INTERNATIONAL CIVIL AVIATION ORGANIZATION
NATIONAL ACADEMY OF SCIENCES OF UKRAINE
MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL AVIATION UNIVERSITY

PROCEEDINGS

THE SIXTH WORLD CONGRESS "AVIATION IN THE XXI-st CENTURY"

“Safety in Aviation and Space Technologies”

September 23-25, 2014

Volume 2

KYIV 2014

SYMPOSIA

Volume 1

SYMPOSIUM 1. MODERN SPACE AND AVIATION TECHNOLOGIES
1.1. Latest technologies for maintaining aircraft airworthiness
1.2. Aerodynamics and flight safety
1.3. Fatigue and fracture of aircraft structures
1.4. Problems of recovery controllability of the aircrafts
1.5. Engines and Power Installations
1.6. Latest technologies for maintaining aircraft airworthiness
1.7. Methods and tools for technical and medical diagnostics
1.8. Automated process control systems
1.9. Specialized Computer Systems and CALS – Technology in Aviation
1.10. The intellectual robot-technical measuring complexes and systems
1.11. Information security in aviation
1.12. Computer systems
1.13. Advanced information technologies in aviation
1.14. Mathematical modeling and numerical methods

Volume 2

SYMPOSIUM 2. UNMANNED AIRCRAFT SYSTEMS (UAS)

SYMPOSIUM 3. AIR NAVIGATION AND ATM SYSTEMS
3.1 Air traffic management
3.2 Communication, navigation, surveillance
3.3 Aviation English and safety of flight
3.4 Avionics
3.5 Complex systems control

SYMPOSIUM 5. ENVIRONMENT PROTECTION
5.1. Chemical technology and engineering
5.2. Environmental protection
5.3. Land management, cadastre and land monitoring
5.4. Biotechnology in aviation

SYMPOSIUM 6. AVIATION CHEMMOTOLOGY

SYMPOSIUM 7. COMMUNICATION FACTOR IN MODERN INTERNATIONAL RELATIONS
7.1. Information and legal principles of international relations
7.2. The transformation of journalism in the context of technologizing the world and the processes of globalization
7.3. The international scientific and technical cooperation of Ukraine in aerospace industry

UDC 537.612.2(045)

I.V. Ostroumov, cand. of science
(National Aviation University, Ukraine, Kyiv)

NAVAIDS FACILITY FOR AIRCRAFT POSITIONING

The key positioning algorithms by data from Distance Measurement Equipment and Very high frequency Omni-range Radio beacons have been discussed. Results of accuracy estimation of different positioning approaches for Ukrainian airspace were represented.

Introduction

Positioning of aircraft location in the airspace is one of the key problems in aviation. Accuracy and availability of coordinate detection are valuable part of flight safety. Many different approaches have been using to improve positioning losses on board of aircraft.

Nowadays Global Navigation Satellite System (GNSS) provides more accurate global position data than other technics. GNSS is represented by GPS, GALILEO and GLONASS satellite systems. In despite of high accuracy of GNSS the special ground base augmentation systems (GBAS) are used in wide areas for GNSS improvements [1].

Each airspace user has to use GNSS equipment for positioning purposes. But some time in some regions accuracy of positioning may be not enough to guarantee the required level of flight safety. It may be result of radio frequency interference, geometry of space satellite location, solar activity and others. Flight management system (FMS) uses other positioning methods to determine the coordinates in case of malfunction airborne equipment of GNSS or inability to determine the coordinates. In this case we can use other positioning technics such as inertial navigation or positioning by signals from radio beacons (NDB, DME, VOR, DVOR). Inertial Navigation System may be used for limited time in consequence of the additive error. Positioning algorithms of FMS are alternative source of position information. It is based on information usage from navigation beacons. According to decreased positioning accuracy the next navigation methods are used: DME/DME, VOR/DME, VOR/VOR, ADF/ADF [2].

DME/DME

The principle of determining the coordinates of an aircraft by DME beacons signal grounds on distance measurement method of positioning. During the flight avionics equipment analyze all of the available DME ground beacons at the point of your location. Available ground beacons are used to determine distance between the aircraft and the beacon with the use of time-based criteria. In cases of two accessible beacons holdings the result of navigation equation solving will be two points of location, one of that will be missed by tracking algorithm as impossible location. In positioning techniques by two radio beacons only pair of beacons with angles from 30° to 150° should be used that depends on RNAV accuracy characteristics[3].

Usually global geocentric coordinate system ECEF is used for aircraft coordinates (x_A, y_A, z_A) detection in case of more than two available ground station [4, 5]. Position of aircraft is found by the solution of navigation equation:

$$D_i^2 = (x_A - x_{\text{DMEi}})^2 + (y_A - y_{\text{DMEi}})^2 + (z_A - z_{\text{DMEi}})^2 ,$$

where x_{DMEi}, y_{DMEi}, z_{DMEi} – coordinates of i^{th} DME ground beacon; Di – real distance between ground station and an aircraft.

Navigation equation may be solved by linearization of equation and then by least square method:

$$\Delta D_i = \hat{D}_i - D_i ,$$

$$\Delta x_i = \hat{x}_i - x_A ,$$

$$\Delta y_i = \hat{y}_i - y_A ,$$

$$\Delta z_i = \hat{z}_i - z_A ,$$

$$\hat{r}_i^2 = (x_A - \hat{x}_i)^2 + (y_A - \hat{y}_i)^2 + (z_A - \hat{z}_i)^2 ,$$

$$a_{xi} = \frac{x_{DME} - \hat{x}_i}{\hat{r}_i^2} ,$$

$$a_{yi} = \frac{y_{DME} - \hat{y}_i}{\hat{r}_i^2} ,$$

$$a_{zi} = \frac{z_{DME} - \hat{z}_i}{\hat{r}_i^2} ,$$

where $\hat{x}_i, \hat{y}_i, \hat{z}_i$ - nominal points coordinates, ΔD – distance between nominal point and aircraft.

According to relation above navigation equation will be represented in the next matrix form:

$$\Delta D = H \Delta X ,$$

where

$$\Delta D = \begin{pmatrix} \Delta D_1 \\ \Delta D_2 \\ \vdots \\ \Delta D_N \end{pmatrix}, \quad H = \begin{pmatrix} a_{x1} & a_{y1} & a_{z1} \\ a_{x2} & a_{y2} & a_{z2} \\ \vdots & \vdots & \vdots \\ a_{xN} & a_{yN} & a_{zN} \end{pmatrix}, \quad \Delta X = \begin{pmatrix} \Delta x_i \\ \Delta y_i \\ \Delta z_i \end{pmatrix}, \quad i = 1 \ldots N .$$

Aircraft location may be calculated by the next relation [3]:

$$\Delta X = \left(H^T H\right)^{-1} H^T \Delta D .$$

Usually for nominal points in represented above approach DME ground station location has been used.

Accuracy of positioning by DME/DME approach depends from geometry location of ground station, ground beacon classes and accuracy of DME. Figure 1 represents accuracy of DME/DME positioning for Ukrainian airspace for altitude of 8000 m.

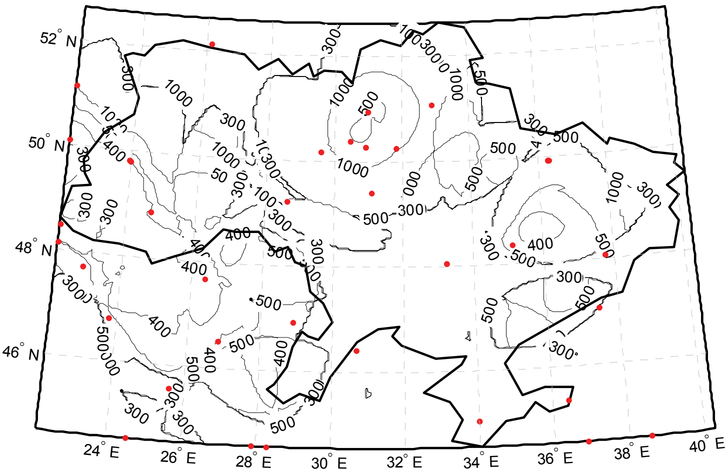

Fig. 1. Accuracy of DME/DME positioning

VOR/DME

Typically ground DME station is grouped with VOR ground radio beacon. They use different frequencies but operate in co-located channels and antennas are located in one place. Co-located group of DME and VOR ground equipment provide aircraft a unique positioning possibility because it is possible to calculate position of aircraft by distance (*d*) to ground radio beacon from DME and azimuth (α) to VOR equipment. Of course it needs information about ground beacon antennas location (x_{VOR}, y_{VOR}).

Navigation equation contains simple trigonometric functions because it is result of rectangular triangle relations:

$$x_A = \begin{cases} x_{VOR} + d\sin(\alpha), if\, 0 \le \alpha \le \dfrac{3\pi}{2} \\ x_{VOR} - d\sin(\alpha), if\, \dfrac{3\pi}{2} < \alpha \le 2\pi \end{cases},$$

$$y_A = y_{VOR} + d\sin(\alpha).$$

Accuracy of this positioning approach indicates bad characteristics according to DME/DME position approach.

VOR/VOR

Positioning by VOR equipment is grounded on angular positioning approach. VOR equipment provides angles between north and direction to the ground station. Also it needs information about location of ground stations.

Location of aircraft is calculated by rectangular triangles in plane of ground station [6]. Typically North-East-Down (NED) Cartesian coordinate system has been used for coordinate detection. Location of VOR ground station holds the center of NED coordinate system.

Navigation equation grounds on relations in rectangular triangles [7]. Aircraft position detects by the following simple equation for n^{th} number of ground stations:

$$tg(\alpha_i) = \frac{\Delta x_i}{\Delta y_i} = \frac{x_A - x_i}{y_A - y_i}, \; i=1..n,$$

It can be represented in other form:

$x_A - y_A tg(\alpha_i) = x_i - y_i tg(\alpha_i)$, i=1..n,

where x_A , y_A – aircraft position,

x_i , y_i – VOR ground stations location,

α_i – VOR azimuths.

In matrix form:

$$A \cdot X^T = B,$$

where

$A = [1 \quad tg(\alpha_i)]$, $X = [x_A \quad y_A]$, $B = [x_i - y_i tg(\alpha_i)]$, $i = 1...n$.

Aircraft location by VOR information is calculated by the following formula [8]:

$$X = \left(\left(A^T A \right)^{-1} A^T B \right)^T .$$

But positioning by VOR information has been limited by VOR ground station geometry location and in case of aircraft location at the line which connects two ground stations it is impossible to solve positioning equation.

The geometric dilution of precision (GDOP) coefficient shows geometrical influence of ground station location on position accuracy. GDOP usually is a part of total precision. Result of Analysis of Ukraine national VOR ground beacon system (represented on figure 2) represents availability to receive VOR signals on 1.8% country territory from 6 beacons; 4,6% – 5; 22,2% – 4; 52,4% – 3 and 19% – less than 2.

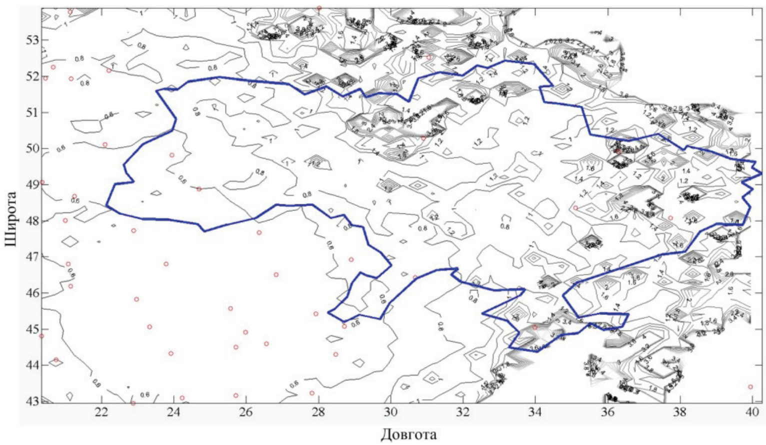

Fig.2. Coefficient of GDOP for VOR/VOR positioning in Ukrainian airspace

Therefore navigation by VOR station signals is available on 81% of Ukraine area. GDOP coefficient for VORs ground station system in Ukraine region has the following view:

- for 3.8% Ukrainian airspace GDOP coefficient will be less than 1,
- for 78.8% – from 1 to 2;
- for 17.4% – more than 2.

Conclusions

All of represented positioning algorithms have been computing inside of FMS. During the whole flight FMS controls positioning information from GNSS sensors and if it recognizes bad accuracy or unavailability it automatically uses inertial principle and then after some time DME/DME, VOR/DME or VOR/VOR positioning algorithm.

Alternative positioning systems are extremely important today. Result of investigation indicates that accuracy of positioning depends on geometry of ground station location. DME/DME approach is the most useful for Ukrainian airspace. To improve safety of flight the best way is to increase a number of ground DME stations.

References

1. Харченко В.П. Авіоніка / В.П. Харченко, І.В. Остроумов. — К.: НАУ, 2013. — 281 с.

2. Остроумов І.В. Інтеграція координатної інформації у обчислювальній системі літаководіння / І.В. Остроумов // тези науково-практичного семінару Сучасні проблеми авіакосмічних технологій та систем 17-23 червня 2013 року - Житомир. — 2013. — 19 с.

3. Правила аеронавигационного обслужи-вания. Производство полётоввоздушніх су-дов. Том II. Построение схем визуальных полётов и полётов по приборам. Doc 8168. OPS/611. – ICAO, 2006. – 872 с.

4. Остроумов І.В. Оцінювання точності DME/DME позиціонування для повітряного простору України / І.В. Остроумов // Проблеми інформатизації та управління: Збірник наукових праць. — 2013. — Т. 43, № 3. — С. 61-67.

5. Остроумов І.В Використання радіомаяків DME для визначення місцеположення у повітряному просторі України / І.В Остроумов, Т.Б. Лопатко // Вісник інженерної академії України. — 2013. — № 4. — С. 300-305.

6. Остроумов І.В. Оцінка точності позиціонування за сигналами радіомаяків VOR / І.В. Остроумов // Проблеми інформатизації та управління: Збірник наукових праць. — 2012. — Т. 339, № 107. — С. 102.

7. Ostroumov I.V. Position detection by angular method in air navigation / I.V. Ostroumov // The Fifth World Congress “AVIATION IN THE XXI-st CENTURY” - quot;Safety in Aviation and Space Technologiesquot;. Volume 2. – Kiev: NAU, 2012. — 2012. — Is. 32. — 32 p.

8. Ostroumov I.V. Positioning by VOR signals in Ukraine region / I.V. Ostroumov // Problems of CNS/ATM development and ATM. International Scientific-Metodical Conference of Researches, November 28 – 30, 2012 : theses.. — 2012. — 74 p.