper have been designed. The primary navigational infrastructure is GNSS while the secondary sensors are DME/DME and IRS *(Inertial Reference System)*. This RNP type is used in approach and landing procedures. The standard RNP value in final approach is RNP 0.3 (the maximum allowed lateral deviation is ±0.3 NM from the nominal flight path during 95% of flight time), and the minimal value is RNP 0.1. For the segments of initial, intermediate and missed approach, the standard value is RNP 1 while the minimum is RNP 0.5. Total horizontal system error (TSE) with this RNP type is limited to ±0.1NM in any segment whereas with RNP APCH it is limited to ±0.3 NM only in final approach and to ±1 NM in any other segment, and therefore those two RNP types with similar names should not be mixed.

Airborne navigation system, among other things, needs to have a built-in database of complete approach procedures including vertical angles, missed approaches and transitions for a given airport.

It is not necessary to carry out flying inspections of navigational signals for this RNP type because it relies on GNSS. According to the document AC 20-138, accuracy of GPS sensors during at least 95% of flight time must be higher than 36m or higher than 2m for augmented GPS sensor (i.e. SBAS or GBAS). Maximum deviations of IRS are limited to 2NM per hour of flight for flights up to ten hours. It is assumed (in the documents) that the systems which meet those standards have the maximum deviation of up to 8NM per hour of flight during the first 30 minutes after aircraft position updating has stopped with probability of 95%.

4. Benefits and possible issues with RNP implementation

The principal benefits that implementation of RNP brings to the global aviation and society are:

- **significantly increased capacity and efficiency of airspace** – improved aircraft navigation performance enable decreased separation minima which means that less airspace is needed for the same operations; dynamic air traffic management is enabled; offset routes are enabled.
- **improved flight safety** thanks to more accurate navigation; significant decrease in the number of *Controlled Flights into Terrain – CFIT*, especially during nocturnal approaches to the airports surrounded by high mountains or other obstacles.
- **increased accessibility of certain airports** – decreased influence of poor weather conditions to operations, less cancelled and delayed flights and associated costs due to less constraining obstacle clearance minima.
- **more direct routes** – overflying of ground-based navaids is not necessary any more, shorter flights, operational costs are decreased.
- **less crew and air traffic control workload** – flight paths are defined by waypoints, voice communication between the crew and ATC is reduced; data-link application is also very useful for this purpose.
- **major fuel and flight time savings** – 4D *gate-to-gate* air traffic management is enabled, less time spent in holdings on ground and sky.
- **more environment-friendly** – consequence of decreased block-time, less noise and air pollution, more flexible design of procedures enabled;
- **optimized vertical profile** – smoother climb, cruise and descent, economically optimised; also a merit of replacement of conventional *Dive and Drive* approaches with the new ones - CDA *(Continuous Descent Approach)*.
- **increased predictability and repeatability of flight paths** – flight paths can be defined and followed more precisely now; prerequisite for structuring traffic flows in a congested terminal airspace.
- **more flexibility in procedure design** – procedures can suit better specific locations and needs, easier because less airspace is needed, no need for radar monitoring, less restrained by ground-based navaids.

Some of the issues noted during implementation of PBN worldwide which definitely need to be addressed in order to encourage and improve further implementation of PBN are:

- **data integrity** is absolutely critical, therefore, approved data-suppliers and data-integrity controls are essential; new concept planned where the user *pulls* information (instead of today's push concept); global aeronautical database is needed;
- **mixed-capability environment during implementation process** – as implementation of PBN progresses, more and more operators become ready for RNAV/RNP operations, but even those that are neither PBN-ready nor will be in the near future need to be served adequately by ANSP by means of conventional navigation;
- **loss of external signal or failure of on-board RNP system** – flight depends very much on electronics, emergency procedures need to be more developed;
- **adequate FMS needed** – a modern FMS needs to support RNAV-RNP holdings as well as RF legs, which was not the case with the first RNAV-RNP on-board systems;
- **vast investments** needed in staff training, equipment, maintenance and research;
- **standardisation and other issues** which are constantly being addressed at various international meetings and workshops;
- **political issues** – GNSS signal is controled by a rather small number of countries which rises the question of reliability in sense that the signal could be shut or degraded by the few countries that control it in certain zones in a certain period.

4.1. Examples of RNP implementation

Practical implementation of RNP could be illustrated very well by examples of several of the least accessible airports in the world where any approach by means of conventional navigation would be extremely hard or maybe even impossible. For example, approach procedures for Chinese airports of Linzhi (ZUNZ) and Lhasa (ZULS) in Tibet are based on RNP AR APCH and designed in the way that an approaching aircraft practically follows the valley of the river flying between very high mountains (instead overflying them) which drastically lower the decision altitude. In a similar way are designed RNP approach and landing procedures for Austrian Innsbruck (LOWI) and Canadian Kelowna (CYLW) airport. Those are perfect examples how implementation of RNP could help achieving clearly structured flows which consequently lead to much more efficient use of airspace.

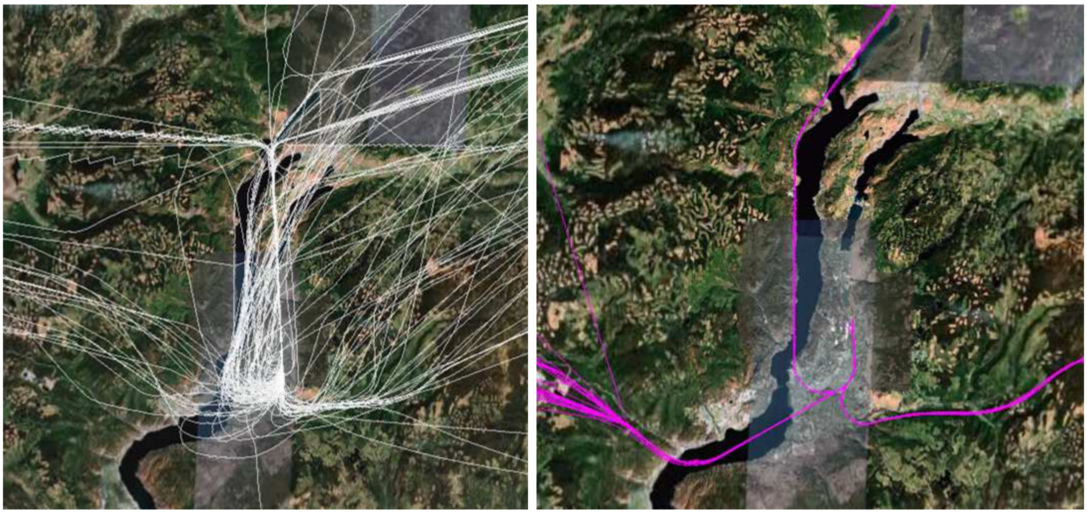

before **after**

Figure 2: Approach flows at Kelowna (CYLW) before and after RNP implementation (Source: *Naverus Inc.*)

5. Barometric Vertical Navigation (Baro-VNAV)

The essence of Baro-VNAV is calculation of vertical component of a 3D flight path that an aircraft should follow based on measured static pressure. In the phase of final approach, this vertical component is determined by the *Reference Datum Height (RDH, or Threshold Crossing Height – TCH in FAA documents)* and *Vertical Path Angle (VPA)* which is usually approximately 3°. All data necessary for calculation of the vertical component of a 3D flight path is stored in on-board navigation system database – except the data on current local pressure and temperature essential for an accurate calculation. On-board RNP system for lateral navigation must be certified to comply with the standards for approach operations at RNP-RNAV≤0.3 if it is to be used for Baro-VNAV approaches.

Since it is based on barometric altimetry, Baro-VNAV does not require any particular navigational infrastructure. That makes Baro-VNAV an excellent choice for the carriers that fly frequently to remote airports where precision approaches are not possible. Although it has somehwat higher landing minima than ILS, Baro-VNAV enables approach and landing to airports in a delicate geographical environment following flight paths similar to those of precision approaches and without any particular infrastructure.

For smooth operation of the system, it is essential that the local pressure and temperature of the airport to which the approach is being made are known to the crew. In this case it is undrestood that those values are measured by the equipment at the airport and in no case by some remote measuring methods. Values of the local temperature and pressure are also essential for compensation of deviation of actual vertical path angle (VPA) from the nominal one due to change of local pressure and temperature. Advanced navigation systems do the compensation automatically. When designing procedures, a temperature range in which the published procedures can be flown without temperature compensation needs to be determined.

6. Continuous Descent Approach – CDA

Continuous Descent Approach (CDA) represents a new concept which is expected to contribute very much in reduction of noise, air pollution and fuel consumption. By CDA, approach is flown with a constant gradient at minimal thrust instead of alternating descent and level flight with added thrust as it is flown in a conventional approach.

The constant descent gradient is usually approximately 5.2% or 3° which is also the most frequent gradient of ILS *Glide Slope*. It is said that this angle is the easiest to maintain during a prolonged period of time. The altitude from which CDA begins should be as high as possible in order that positive effects of CDA be maximised. However, this altitude differs very much depending on an airport and even approach. A CDA could be executed by verbal commands from ATC or by STARs. There are still no harmonised international standards regarding implementation of CDA.

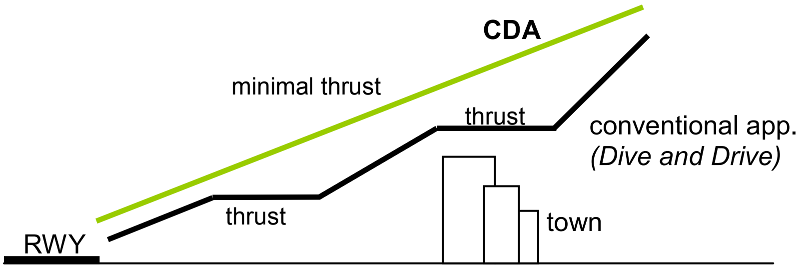


Figure 3: Continuous Descent Approach (CDA)

7. The airports

Airport “Nikola Tesla” (LYBE) has a single runway in direction 122° - 302° (12/30). Its dimensions are 3400m x 45m and it is equipped with ILS CAT IIIb. It is important to note that ILS CAT IIIb is expected to become operative as of December 2008 and that at the time this paper and calculations in it were made, only ILS CAT II and CAT I were operative on RWY 12 and 30 respectively. Aircraft category C is predominant at the airport. According to the official statistics, the airport had 43448 operations during 2007 and approximately 2.5 million passengers which was approximately 3% and 13% more than in 2006 respectively. The trend of growth continues throughout 2008 at approximately the same rate as it was in 2007.

Airport “Batajnica” (LYBT) is currently not available to civil commercial flights. Runway 12L/30R which is 2500m long and 45m wide is planned for potential civil operations at the airport and therefore only this runway is considered and referred to in the rest of the paper. There are no classic SID and STAR currently available but when needed, for special flights, special temporary procedures are issued.

Both of the airports have their own TMA, but currently there are conventional SID and STAR flows for “Nikola Tesla” running through TMA “Batajnica”.

8. Procedure design

8.1. General considerations

The main objective of design and implementation of the proposed procedures is separation of approach flows for the two airports at a strategic level. The calculations are based upon ICAO *Required Navigation Performance Authorization Required Procedure Design Manual*, Final Draft ver. 1.0, November 29th 2007 and are done using *MS Excel*. For calculations of the final approaches *RNP SAAR MS Excel Spreadsheet v.2.0.* was used which represents an FAA equivalent of the software for final approach calculation available on ICAO *RNP AR CD-ROM* (the ICAO version was not available to the author at the moment).

RNP AR APCH was applied in combination with Baro-VNAV, and vertical profile is optimised according to CDA concept with descent gradient of 5.2% (3°). All the elements of the procedures are calculated for aircraft category D having IAS at threshold (V_{at}) between 261km/h (141kt) and 307km/h (166kt). Of course, procedures can be flown by aircraft of lower categories as well. This aircraft category was chosen as a benchmark after an insight into the current population of aircraft served by LYBE has been made as the highest category expected on both airports.

Standard RNP values are adopted: RNP 0.3 in final approach and RNP 1 in all other segments since there are neither significant obstacles nearby nor any special operational benefits of using smaller RNP values were observed. During the procedure design, some other standard values were also adopted aiming to maximise accessibility and reduce complexity of the procedures, such as for example *bank angle=18°* in turns.

The minimum vertical separation on crossings of the approach flows of LYBE and LYBT is 2000ft for maximum safety. When the initially achieved vertical separation was less than 2000ft, appropriate interventions were made such as additional decrease in altitude of the lower flow at the crossing and regulation of descent gradient on certain approach sectors. A descent gradient somewhat lower than 5.2% was used along certain sectors of approach in order that the minimum vertical separations on two or more successive crossings could be met.

Following the recommendations of *"Eurocontrol Airspace Planning Design Manual"*, Section 5: Terminal Airspace Design Guidelines, January 17th 2005 for airspace complexity reduction, unification of TMA Beograd and TMA Batajnica was proposed. In the vertical plain, the new TMA would still comprise airspace up to FL145, but allowing for potential later changes or delegation depending on analysis of flows by altitudes. Entry fixes were defined on the borders of this new TMA. Those fixes are already defined in the Lower and Upper airspace and are placed either on two-way airways or on single-way airways which lead to the airports LYBE and LYBT. The other fixes which are also on the border of TMA but on the outbound one-way airways (for example TONDO) could be defined as exit fixes of the TMA and incorporated in SIDs – i.e for outbound traffic (which is not addressed in this paper). SID and STAR flows need to be assessed together in order that terminal airspace could be optimised and vertical separation minima of inbound and outbound flows could be met.

8.2. Turns

All turns are set to be horizontal, following the recommendations of ICAO, although modern navigation systems are capable of turning in a descent using autopilot. The background of those recommendations is the fact that it is much easier for pilots to fly and monitor flight parameters when turns are horizontal which also improves safety and accuracy in procedure following.

Since the distance between runway axes of the two airports is approximately 10km, completely independent parallel operations on LYBE and LYBT can be performed.

For procedure desing, TF *(Track to Fix)* and RF *(Radius to Fix)* legs were used while turns are defined as *Fly-by*, *Fly-over* and *RF* turns.

With the aim of perfectly fitting horizontal turns into the vertical profile of CDA and due to relatively complex interdependence of factors such as wind, altitude, turn radius etc., an iterative procedure was conceived and applied in calculation of turn parameters. The procedure was practically carried out using *MS Excel* and appropriate formulas. The basic idea and the parameters used in calculation are shown in figure 4.

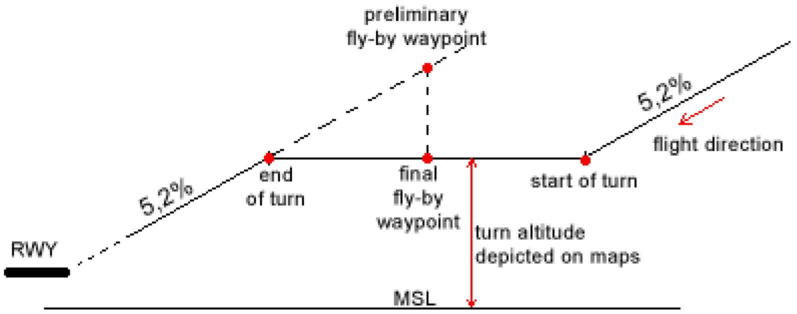


Figure 4: Fitting horizontal turns into vertical profile of CDA

8.3. Approach flows

Figure 5 shows proposed approach and landing procedures to runways 12 and 12L of airports LYBE and LYBT and figure 6 shows the same for runways 30 and 30R. The procedures are drawn using *Autodesk AutoCAD* respecting all calculated parameters and predefined elements such as for example airport and fix coordinates. Data on fixes, airports and other relevant elements was provided through an excellent cooperation between The Air Traffic and Transport Dept. of The Traffic and Transport Engineering Faculty, Belgrade and SMATSA (Serbia & Montenegro Air Traffic Service Agency).

Approach flows with their waypoints, turns and crossings with vertical separations are shown as well as approach and missed approach holdings. Certain segments common to flows of both airports are of a single colour of one of the flows because of overlapping of 3D flight paths when projected to a 2D paper or screen.

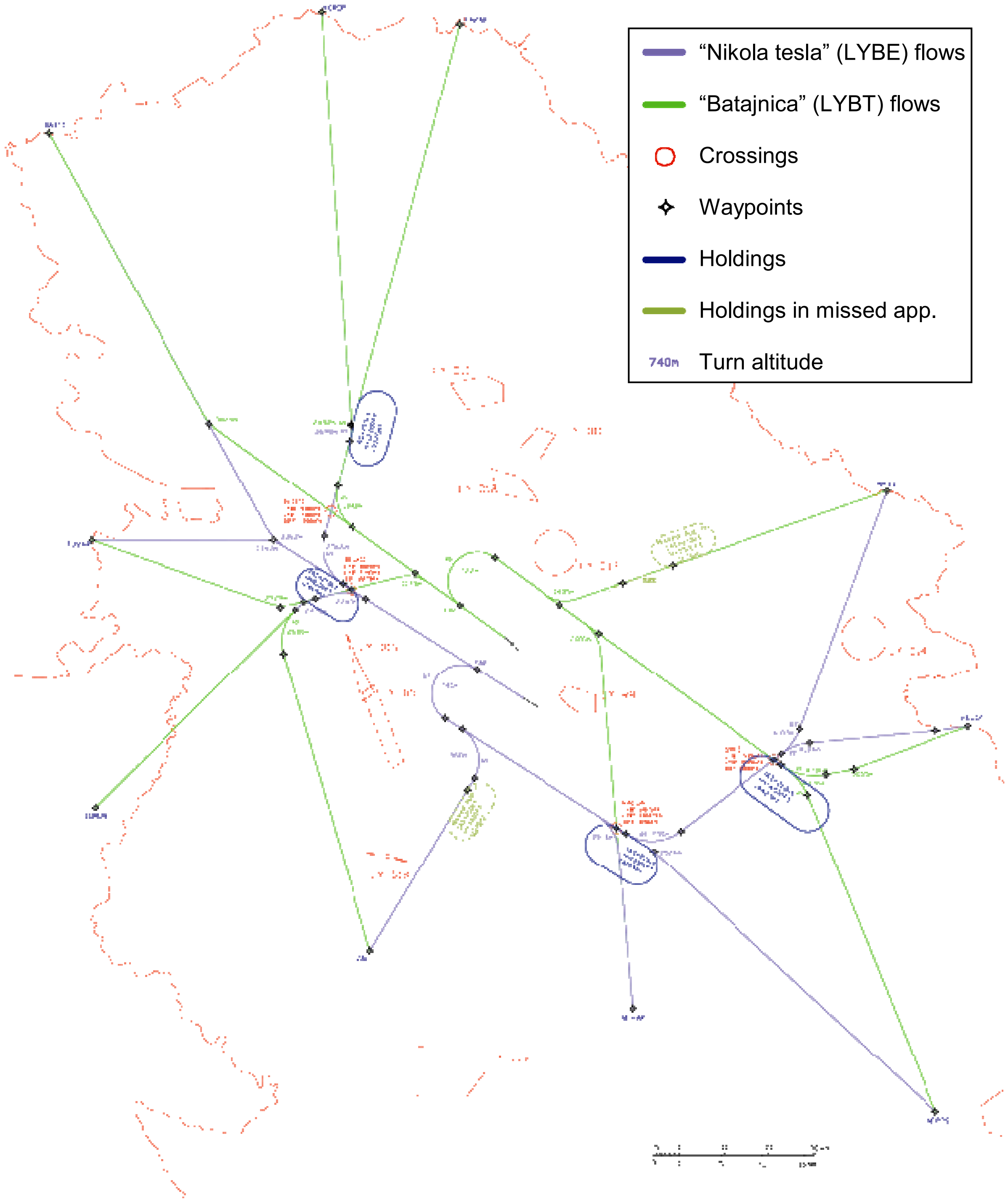


Figure 5: Approach flows to runways 12 and 12L of airports “Nikola Tesla” and “Batajnica”

When runways in direction 12 are active, aircraft inbound from northwest make a direct approach whereas those inbound from southeast fly a downwind leg and vice versa when runways in direction 30 are active.

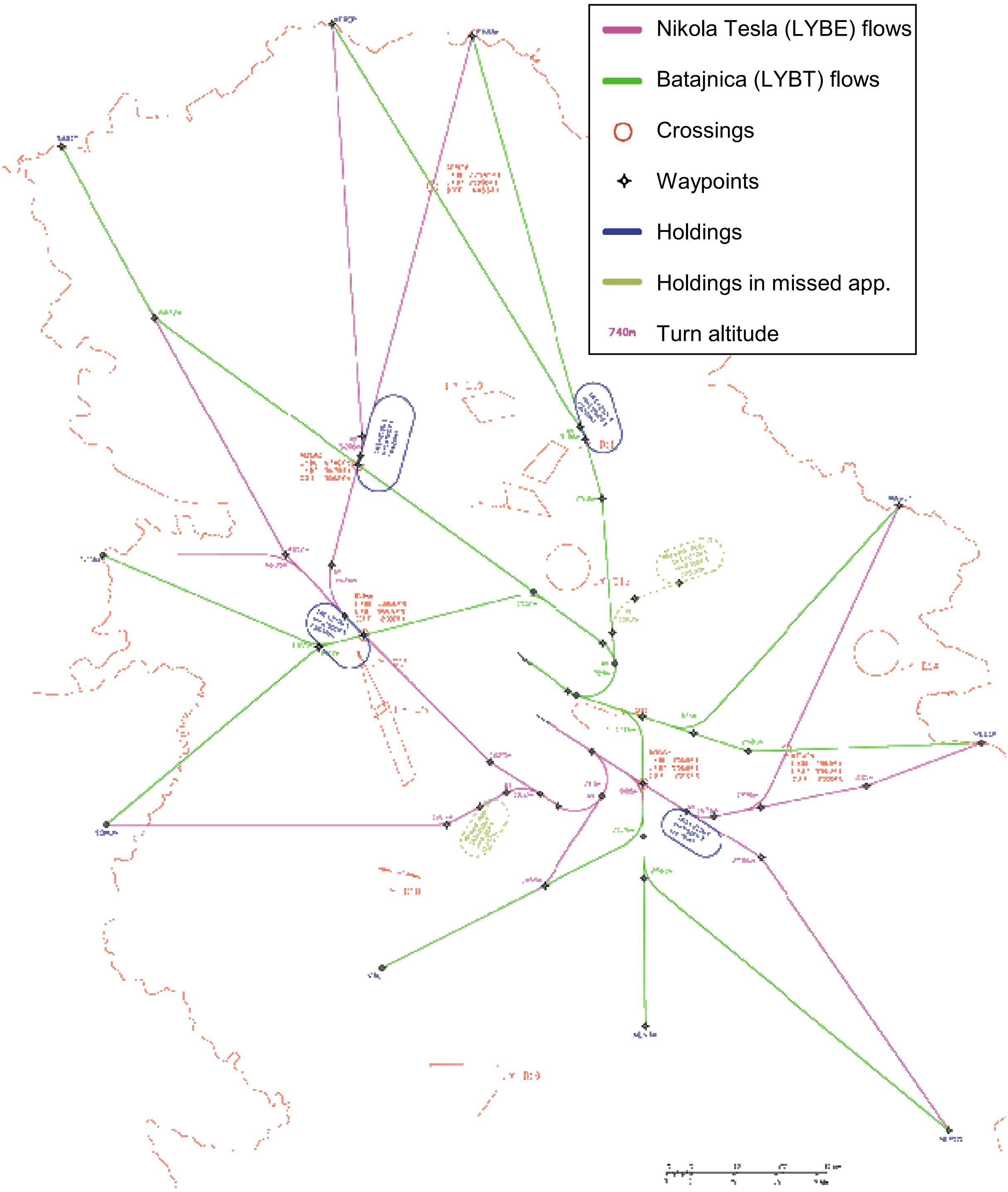


Figure 6: Approach flows to runways 30 and 30R of airports “Nikola Tesla” and “Batajnica”

9. Holdings

All holdings, including both in approach and in missed approach for both airports are defined in accordance with RNP holding criteria. Speed in holdings is limited to IAS=210kt everywhere, and the other parameters change depending on a specific holding.

Holdings in approach are defined mostly on crossings of approach flows to LYBE and LYBT in order that aircraft inbound from as many as possible flows could use them. Holding altitudes are determined in the way that upon leaving a holding pattern CDA may be continued smoothly and that vertical separation minima are secured. The maximum holding altitude is determined to suit the higher of the flows that are crossing each other at a holding fix which is then rounded to the first bigger with the step of 100ft. The aircraft inbound from the lower flow will execute holdings on an appropriate lower altitude. Holding waypoints are defined as fly-by to allow direct routing which practically means that an aircraft could proceed to the next waypoint in the procedure regardless of its current position within the holding. Such solution should increase flexibility and contribute to better dynamic response to current traffic situation in the airspace.

10. Final approaches

All final approaches consist of a single TF leg *(Track to Fix)*. Containment area is linear and all its elements are determined by RNP 0.3. Length of this segment for runways 12 and 30 of LYBE and runway 12L of LYBT is 6.5NM (≈12km), and for 30R LYBT it is 6.32NM (≈11.7km) due to nearby areas or restricted flight.

Baro-VNAV is used for vertical guidance. Since there are no obstacles neither in segments of final nor missed approach, decision height is set to the minimal allowed value: DH=75m. However, this decision height is higher than the decision height provided by existing ILS equipment. According to AIP of Republic of Serbia, for LYBE runway 12 and ILS Cat II DH=100ft (≈30,5m). Therefore, in very poor weather conditions the final approaches could be executed with help of ILS. The proposed procedures could be flown by aircraft with on-board navigations systems not featuring automated temperature compensation when the local temperatures are in range from -13,2°C to +14,2°C.

RNP SAAR MS Excel Spreadsheet v.2.0. was used for calculation of the final approaches. As an example, final approach to runway 12L of LYBT is shown in the figure 7 while the other final approaches are done in a similar way. Big numbers next to the flight path show the altitude at which the turn is executed, RF stands for an RF turn and small numbers represent terrain elevation.

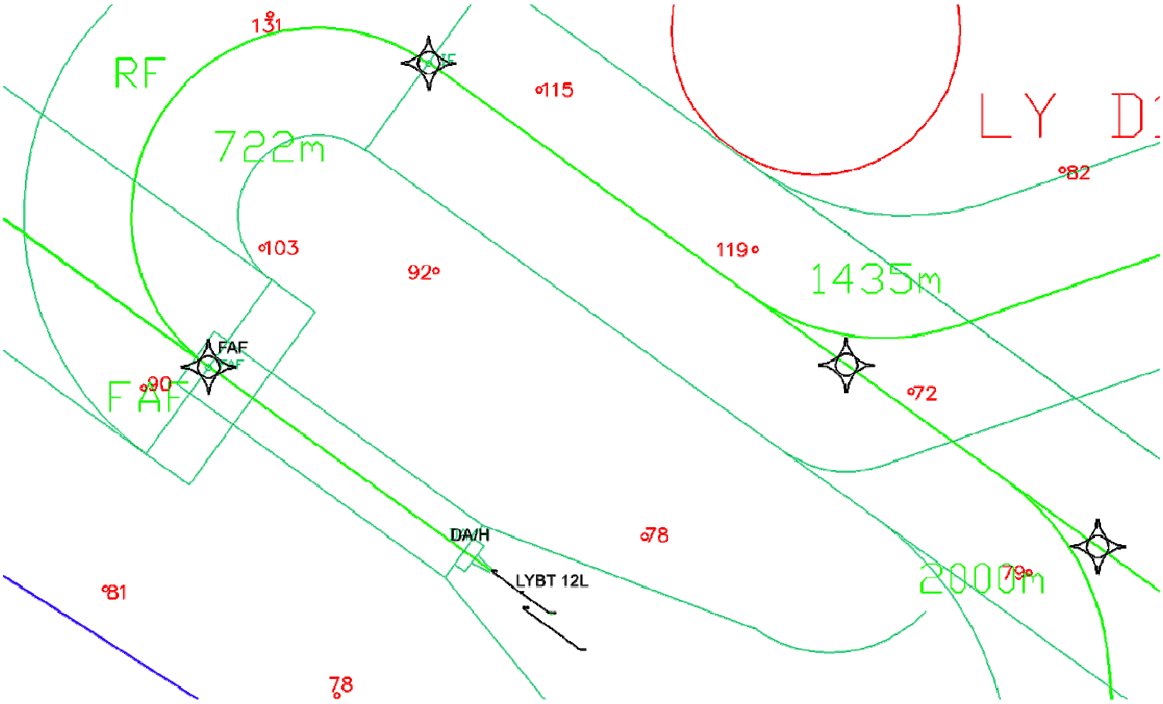


Figure 7: Final approach to runway 12L of “Batajnica” airport

11. Missed approach segments with MAP holdings

A missed approach segment starts from DA/H point in final approach. From that point to the point where the width of the segment reaches ±2RNP, the outer borders of the containment area are at an angle of 15°. A missed approach segment ends at a holding waypoint, by returning of an aircraft to an airway or by a new approach attempt. In design of missed approach segment only TF legs were used for a straight flight and RF legs for turns. The priority was minimisation of total complexity in the segment which is why the minimal number of legs were used and turn amplitude was limited. The standard nominal climb gradient of 2.5% and the standard missed approach RNP value of RNP 1 were used. The turns are not to be made before reaching segment width of RNP 1. Vertical separations at the points where initial or intermediate approach flows cross over the missed approach flow are in range between 829m up to 1593m being in most cases over 1300m.

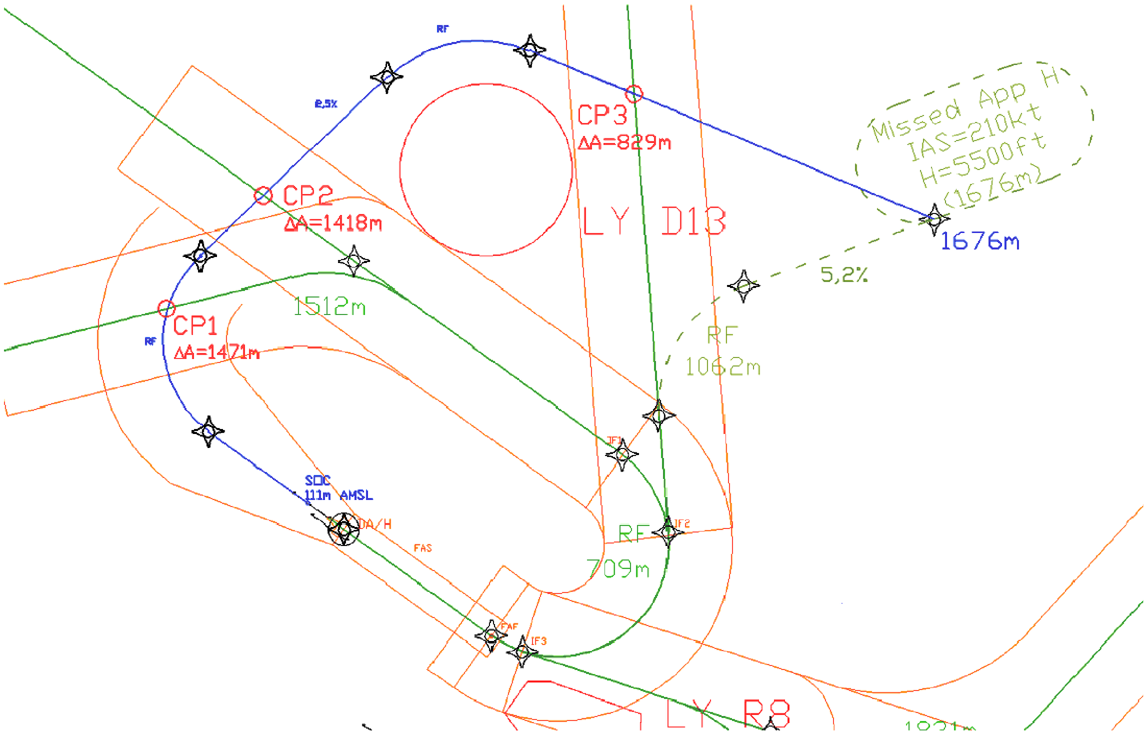


Figure 8: Approach to runway 30R of "Batajnica" airport including the missed approach segment with its holding

As it could be noticed in figure 8, a short path for leaving the missed approach holding and joining to approach flows has been designed. The path consists of a TF leg with descent gradient of 5.2% and of a horizontal turn in an RF leg. At the point where the path joins the approach flow, an aircraft which was flying along the path would have the same altitude as if it had arrived to that point from an approach flow which allows an aircraft to follow the STAR procedure from this point to touchdown without any adaptation being necessary.

Missed approach holdings for a single airport are defined at the same waypoints regardless of the runway in use aiming for increased flexibility and reduced complexity. Immediately upon leaving a holding, an aircraft maintains its altitude until intercepting a 3D flight path defined by STAR and from that point proceeds with its approach according to STAR.

RNP holding waypoint for airport "Nikola Tesla" is defined at the same coordinates where NDB OBR is positioned which could be useful in possible emergency situations.

12. Conclusion

The task of approach and landing procedures desing for airports "Nikola Tesla" and "Batajnica" was a great opportunity of demonstrating potential of modern concepts such as RNP, Baro-VNAV and CDA. Reorganisation of terminal airspace and design of new procedures were needed due to possible introduction of a new runway in use for civil operations.

Reorganisation of terminal airspace was also considered in this paper. Unification of TMA "Beograd" and TMA "Batajnica" was proposed and entry fixes to the new TMA were determined. Approach and landing procedures were designed according to RNP AR APCH criteria. Baro-VNAV is applied for vertical guidance. Vertical profile of the procedures has been optimised as CDA with gradient of 5.2% (3°) as much as possible. All turns except those in missed approach segments are horizontal according to ICAO recommendations. Turn parameters have been calculated for appropriate altitudes in order to fit into CDA profile. An iterative procedure was applied for this purpose.

Holdings in approach segments are designed in accordance with RNP holding criteria. They are positioned in a way which allows aircraft to attempt a new CDA by following a STAR procedure without any adaptations upon leaving a holding. Also, an aircraft is able to leave holding from any position since the holding fixes are defined as fly-by waypoints.

Implementation of RNP AR APCH in combination with Baro-VNAV and CDA at "Nikola Tesla" and "Batajnica" would bring many benefits without any observed negative side effects. As an illustration, one of the numerous benefits is reduction in distance flown from the fix NEPOS (southeast entry fix to the new TMA, already exists) to the threshold of runway 12 of "Nikola Tesla" airport. Following curent conventional approach procedure NEPOS 1A from NEPOS to fix LOGAR and procedures for approach and landing with ILS ILS from LOGAR onwards, it is necessary to fly approximately 189.83km. Following the RNP procedures proposed in this paper, from NEPOS to LYBE runway 12 threshold, 171.67km are to be flown, which is 18.16km or 9.57% less than by the current conventional procedures. Furthermore, it has to be noted that current conventional procedures for LYBE have practically no constraints imposed by the flows inbound to LYBT whereas in consideration of the proposed RNP procedures those constraints were taken account of.

More accurate navigation enables a higher degree of predictability and repeatability of flight paths, smaller protection areas and separation minima than it is the case when conventional navigation is applied. Approach flows now require less airspace since they are structured on a strategic level. Also, thanks to more accurate navigation, now it is possible to design procedures in a way that zones of restricted flight have significantly less influence on approach flows, if not any. Flight safety is also improved thanks to monitoring, alerting and navigation containment functions of RNP on-board navigation systems. Consequently, ATC workload is reduced as less vectoring is needed.

Since there are no high mountains or other obstacles near the airports, an amazing potential of RNP and Baro-VNAV to decrease landing minima has not been emphasised in this case. Decision height for a Baro-VNAV approach is somewhat higher than the one for an ILS approach. Final approaches could be also executed using ILS if needed, but it is good that Baro-VNAV approaches are defined as well since they require only data on local temperature and pressure besides an appropriate operating on-board RNP navigation system.

Significantly higher time and fuel efficiency is obtainable by replacing coventional *Dive &* Drive approaches with CDA. Nowadays, when fuel prices are so high, it is needless to emphasise the importance of increasing fuel efficieny in approach any further. Time savings are important for whole transport system: shorter flights for passengers, rotations and reduced operational costs for airlines etc. Design of RNP procedures is also a step towards a more efficient application of 4D ATM.

The new procedures are more environment-friendly. With more direct and efficient approaches need less time and fuel leading to decreased environmental impact in form of air pollution and noise.

Although SID procedures have not been proposed in this paper, their desing in a more flexible way is enabled by the savings in airspace needed for approaches acheived through optimised STARs.

It can be argued that PBN is definitely a concept of futurewhich brings vast benefits to global aviation, although there are still certain issues that need to be addressed. Implementation of PBN is a complex process, but broad and very positive experience gained through numerous cases where it had been already implemented encourages further efforts. Further standardisation on a global level is essential in order than efficiency of implementation could be improved. It is also important to continue research and development of new long-term solutions to secure efficient operation of global air traffic and transport system in the environment of consantly increasing challenges.

Note

The topic is addressed with far more details in diploma thesis of Vojislav Milosavljević, originally titled *“Procedure za prilaz i sletanje na aerodrome “Nikola Tesla” i “Batajnica” primenom RNP AR APCH i Baro-VNAV”* defended at The Faculty of Traffic and Transport Engineering, Belgrade, Serbia on July, 7th 2008. Detailed calculations, figures, explanations of chosen solutions and other are featured in the thesis available at the library of the faculty.

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References

AIP of Republic of Serbia

EUROCONTROL: *“Eurocontrol Airspace Planning Design Manual”*, Section 5: Terminal Airspace Design Guidelines, Januray 17th 2005

Hullah, Peter, EUROCONTROL Experimental Centre, Brétigny sur Orge, France: *“EUROCONTROL’s “Basic” Continuous Descent Approach Programme”*, Aircraft Noise and Emission Reduction Symposium, Monterey, May, 25th 2005.

ICAO Doc. 9613 Final Working Draft 5.1: *Performance Based Navigation Manual*

ICAO *Required Navigation Performance Authorization Required Procedure Design Manual*, Final Draft ver. 1.0, November 29th 2007.

Naverus Inc. *(http://www.naverus.com),* Case studies, examples of RNP procedures for airports Linzhi (Tibet, China, ZUNZ), Brisbane, Queenstown, Canberra (Australia), Kelowna (CYLW, Canada) and Juneau (Alaska) and comparison of RNP and ILS approaches

Tarbert, Bruce, FAA RNAV and RNP group, *“Area Navigation (RNAV) and Required Navigation Performance (RNP)”*, CDA Workshop, January 19th 2006

Tong, Kwok-on, ATM Boeing Commercial Airplanes, *“Continuous Descent Approach Design for Independent Dual Runway Operation at IAH”,* CDA Workshop, Atlanta, April 18-19 2006.

Glossary

AIP	Aeronautical Information Publication
ANSP	air navigation service provider
APCH	approach
ATM	air traffic management
Baro-VNAV	barometric vertical navigation
CDA	continuous descent approach
CFIT	controlled flight into terrain
DA/H	decision altitude/height
DME	distance-measuring equipment
DTA	turn anticipation distance
FAA	Federal Aviation Administration , the US aviation authorities
FAF	final approach fix
GNSS	global navigation satellite system
GPS	global positioning system
IAF	initial approach fix
IAS	indicated airspeed
ILS	instrumental landing system
IRS	inertial reference system
km	kilometre(s)
kt	knot(s)
LNAV	lateral navigation
LYBE	ICAO designation for airport “Nikola Tesla”, Belgrade, Serbia
LYBT	ICAO designation for airport “Batajnica”, near Belgrade, Serbia
MOC	minimum obstacle clearance

NM	nautical mile
OAS	obstacle assessment surface
OCA/H	obstacle clearance altitude/height
PBN	performance based navigation
RDH	reference datum height
RF	ARINC leg type: radius to fix
RNAV	area navigation
RNP	required navigation performance
RWY	runway
RNP AR	required navigation performance authorization required
SID	standard instrument departure
STAR	standard terminal arrival
TF	ARINC leg type: track to fix
TMA	terminal airspace
TSE	total system error
Vat	speed at threshold
VNAV	vertical navigation
VOR	very high frequency omni-directional radio range
VPA	vertical path angle