NEW PBN PROCEDURES FOR KUNOVICE AIRPORT COMPUTER SIMULATION

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Summary: The article aims to investigate an impact of new STAR procedures intended to be implemented on the Kunovice airport (LKKU) compared with current state. The new Standard instrument Arrivals (STARs) and Departures (SIDs), which were designed according to the Performance Based Navigation (PBN) concept, are expected to bring benefits such as increased airspace capacity, flexibility or ATC controller workload decrease. The new procedures design is presented in first part of the article.

In the second part, the article introduces the simulation tool Visual Simmod used for simulation experiment. The simulations on the models of new and current design on the several traffic samples are performed and the results are analyzed.

Key words: area navigation, delay, PBN, RNAV, RNP, SID, simulation, STAR, Visual Simmod

INTRODUCTION

In May 2013 were introduced new RNAV SID and STAR procedures for Brno-Turany airport (LKTB). In February 2014 were published new LPV approaches for runway 28/10 of the LKTB. Subsequently to above mentioned changes in the TMA Brno were designed new procedures for Kunovice airport (LKKU) which is the second airport with instrument procedures located in the CTA Brno. The new SID, STAR and LPV procedures were introduced in earlier articles (1), (2) and (3) .

This article aims to present a result of an effort to investigate an impact of new procedures design on overall traffic within the TMA Brno. For this purpose, fast time simulations were used as one of the possible ways how to test new procedures. As a tool was chosen software known as Visual Simmod, the tool to simulate both airspace and ground movement of aircraft.

The expected output of the study is a comparison of quality of the service provided by the current conventional and newly designed procedures. Quality of the service provided by a traffic system is usually expressed by level of delay change with the changing number of elements (aircraft) entering the model.

1. NEW RNAV PROCEDURES DESIGN FOR LKKU

As mentioned above, in earlier articles were presented various studies of new RNAV PBN based SID and STAR procedures for LKKU 21C/03C runway. Also new LPV

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approaches were designed and introduced (1), (3). All of the new LKKU procedures, same as in case of LKTB, are intended to comply with PBN RNAV-1 navigation specification supported by GNSS only. Let's make a recapitulation of new RNAV procedures layout.

1.1 LPV approach and RNAV STARs runway 03C

The design of a horizontal shape of the RNAV arrivals is based on the intended position of the initial approach fix (IAF). In the case of runway 03C of the LKKU, there were investigated two variations, which differ in solution of arrival from the waypoint MAVOR and in number of IAFs used for approach.

The first variation uses only one IAF located in the south-west direction from the runway 03C threshold. In this case the MAVOR arrivals cross the runway axis using the current NDB-KNE as RNAV wyapoint. The advantage of the solution with one IAF is in the simplicity of this configuration. The disadvantage can be found in the trajectory length from MAVOR and the necessity of the runway axis crossing.

The second variation has two IAFs placed on both sides of the runway axis. In this case the aircraft arriving from MAVOR waypoint doesn't cross runway axis. Compared to the first option, the length is expected to be shorter. The risk of this solution can be found in too short distance to descent from MAVOR to intended final approach fix (FAF) which is expected to be in altitude 2500 ft and in the height of the terrain in this particular part of the TMA. This would result in inappropriate minimum flight altitudes (MFA). Other disadvantage is the horizontal shape due to its segments lengths and number of turns in the procedure.

After all advantages and disadvantages were taken in account the idea of two IAFs were found as inappropriate and was abandoned and further were developed only the first option. Both mentioned possibilities are shown in the Figure (Fig. 1).
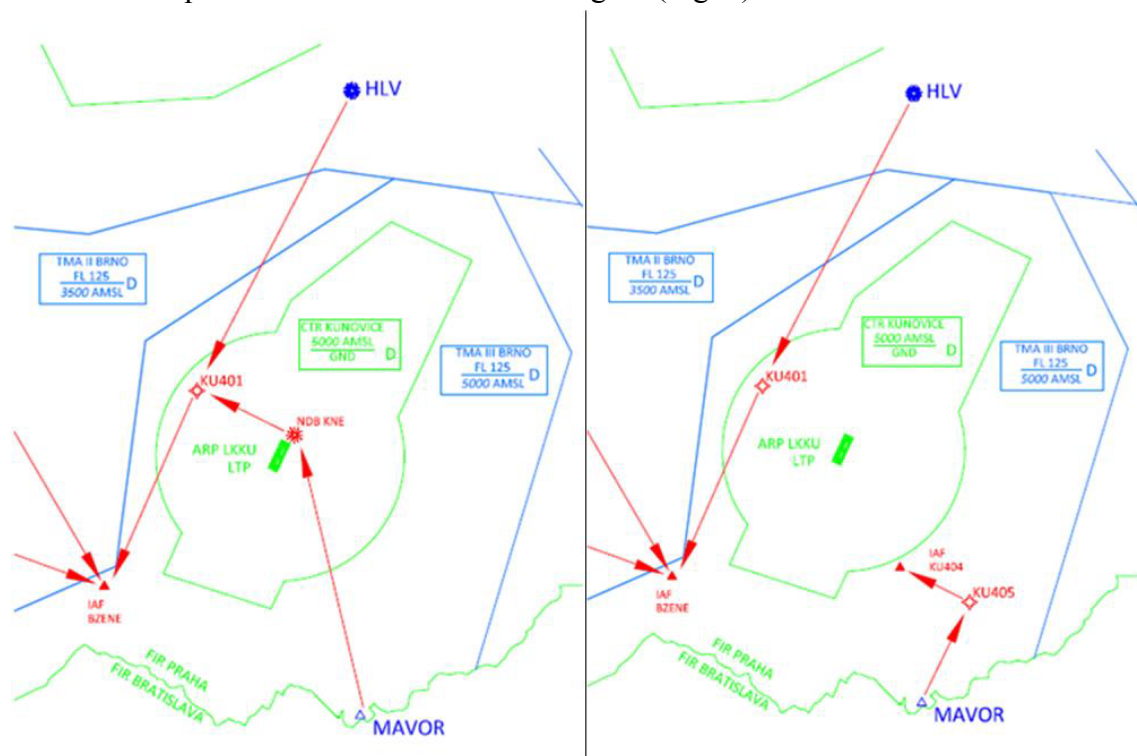
Source: Author

Fig. 1 - Two variation of RNAV STARs for runway 03C of LKKU

As soon as the final shape was known, the procedures development started from design of approach procedure. The intention is to do provide a shape of the approach which has the both values vertical path angle (VPA) and FAF height same as current NDB approach for runway 21C. The reason for this was to maintain continuity with current practices. The result is a new design prepared in accordance with PBN adapted to the requirements of airspace users and local conditions. The final layout of runway 03C RNAV arrivals and approach shape is depicted in the Figure (Fig. 2).
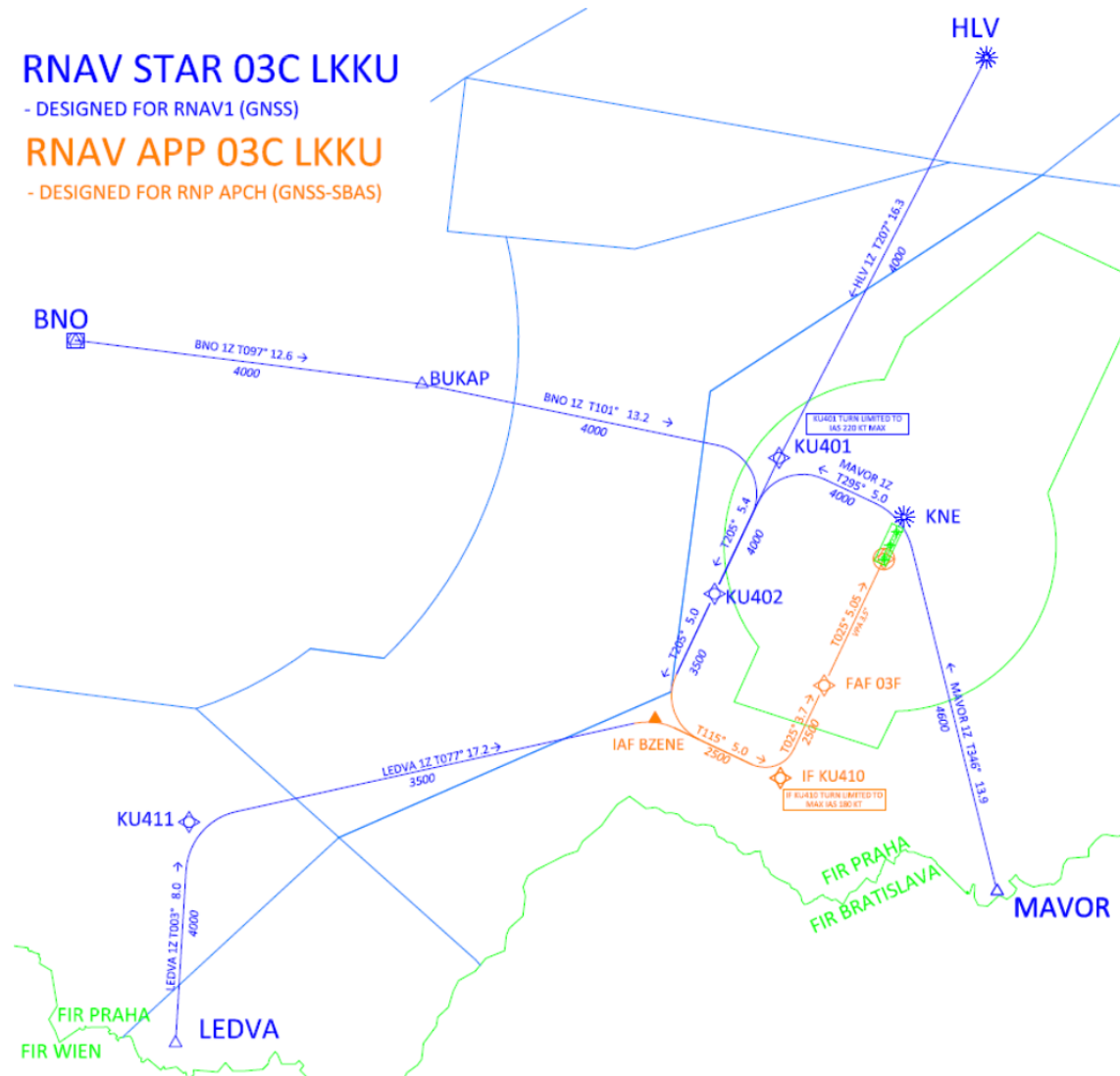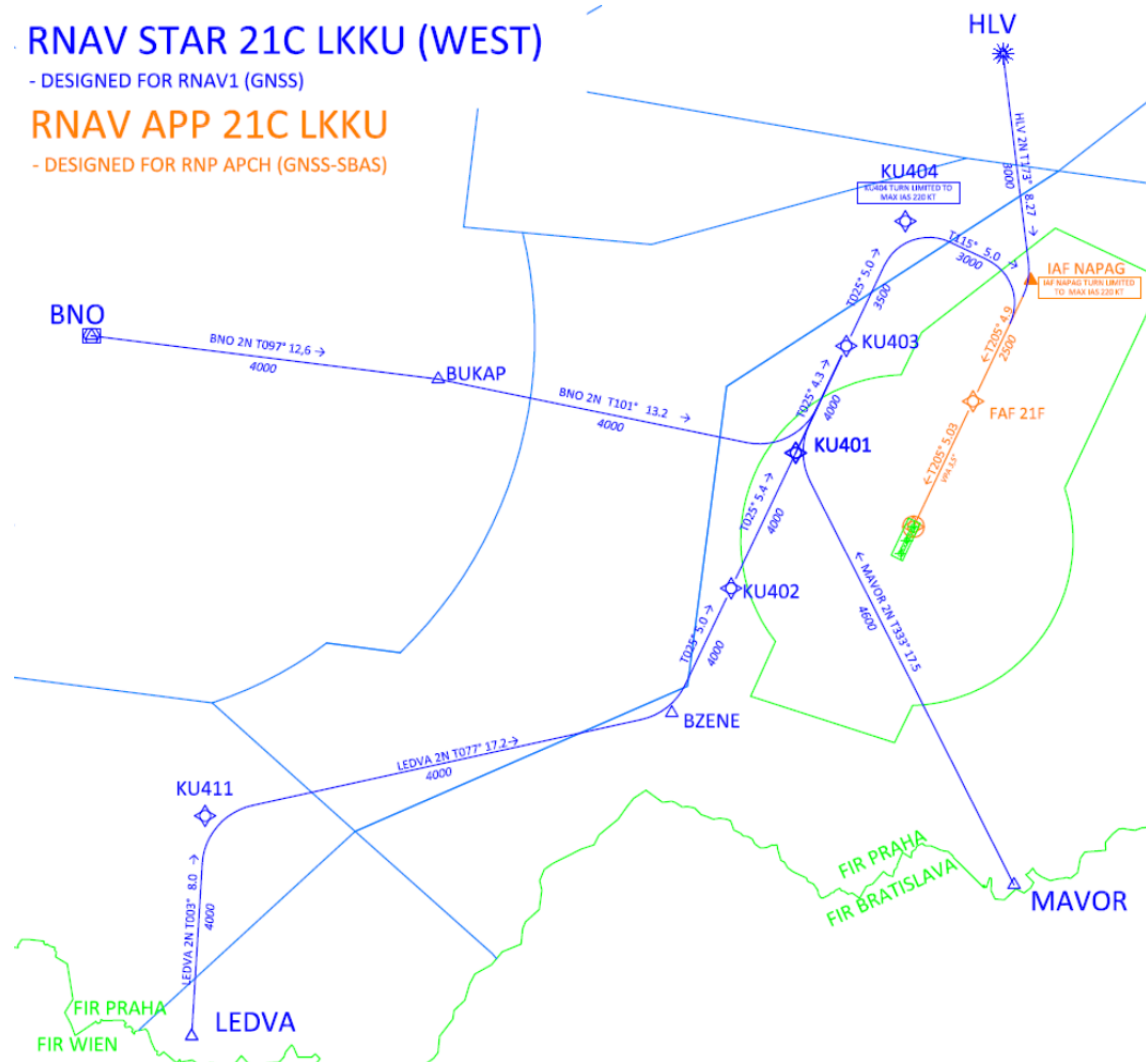

Source: Author

Fig. 2 – New proposal of runway 03C RNAV arrivals and approach

1.2   LPV approach and RNAV STARs runway 21C

The practice in designing the STAR and approach procedures for runway 21C is analogous compared to the runway 03C procedures design. To assumptions mentioned were added to use current waypoint NAPAG as an IAF for intended RNAV approach. This resulted in the design of STAR and approach shown in the Figure (Fig. 3).

Source: Author

Fig. 3 - New proposal of runway 21C RNAV arrivals and approach – variation West

There was also prepared an alternative version of STAR procedures with the downwind phase conducted in the east direction of the runway axis. The advantages of that solution are that the arriving aircraft doesn't need to fly over the Otrokovice VFR airport (LKOT) and the downwind phase is whole "sheltered" by the CTR Kunovice. The disadvantage of the east variation is that the east part of the CTA Brno is intended for test-flights of the Aircraft Industries Company and for the VFR flights. The higher minimum radar vectoring altitude can be also considered as slight disadvantage. The East alternative is shown in the Figure (Fig. 4).
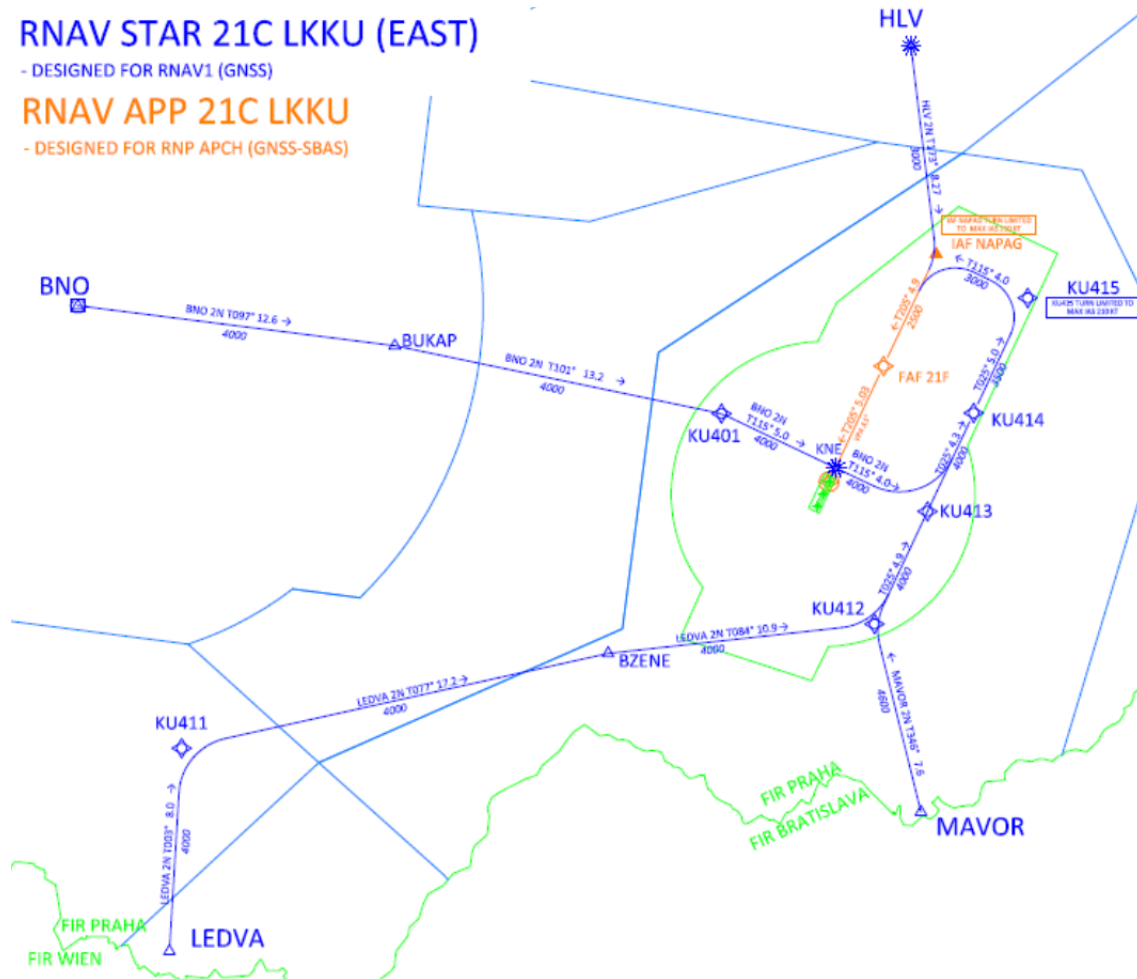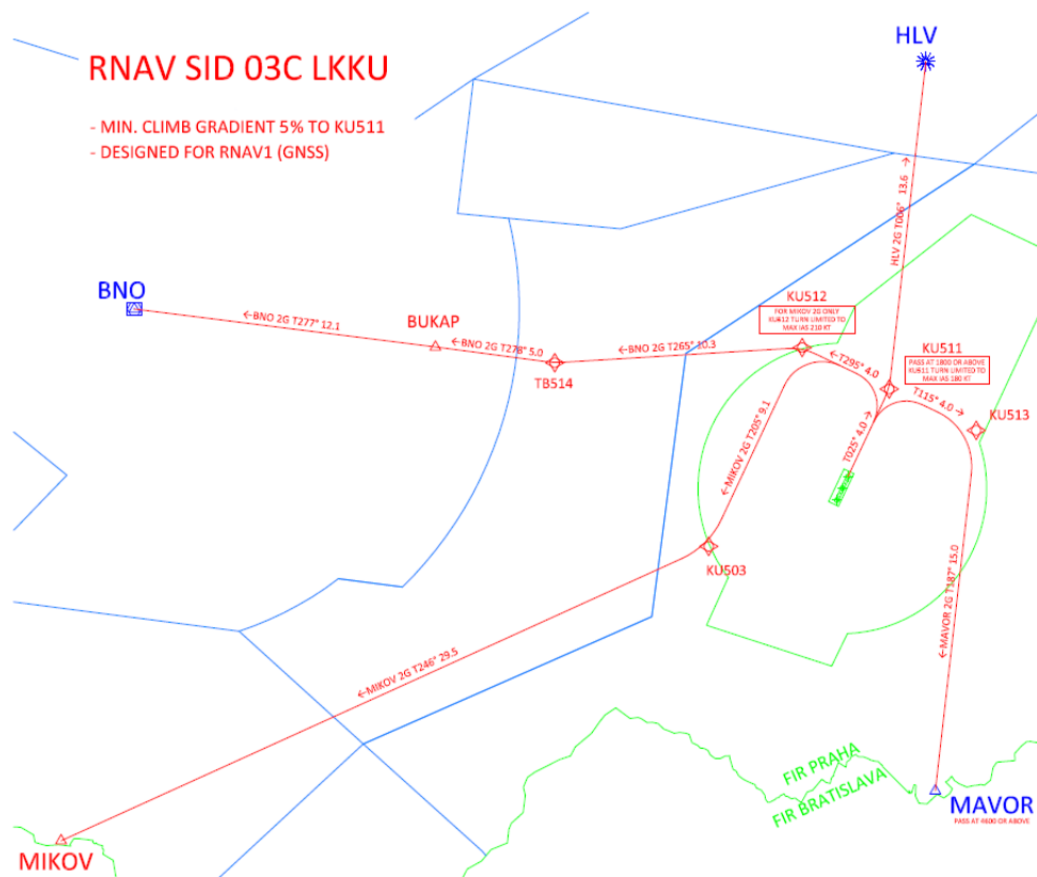

Source: Author

Fig. 4 - New proposal of runway 21C RNAV arrivals and approach – variation East

1.3 RNAV SIDs runway 03C and 21C

The basic purpose of any type of Standard Instrument Departure (SID) is to secure the trajectory of departing aircraft from Departure End of the Runway (DER) to first route waypoint or fix. The SID procedure is also intended to let the plane accelerate, climb to cruising level, separate it from arrivals and obstacles.

The implementation of RNAV procedures for LKTB airport led also to increased activity in design of SID for LKKU. This is due to inconvenience between new LKTB RNAV procedures and current LKKU SIDs caused by utilization of some of former LKTB waypoints or fixes (NESVO, BOLMU). This affects the effectiveness of use of the airspace, airtraffic controller workload, capacity or safety. One of the high-level requirements from airspace users was to reduce this inconvenience providing new departure routes design which will allow higher harmonization between LKTB and LKKU. Another requirement was to reduce current dead-reckoning (DR) after takeoff stages. The most appropriate solution is to utilize RNAV-1 PBN specification with GNSS support.

Specifically, the departures to BNO waypoint will share waypoints TB514 and BUKAP with LKTB runway 28 arrivals. On the other hand, the departures to the MIKOV waypoint will be now horizontally separated from LKTB arrivals. Departures to HLV waypoint was designed as simply as possible. MAVOR departures are conducted in the east side of the runway axis compared to current state in both runway 03C and 21C. The layout of new RNAV SID for runway 03C and 21C is depicted in the Figures below (Fig. 5, 6).

Source: Author

Fig. 5 - New proposal of runway 03C RNAV departures
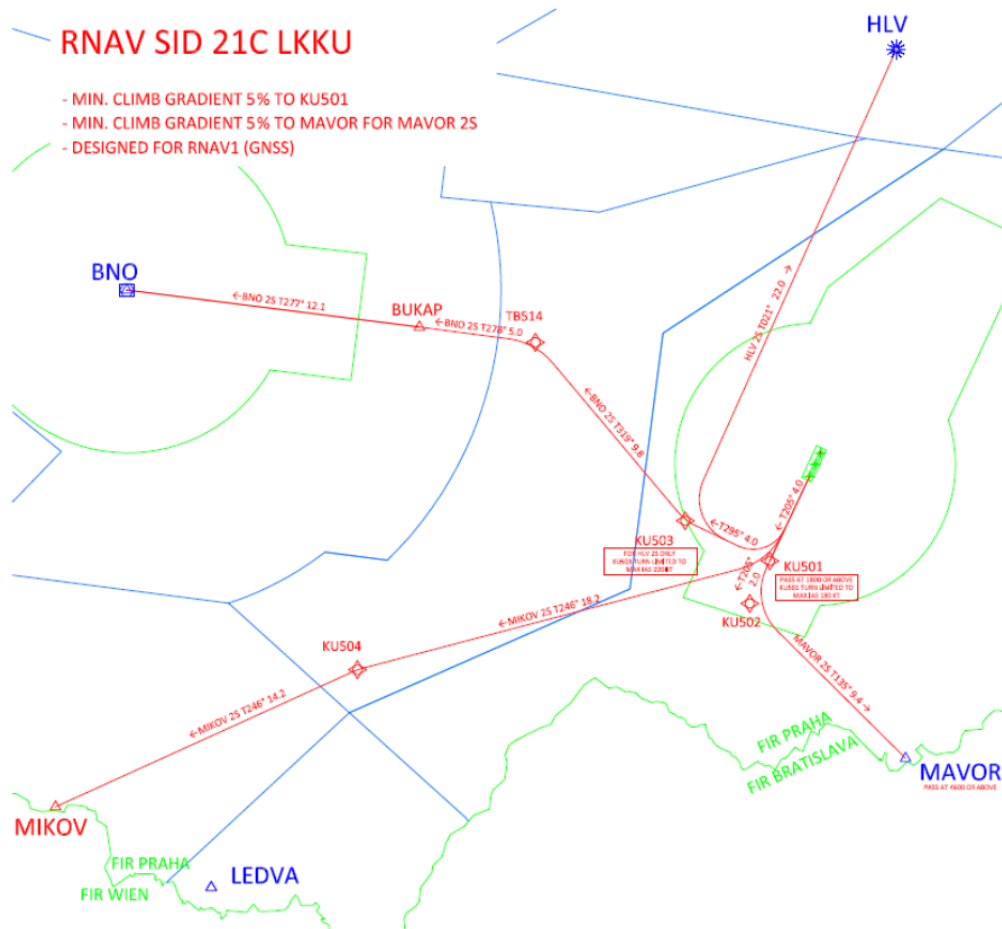
Fig. 6 - New proposal of runway 21C RNAV departures

2. VISUAL SIMMOD – SIMULATION EXPERIMENT

Visual Simmod is a product of AirportTools, Inc which was founded in 2001. In about four years it has been developed a set of tool intended to simulate both airfield and airspace operations based on utilization of SIMMOD (FAA's Airport and Airspace Delay Simulation Model) model (4).

The principle is built up on event-step simulation with individual aircraft tracing on the node-link structure model. The model provides the possibility of adjustment the procedural rules as an intrail node separation, link capacity, aircraft type airborne speed range etc. The Visual Simmod software enables to measure individual aircraft delay along its intended route. The data to analyze after particular simulation run are provided through Simmod Reporter, one of the Visual Simmod modules. For further analysis the Simmod Reporter outputs are provided in Comma Separated Values (CSV) format compatible with variety of spreadsheet applications. In intended post experiment data processing we will focus on the total airborne delay, as most important indicator of airspace system capacity.

2.1 Simulation model of LKKU TMA procedures

The experiment is based on measurement of different airborne delays for three LKKU SID/STAR configurations with changing number of aircraft entering the model during one

simulation hour. The idea is to compare behavior of traffic simulation of current conventional procedures and new RNAV – PBN routes. There were assembled and adjusted four different models in Simmod Network Builder (Fig. 7):

- Model 1 – Conventional SID/STAR/approach runway 21C
- Model 2 – RNAV SID/STAR - WEST /APV approach runway 21C
- Model 3 – RNAV SID/STAR - EAST /APV approach runway 21C
- Model 4 – RNAV SID/STAR/APV approach runway 03C
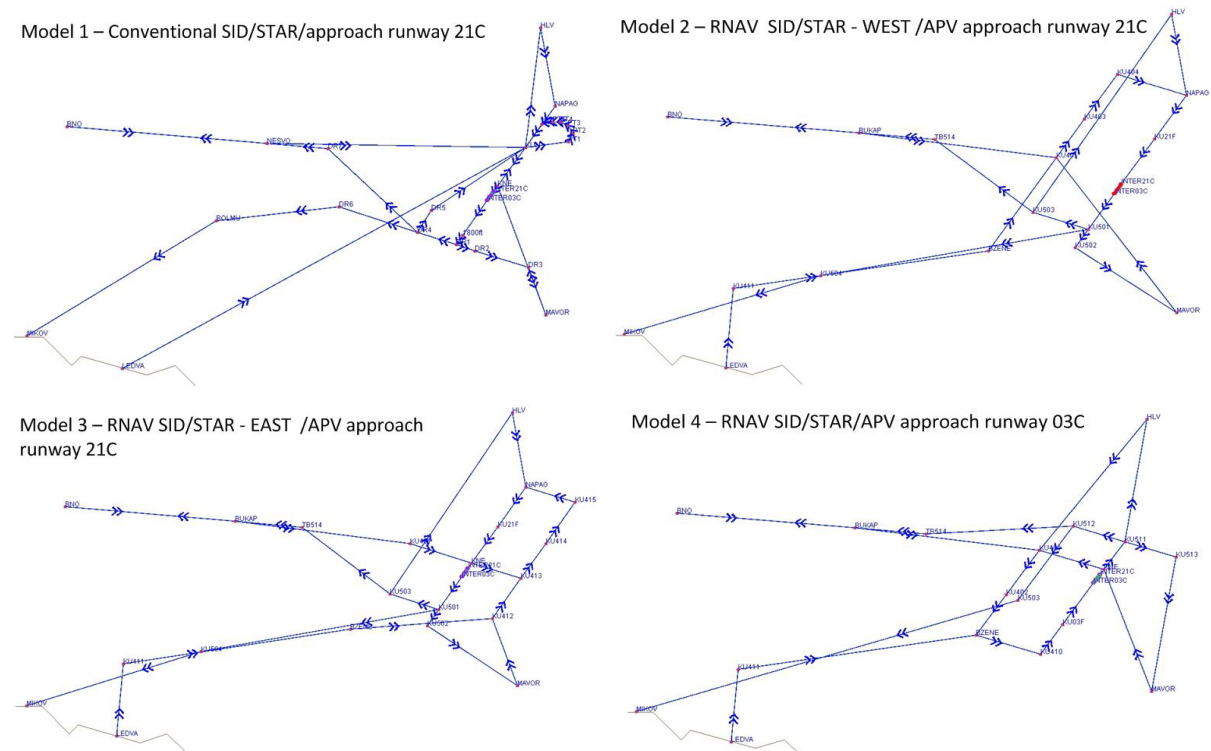
Source: Author

Fig. 7 – LKKU airspace models in Visual Simmod Network Builder

2.2 Model setup description

All four models need to be set before simulation. Visual Simmod allows to an user adjustment of many input parameters. For the LKKU study purposes there is major focus on the airspace logic setup. First of all it is necessary to define the aircraft movement control strategy. The strategy used significantly affects the traffic flow behavior and consequently the total airborne delay. The Aircraft movement control strategies in Visual Simmod are classified as follows:

- Level I – Node arrival control
    - o Type 1 - QFIFO
    - o Type 2 – SpeedFit
    - o Type 3 – MultiFit
- Level II – Metering control
- Level III – Flow control

From above mentioned aircraft control strategies the Level I is mandatory for all nodes in model while Levels II and III are optional. The principle of Node arrival control (Level I) is based on arrival queue compilation for each node in the model. Depending on the Type used, Simmod drives arriving aircrafts.

The simplest type is the QFIFO where the aircrafts entering the arrival queue is always put in the end of the queue. Algorithm then assesses if the Time Of Arrival (TOA) to the specified node corresponds with required intrail separation. When the separation is threatened, the aircraft is slowed down or vectored to achieve appropriate TOA. If speed change or vectoring is not enough, the aircraft holds on the preceding airspace node. Nevertheless, the position in the queue remains the same till the airspace node is sequenced.

The other two types, SpeedFit and MultiFit, assess TOA in the same manner as QFIFO with the difference that Type 2 and 3 can place the new entering aircraft not only in the end of the queue. This difference is most visible by the merging trajectories with different lengths of merging links. SpeedFit logic tries to find best position in the queue using speed adjustments and vectoring of the appropriate aircraft. The MultiFit algorithm drives the arriving aircraft queue placement using additional speed adjustment, vectoring and holding of the preceding and succeeding aircraft.

For purposes of presented study, it was used Level I-MultiFit (Type 3) control strategy due to its behavior that is most similar to the real air traffic controller. The optional Levels II and III were not applied. More detailed description of the Visual Simmod aircraft movement control is available in the Visual Simmod reference documentation (5).

2.3 Traffic sample

When the model of airspace is created and rules are set it is time to determine the simulation run strategies. The goal of this study is to find an impact of proposal of change from conventional to PBN procedures for the Kunovice airport. The simulation strategy is given by the output investigated. In the case of LKKU study, the measured response is the total airborne delay on four LKKU airspace models presented earlier. The intended simulations are performed with six different traffic samples for each model. The entry-exit waypoints (HLV, MAVOR, LEDVA, MIKOV, BNO) traffic distribution is based on LKKU traffic statistics in 2012 and 2013. The time interval between two aircraft entering the same procedure is constant. The value of time interval depends on total number of aircraft and entry-exit waypoint. According to traffic statistics as a representative aircraft type has been chosen Cessna Citation-3 business jet. The traffic sample data are presented in the Table (Tab. 1).

Tab. 1 – Traffic data samples

	SAMPLE 1		SAMPLE 2		SAMPLE 3		SAMPLE 4		SAMPLE 5		SAMPLE 6	
NUMBER OF MOVEMENTS [number/hour]												
ENTRY/EXIT WAYPOINT	**8**		**16**		**30**		**44**		**54**		**62**	
	ARR	DEP	ARR	DEP	ARR	DEP	ARR	DEP	ARR	DEP	ARR	DEP
HLV	1	1	2	2	3	3	5	5	6	6	7	7
MAVOR	1	1	1	1	2	2	3	3	4	4	5	5
LEDVA (MIKOV)	1	1	2	2	4	4	6	6	7	7	8	8
BNO	1	1	3	3	6	6	8	8	10	10	11	11
Time interval [min]												
HLV	60		30		20		12		10		8.6	
MAVOR	60		60		30		20		15		12	
LEDVA (MIKOV)	60		30		15		10		8.6		7.5	
BNO	60		20		10		7.5		6		5.5	

Source: Author

2.4 Results and analysis

There were performed six simulation runs for each of the four models defined in the Visual Simmod. The observed output parameters are following:

- TAT – Total Airborne Time (Sum of all airborne times of all aircraft including delay)
- UAT – Undelayed Airborne Time (Sum of all airborne times of all aircraft excluding delay)
- TAD – Total Airborne Delay (see Equation (1))

$$TAD = TAT - UAT \tag{1}$$

- TAD/TAT – The percentage contribution of TAD to TAT
- Delay per aircraft – Average delay of one single aircraft
  Measured output parameters are presented in the Table (Tab. 2).

Tab. 2 – Measured output parameters

| SAMPLE		SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	SAMPLE 6
NUMBER OF MOVEMENTS [number/hour]		8	16	30	44	54	62
Model 1	TAT [hours]	1.19	2.52	4.77	8.57	9.02	12.37
	UAT [hours]	1.14	2.43	4.52	6.00	3.54	3.62
	TAD [minutes]	2.88	5.26	14.79	154.47	328.53	525.23
	TAD/TAT [%]	4.03	3.48	5.17	30.03	60.73	70.74
	DELAY PER AIRCRAFT [minutes]	3.08	3.24	6.43	49.31	38.34	26.86
Model 2	TAT [hours]	1.32	2.76	5.34	7.80	10.50	13.49
	UAT [hours]	1.31	2.74	5.26	7.52	9.28	10.59
	TAD [minutes]	0.38	1.02	4.61	16.90	73.33	174.16
	TAD/TAT [%]	0.48	0.61	1.44	3.61	11.64	21.52
	DELAY PER AIRCRAFT [minutes]	0.40	0.63	2.01	5.40	8.56	8.91
Model 3	TAT [hours]	1.34	2.89	5.58	8.08	10.52	13.54
	UAT [hours]	1.33	2.84	5.45	7.82	9.62	10.89
	TAD [minutes]	0.75	2.82	7.70	15.18	54.06	158.84
	TAD/TAT [%]	0.94	1.63	2.30	3.13	8.57	19.55
	DELAY PER AIRCRAFT [minutes]	0.81	1.73	3.35	4.85	6.31	8.12
Model 4	TAT [hours]	1.49	2.94	5.43	8.03	10.73	14.34
	UAT [hours]	1.33	2.74	5.22	7.56	9.20	10.41
	TAD [minutes]	9.67	11.59	12.90	28.00	91.40	235.88
	TAD/TAT [%]	10.81	6.58	3.96	5.81	14.20	27.41
	DELAY PER AIRCRAFT [minutes]	10.34	7.13	5.62	8.94	10.67	12.06

Source: Author

From measured parameters has been assembled a graph of TAD behavior with changing number of movements per hour (see Fig. 8). As expected, the TAD of Model 1 (current procedures) shows earlier increase when compared to Models 2, 3 and 4. In addition, its absolute value is significantly higher when the number of movements per hour crosses value 30. This is caused by the principle of conventional manner of navigation, thus necessity of overflying the ground navaid. In this case, it is the NDB KUN where it is generated a considerable portion of the TAD.
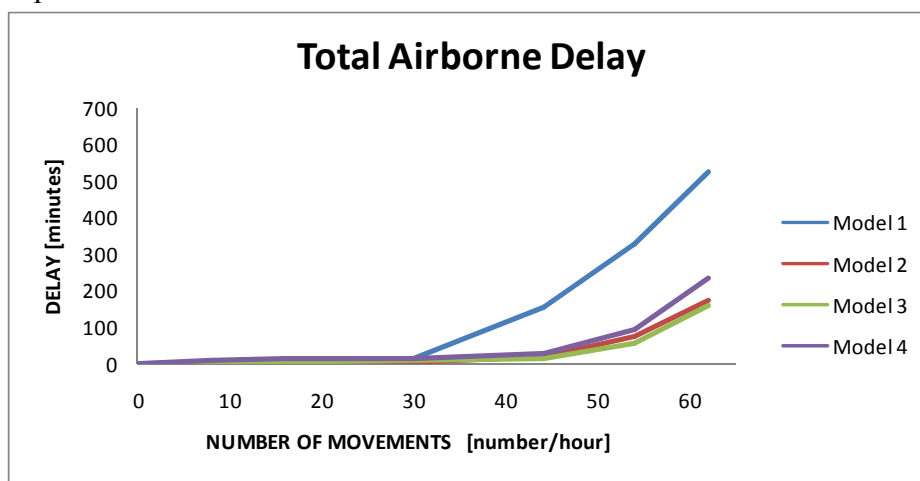
Source: Author

Fig. 8 – Modeled Total Airborne Delay (TAD)

Interesting findings have arisen when the TAT and UAT behavior was investigated (see Fig. 9). The expectation was that with increasing number of movements UAT will increase almost linearly with non-linear change in TAT (caused by delay increase). This expectation was fully fulfilled with exception of Model 1. The decrease of UAT indicates that there were some aircraft without airborne time. In this particular case, for Samples 5 and 6 there no departing aircraft allowed taking off due to permanent runway blocking by landing aircraft. Simmod detected a ground gridlock and rejected all departures from the simulation. This can be evaluated as a system collapse. On the other hand, the models of new procedures (Models 2, 3, 4) show stable and expectable behavior even beyond the number of movements level where Model 1 collapsed. This is a strong argument for PBN support.
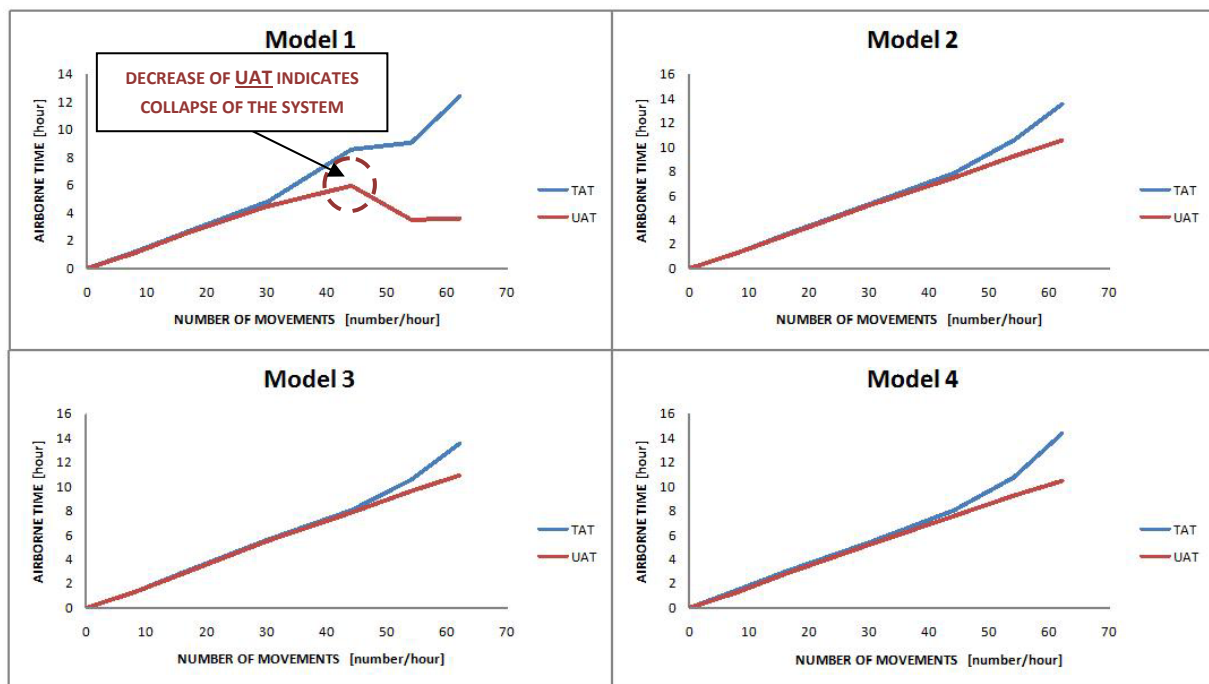
Source: Author

Fig. 9 - TAT and UAT behavior

CONCLUSION

Increasing navigation performance across the civil aviation gives a good chance to utilize evolution of GNSS. It brought more possibilities for small airports increase their operational availability than in the past. The important role plays the concept of PBN. It covers these opportunities and provides set of navigation specifications which define particular procedure requirements on onboard area navigation system functionalities as well as on airspace planning and procedure design.

This article aims to show advantages of PBN for the TMA procedures using the fast time simulation tool called Visual Simmod. During the experiment there were tested different compositions of TMA procedures for LKKU airport. The simulations were conducted on the six traffic samples differing in number of movements per hour. On the basis measured data provided, it was performed a comparison analysis of new PBN based procedure layouts with current conventional SID and STARs. The analysis showed strong benefits of PBN in terms

of airspace use flexibility and capacity. It can be also expected the subsequent benefits such as decreased air traffic controller workload, increased safety or fuel consumption.

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