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INTRODUCTION OF DIFFERENT SPECIFICATIONS OF NAVIGATION POSITIONING ACCURACY BASED ON THE PBN PERFORMANCES BY THE DME/DME

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Abstract. *The article describes the strategy implementation of performance based navigation in Ukraine. The authors investigated the accuracy of the aircraft position using DME/ DME as a navigation aid and the possibility of simplifying the construction zone correction for a given accuracy. The simulation results on prescribed accuracy zones defining with the aid of program developed by the authors of the article are provided.*
Keywords: application of DME/ DME; DME beacon; navigation specification; performance based navigation.

1. Introduction

In the CEE region, the need for air navigation services is constantly increasing. In Ukraine, the number of passenger traffic by 12 months compared to the same period in 2010 increased for 36.7% (Fig. 1). It is expected that this trend will continue in the coming years (according to the Department of Economics and Finance of the State of Ukraine).

All states are faced with the need to solve the problem of safely increasing capacity, efficiency and access to the airports. These restrictions are caused mainly due to the dependency on conventional navigation aids (e.g., VOR, DME, NDB), limiting routes and procedures for the physical location of ground navigation aids. Obviously, increasing the capacity of an Air Traffic Management (ATM) is necessary to serve future traffic flows and to increase the efficiency of operations.

At the 36th Session of ICAO in Assembly Resolution A36/23 it was agreed that from 2009 all countries should have a Performance Based Navigation (PBN) implementation plan to ensure global harmonization and coordinated transition to PBN in 2016.

This resolution was replaced in 2010 by the Resolution of the 37th Assembly of ICAO A37/11 with the following requirements:
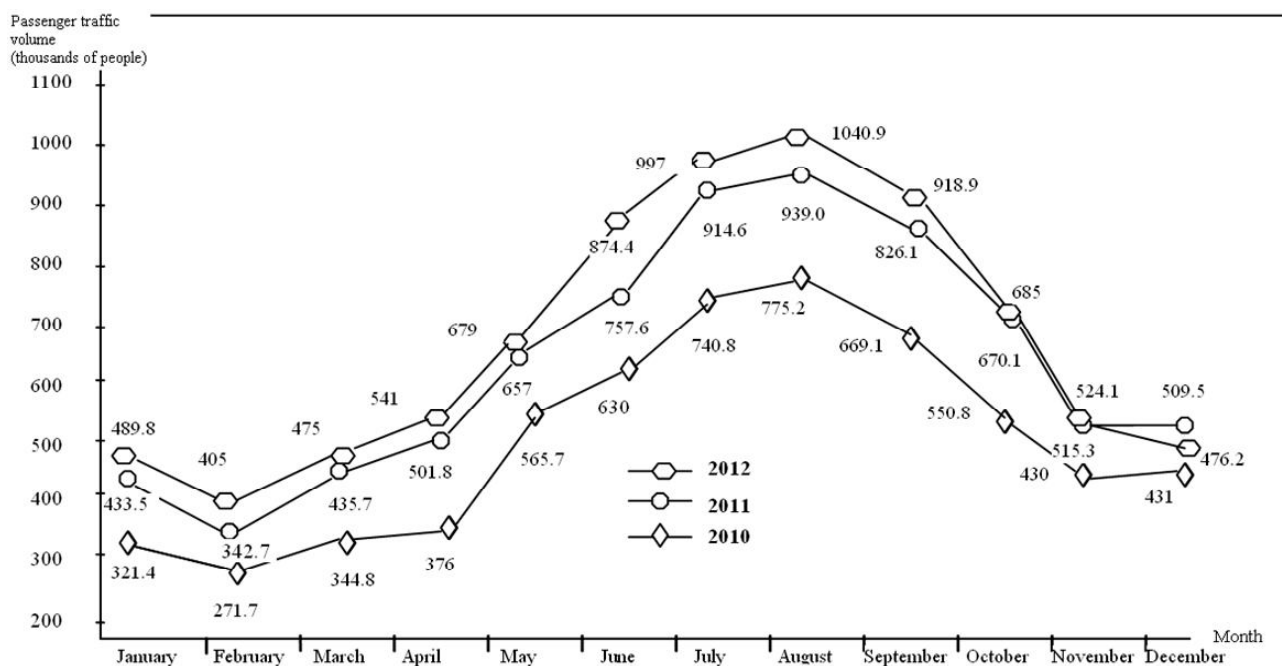

Fig. 1. Dynamics of monthly passenger traffic by air transport in Ukraine, thousands of passengers

— the introduction of flights based on RNAV and RNP (where it is necessary) on the route and terminal areas according to the established deadlines and intermediate stages of control;

— implementation of approach procedures with vertical guidance (APV) (Baro-VNAV and / or GNSS with augmentation), including only the minimums for LNAV from all ends of the runway is equipped as the main approach procedures or backup schemes for accurate augmentation), including only the minimums for LNAV schemes for accurate measures for landing by 2016 with intermediate stages:

— 30% by 2010, 70% by 2014;

— implementation of straitening approach procedures only on LNAV bases, as an exception to paragraph 2 above for equipped for instrument approach runway at airports where there is no local installation altimeters and no aircraft is properly equipped for APV with a maximum take-off weight 5700 kg or heavier.

Through the implementation of PBN and GNSS technologies MCA seeks to promote more efficient usage of airspace and greater flexibility in drawing up schemes that together lead to the improved safety, capacity, predictability, operational efficiency, fuel economy and environmental impact.

2. PBN Implementation Strategy in Ukraine

The strategic objective of PBN implementation in Ukraine is the usage of RNAV or RNP in accordance with ICAO EUR Regional Planning for PBN, in which the performance benefits are achieved with respect to air traffic capacity, safety, efficiency, and / or the environment.

In order to develop a strategy of PBN implementation in Ukraine and to ensure that the coordination of an appropriate roadmap a Ukrainian Working Group on PBN was created. The group involved representatives from relevant authorized agencies (civilian and military) and the aviation industry concerned (airlines, airports, ATC providers, ASTC Antonov, NAU) (Fig. 2) [3].

Objectives of implementation have been established at the regional level in the Regional Air Navigation Plan, ICAO EUR and concepts of SES II and SESAR ATM, relating to air traffic services, airspace and flow control.

Legal framework of Ukraine and aviation regulations should establish the basis for certification of airborne equipment; approve safety

Fig. 2. Roadmap for PBN implementation in Ukraine

circuits of operations in accordance with PBN and operating permissions for operators and crew members.

The State should be prepared to consider applications for certification and issuance of permissions, and to properly consider the conditions for their issuance. During the transition, an ATC system must serve as a wide range of characteristics of an aircraft, which can vary from basic navigation VOR / DME to modern aircraft avionics and FMS GNSS. Aircraft equipped by RNAV with the respective characteristics shall be served by air traffic controllers for the provision of benefits compared to aircraft that do not have RNAV equipment.

Strategic Roadmap summarizes principles that should be applied for the implementation of PBN; it contains a description of the various navigation applications and determines future actions of authorities and the aviation industries.

3. Current status of PBN implementation

The State has recently approved the preliminary plan for implementing short-term PBN. Ukrainian Aeronautical Information Service (AIS) has published aeronautical information Circular (AIC

05/11 dated 10 November 2011) containing information about entering navigation based on characteristics (PBN) in the terminal airspace of Ukraine. By the State Program of Ukraine's airspace for 2010–2014 years included a number of measures to implement RNAV.

In order to implement the characteristics of RNAV 1 (P-RNAV) to work in the appropriate TMA (TMA) a working structure at the regulator was defined and a working group was set up.

For input circuits of RNAV and RNP a distinction in the following areas is made:

I. On the route.

II. Terminal area, including the arrival and departure routes.

III. Approach and landing.

In 1998, B-RNAV became mandatory as the main mean of navigation on the route across the airspace of ECAC, from flight level FL95 or above, with the VOR / DME available where a prediction is necessary for backward navigation and for use in domestic ATS routes in the lower airspace

— ICAO Coordination Group on the European Development Program recommended route segment (UIR) in the airspace of Ukraine to coordinate in accordance with the European plan. The applicable principles to implement PBN en-route (UIR):

— RNAV-5 (current B-RNAV) will gradually be removed from usage and will be followed by the application of RNAV-1;

— Requirements "on route" are based on:

a) PBN specifications for the appropriate terminal area ensure a smooth transition for arriving and flying aircrafts;

b) results of the evaluation and forecast characteristics fleet.

Airspace of Ukraine consists of 5 regional control centers ATS.

The maximum flight level (DFL), which separates the upper airspace of the services from the bottom, now it is flight level FL 275, but can be changed due to integration with the European network.

Air Traffic Service is provided by GP UkSATSE which is certified by the State Aviation Service. As over the territory of Ukraine the required accuracy of global satellite navigation systems is not guaranteed (the nearest ground control correcting station is located near Warsaw), for the solution of area navigation tasks we can use the data beacon DME / DME.

4. Investigation of the position accuracy when using DME / DME

Use of DME / DME as a navigation aid requires consideration of some features:

a) the maximum range of the DME with regard to theoretical radio horizon is 300km/160n.m;

b) the work area is within the angle of intersection at station in DME 30 and 150 ;

c) means of DME, which is within 5.6 km from the specified line path should not be used for navigation;

d) consideration of the presence of published restrictions in that work area.

According to p.3.7.1 [2], airspace designer must conduct theoretical checking of the route integrity to the appropriate area of DME in any point of the route, and redundancy (more than two). With the availability of only a couple of DME, these stations are considered critical and will be appeared on the map.

Ground-based equipment can has an error not great than 185 m / n.m over 95% of the flight time. Accuracy of onboard equipment is calculated by the formula

$$2\delta = 2\frac{\sqrt{\delta_{1air}^{\ 2} + \delta_{1sis}^{\ 2} + \delta_{2air}^{\ 2} + \delta_{2sis}^{\ 2}}}{\sin\alpha},$$

where $\delta_{sis} = 0.05$ n.m;

$\delta_{air} = \text{MAX}\ \{0.085$ n.m, 0.125% range$\}$, using two DME $\alpha = 30^\circ$, and more than two —

$\alpha = 90$

Accuracy of the technique of piloting is determined by the phase of flight [2]. Admission to the calculation of the system associated with the implementation of WGS-84 data is $\pm$ 463 m (0.25 n.m). The theoretical maximum of radio horizon in kilometers is calculated by the formula

$D = 4.11\ \sqrt{h}$, where h is the relative altitude of the aircraft in meters.

All these factors should be considered when building action area and calculating the maximum error. The geometric method is given in the ICAO document [1] and is valid to ensure accuracy RNP5 and requires a great expenditure of time and can lead to significant errors in the calculations.

In order to explore the possibilities of navigation with higher requirements in the calculations we used the following approach.

We used the two-dimensional model for the definition of the current values of the coordinates (x, y) through the value range from the radio

navigation means with known coordinates. Local rectangular coordinate system is defined so that DME is are located at the points with coordinates (b, 0), (–b, 0) (Fig. 3).

Y

R_2

(x,y)

R_1

-b   O   b   X
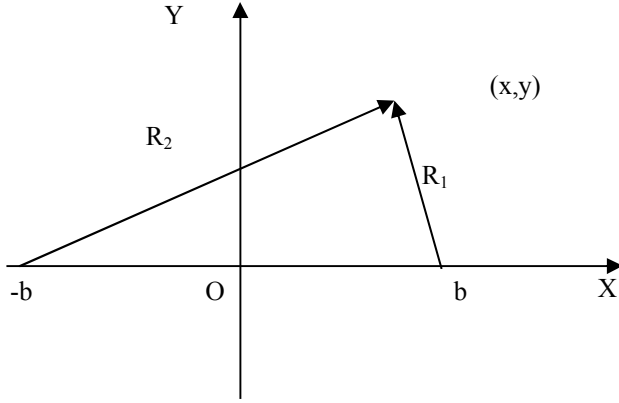
Fig. 3. Model of the current coordinates values definition through the values of ranges from DME

Distances between DME and plane are defined by the formulas

$$y^2 + (x-b)^2 = R_1^2. \tag{1}$$
$$y^2 + (x+b)^2 = R_2^2. \tag{2}$$

Subtracting the equation (2) from the equation (1), we obtain the equation for determining the coordinates x:

$$4bx = R_2^2 - R_2^2,$$

that is

$$x = \frac{R_2^2 - R_1^2}{4b} \tag{3}$$

From equation (1) we obtain the value of coordinate y

$$y = sign(y)\sqrt{R_1^2 - (x-b)^2}. \tag{4}$$

The real measured distances contain errors which are modeled by formulas

$$d_1 = aR_1 + b,$$

$$d_2 = aR_2 + b,$$

with some coefficients a, b. For the model considered we take $a = 0.00125$, $b = 0.46$ km.

Owing to the errors possible values of measured distances are

$$R_{1a} = R_1 \pm d_1,$$

$$R_{2a} = R_2 \pm d_2.$$

Substituting these values into the formulas (3), (4) we obtain the value of coordinates

$$x_a = \frac{R_{2a} - R_{1a}}{4b},$$

$$y_a = sign(y)\cdot\sqrt{R_{1a}^2 - (x_a - b)^2}.$$

Errors of calculated coordinates are

$$erx = x_a - x,$$

$$ery = y_a - y.$$

We take the value

$$Error = \sqrt{erx^2 + ery^2}$$

as an absolute value of coordinate calculation error and study dependence of the *Error* on coordinates values. The numerical simulation was executed in MATLAB program.

As a result of simulation the dependence of the maximum possible error on the point coordinates was determined.

Fig. 4 shows the results of the area border simulation for which the measurement error is more than 1 n. m.
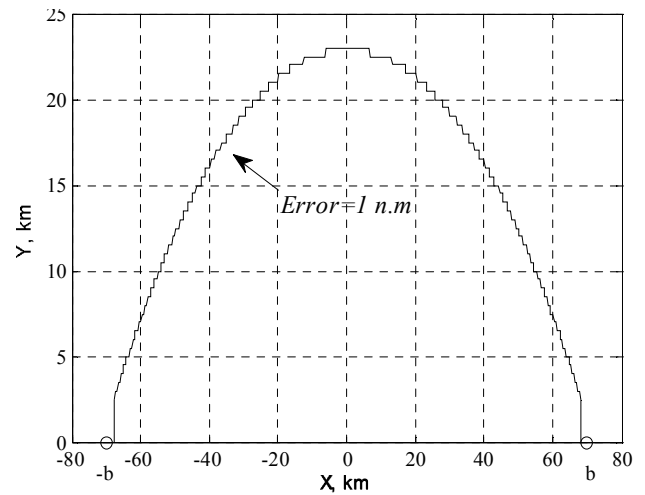
Fig. 4. The border line of the area with an accuracy of more than 1 n. m

For points in the plane located above the border line, the maximum error is less than 1 n. m. With the help of least squares method the set of boundary

points is approximated by the parabola with the equation

$$y = -0.0044x^2 + 0.0017x + 23.0722 \cdot$$

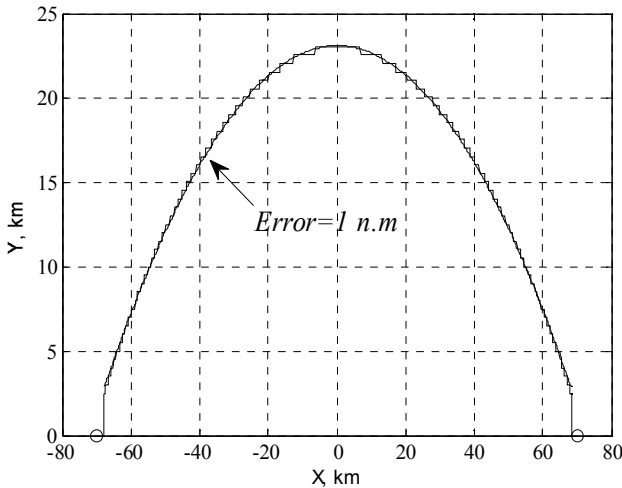The result of the approximation is presented in Fig. 5.

Fig. 5. Approximation of border line with maximum error 1 n. m by the parabola

Results of computer simulation for different initial data are presented in Table.

Calculation of geometric errors depending on the distance between the DME/DME

Error, nm	1	2	3	4	5
Error, km	1,85	3,7	5,56	7,41	9,26
d = 300 km					
Circle radius, km	261,9	438	650,5	864	1104,9
Restrictive angle, °	74,99	41,78	28,87	22,76	19.01
d = 240 km					
Circle radius, km	194,6	371,9	555,2	748,2	922,4
Restrictive angle, °	78,7	39,71	27,69	21,93	18,99
d = 140 km					
Circle radius, km	125,9	243	358,1	371,1	–
Restrictive angle, °	70,48	36,81	26,88	25,4	–

Simulation results of areas with acceptable errors 1, 2, 3, 4 n. m are presented in Fig. 6.
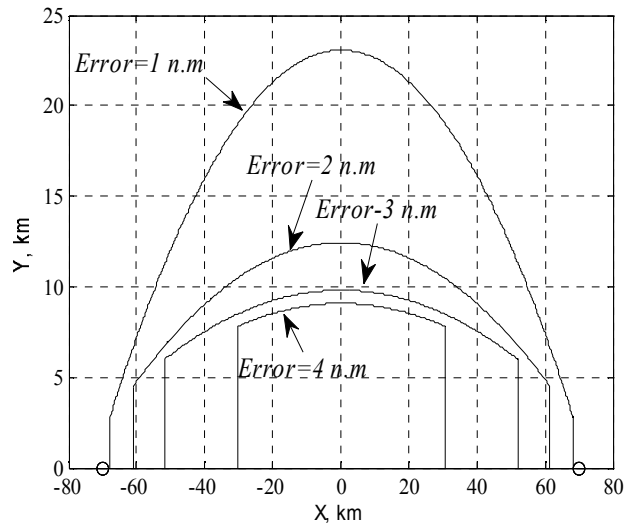

Fig. 6. Simulation results for the errors = 1, 2, 3, 4 n. m

In further investigation it was found that the lines of errors can be described by the circles (Fig. 7).
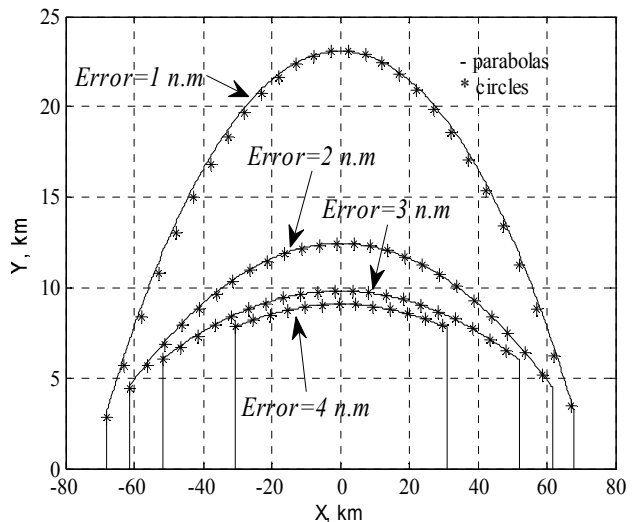

Fig. 7. Comparison of the error lines with the circles

Nowadays Eurocontrol use special software DEMETER for calculation coverage area systems DME. In the similar way accuracy zones for different configurations of DMEs can be constructed.

5. Conclusions

The presented method allows to define the accuracy characteristics of the service area and to determine the number of ground-based DMEs to provide the necessary specifications PBN. If the distance between DMEs is less than 175 km the errors will be less than 5 n. m.

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М.М. Богуненко[1], **В.В.Міщенко**[2]. **Упровадження специфікацій точності позиціонування навігації, що основана на характеристиках PBN за сигналами DME/DME**
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Розглянуто стратегію впровадження в Україні навігації, основаної на характеристиках PBN. Визначено точність положення повітряного корабля при використання DME/DME як навігаційного засобу. Показано можливість спрощення побудови зони корекції для заданої точності. Наведено результати моделювання визначеної зон заданої точності за допомогою розробленої програми.
Ключові слова: використання DME/DME; навігаційна специфікація; навігація, основана на характеристиках PBN; DME радіомаяк.

Н.Н. Богуненко[1], **В.В.Мищенко**[2]. **Внедрение специфікаций точности позиционирования навигации, основанной на характеристиках PBN по сигналам DME/DME**
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Рассмотрена стратегия внедрения в Украине навигации, основанной на характеристиках PBN. Определена точность положения воздушного судна при использовании DME/DME в качестве навигационного средства. Показана возможность упрощения построения зоны коррекции для заданной точности. Представлены результаты моделирования определения зон заданной точности с помощью разработанной программы.
Ключевые слова: использование DME/DME; навигационная спецификация; навигация, основанная на характеристиках; DME радиомаяк.

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