SATELLITE-BASED AUGMENTATION SYSTEMS

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Described in the article is a satellite-based augmentation system. Focus is on the operating principles of these systems and further information on the use of satellite-based systems for precision approach to landing. The example is about the approach minima and the entire approach procedure.

K e y w o r d s: GNSS, SBAS, GPS, signal, approach for landing

1 ÚVOD

Flying has become a common part of life. Navigation systems affect the safety of flight operations. In early age of flying was used only visual navigation. Later was navigation performed by using radio navigation equipment. Technology has improved over the years. In nineties of the twenty century began using navigation with GPS and GLONASS signals. Aircrafts was equipped with modern navigation facilities, which allow land safety at the airport.

Signals of GLONASS and GPS navigation systems are disturbed by many factors. They include ionospheric delays, satellite geometry, multipath, clock errors and weather conditions. Many times is GPS signal not available. All these factors can be eliminated by satellite-based augmentation system. WAAS, EGNOS, MSAS and GAGAN can increase the accuracy of position of flying objects within 3 meters. They are used for precision approach for landing on small and medium airports. They allow operating flights in bad weather conditions.

2 GLOBAL NAVIGATION SATELLITE SYSTEMS (GNSS)

In this time the GNSS includes two fully operational global systems. The first is the GPS. It falls under administration of United States of America. The second is GLONASS, which is used in Russian Federation. Europe is developing Galileo. China is preparing GOMPASS/Bei-dou. India is working on India Regional Navigation Satellite System. Japan is working on Quasi-Zenith Satellite System.[1]

2.1 GPS

In early seventies, the Department of Defense of the United States of America has developed GPS system. It was named Global Positioning System. GPS is satellite navigation system, which sends signals to receivers for precise positioning at any location in the world. It provides 24-hour constant signal coverage regardless of weather conditions. It serves for unlimited number of users. For security reasons is possible for users the signal only receive and not broadcast. Properly certified GPS can be used as a supplement to en route IFR. The accuracy with GPS is 15 within meters.[2][3]

2.2 GLONASS

Russia has developed its own satellite navigation system. It serves to civilian and military sector. GLONASS is the acronym of GLOaľnaya NAvigatsinnaya Sputnikovaya Sistema. Russia began the development of the system in seventies to compete with American system GPS. GLONASS is controlled by Russian Federal Space Agency. It is designed to determinate the exact position to different categories of user. The system is available for 24 hours in all weather conditions.[4][4][5]

2.3 Galileo

In early nineties has European Union recognized the need of its own navigation system. Therefore the European Commission in collaboration with the European Space Agency began to build Galileo. System will serve only in Europe. It will be interoperable with American GPS and Russian GLONASS.[6][7]

It will provide highly precise navigation service under civilian control. Galileo will send messages on two frequencies. It will provide a determination of the position in real time with an accuracy of 1 meter. It guarantees service availability even under extremely conditions. The system is suitable for activities requiring high safety for example operation of train or plane landing. Galileo improves the quality and integrity in comparison with the military system, which are operable. It will be fully operational in 2014.[6][7]

3 SATELITE- BASED AUGMENTATION SYSTEMS (SBAS)

Satellite-based navigation systems are supplements to existing GNSS. SBAS are more accurate, integrate and available compared to GNSS. [8]

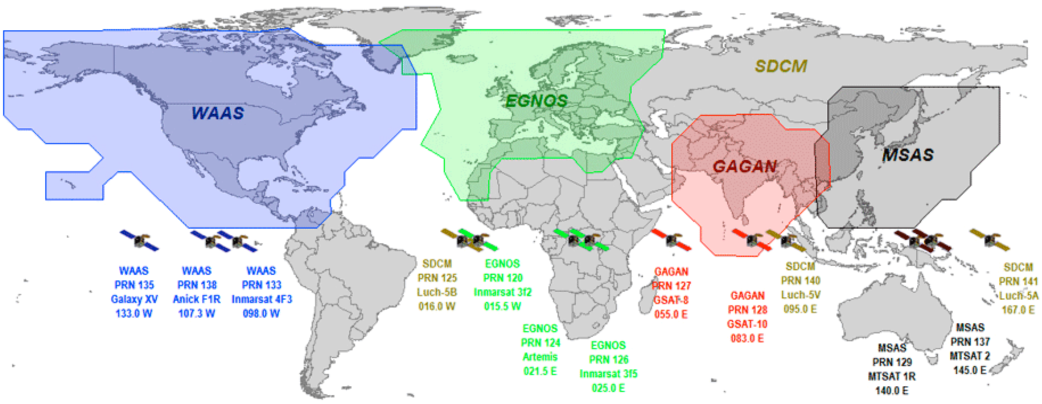

Figure 1 SBAS coverage [9]

SBAB are regional systems. (see Figure 1) European augmented system is EGNOS, in United States of America it is WAAS, and in Japan it is MSAS. India is still working on GAGAN. Russian SDCM is also under development.[8]

SBAS support navigation of aircraft in all phases of flight. It provides precision approach with vertical guidance with decision height lower than 200 ft (60 m) above the threshold of the runway. Precision approach procedures with SBAS are similar to ILS precision approach CAT I. Navigation with vertical guidance is named localizer performance with vertical guidance (LPV). SBAS signal is broadcasts on GPS frequency L1. In the range of 10 years it is expected that the signal will be transmitted at two frequencies.[10]

3.1 WAAS

The longest used SBAS is the Wide Area Augmentation System (WAAS). It was developed in cooperation the FAA and U.S. Department of Transportation in 1992. WAAS is critical part of the strategic goal of FAA for navigation satellite system for civil aviation. FAA developed WAAS to improve accuracy, availability and integrity of GPS signals. Main task of the system is error correction of GPS signal caused by ionospheric delays, time errors or satellite geometry. It provides information about the functionality of each GPS satellite. WAAS can be used as an air navigation system in all phases of flight from take off to precision approach similar to ILS CAT I. The system is in full operation since 2003. [11][12]

WAAS does not need ground navigation equipment for its operation. If WAAS receiver is outside of the coverage or in case of breakdown the WAAS will turn back into operation only by the GPS.[12]

WAAS improves the accuracy, which GPS can determine. GPS can determine position within 15 meters. WAAS can determinate position within 3 meters.[3]

WAAS signals are available in United States, Canada and Mexico. WAAS is used only in United States and Canada.

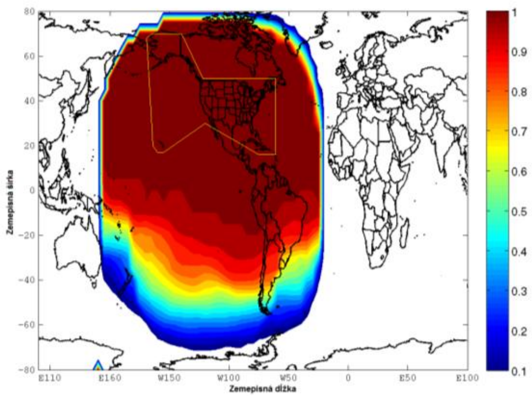
Figure 2 Availability of WAAS signals [13]

3.1.1 Principle of operation

GPS satellites transmit signals on frequencies L1, L2. Wide area reference station receives the transmitted signal. They adjust data obtained from GPS. They send data to the master station. Here are calculated corrections to the GPS. Ground up-link stations send these corrections to geostationary satellites. Satellites transmit edited message to aircraft receivers. The message is broadcasted on the same frequency as GPS L1 - 1575.42 MHz. The message contains orbital corrections, ionospheric corrections, integrity and repaired time. Integrity message inform about satellite functionality in acceptable tolerances.[3][11]

3.2 EGNOS

European Space Agency, the European Commission and the European Organization for the Safety of Air Navigation created a joint project called EGNOS (European Geostationary Navigation Overlay

Service). It is considered as a precursor of Galileo. EGNOS is interoperable with WAAS and MSAS.[14]

The system is designed to improve navigation and to protect civil aviation against misleading data. EGNOS is designed to be used in all forms of transport in Europe. The system was officially put into operation in April 2009. EGNOS is able to cover the whole Europe and North Africa with its signal. Coverage will be extended to countries bordering Europe Union.[14]

EGNOS will be used in aviation, precision agriculture, mapping, maritime, land transportation. It can be used also to standardize the time. System provides a lot of services, which can be used in aviation. For example Safety of life service, EGNOS data access service and open service.

3.2.1 Principle of operation

Ranging and Integrity Monitoring Stations monitor the GPS signals. All stations have a built-in GPS/EGNOS receiver. Stations are tasked to operate the pseudo-range, demodulating the navigation data, mitigate interference, verify signal integrity, compress and transmit the data to the Main Control Center. Calculated correction of GPS signal and integrity are sent to navigation ground stations, which broadcast them on geostationary satellite. Signals are provided to users from this satellite.[16]

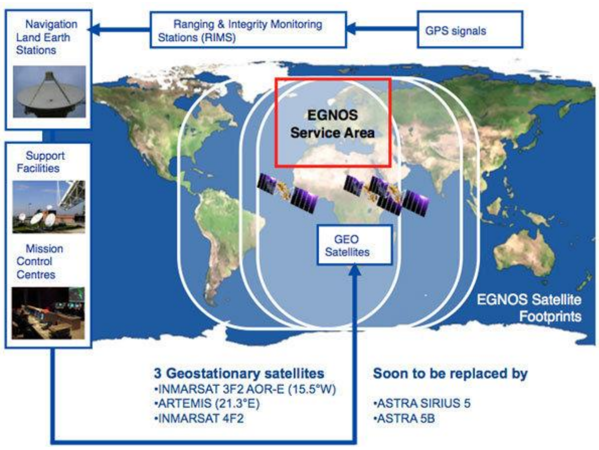

Figure 3 Principle of operation EGNOS [15]

3.3 MSAS

Japanese SBAS is called MTSAT Satellite-Based Augmentation System (MSAS). The system is similar to the American WAAS and European EGNOS. It was developed to be use for aircraft navigation. MSAS was created by the Japanese Space Agency and Japanese agency for civil aviation. MSAS fixes and corrects Differential GPS. It also monitors the reliability and accuracy of GPS signals in real time. MSAS is designed to increase positioning accuracy, continuity, integrity and availability of GPS satellite system. MSAS signal covers Asia and the Pacific Ocean area. System is in accordance with ICAO standards and the SBAS SARPs. The system is fully operational since 2007.[16]

3.2.1 Principle of operation

Figure 4 shows the operation of an MSAS. It is similar to the principle of operation with EGNSOS system. (see 3.2.1)

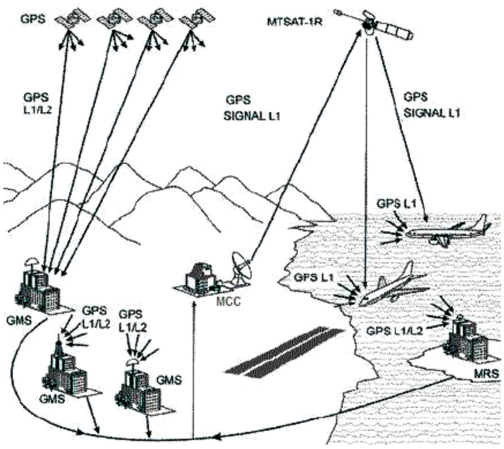

Figure 4 Principle of operation of MSAS [17]

3.4 GAGAN

India has decided to create its own SBAS to increase the accuracy of aircraft positioning. Indian SBAS is called the GPS-Aided Geo Augmented Navigation system (GAGAN). It will provide services in the airspace of India, Bay of Bengal, the Middle East and Southeast Asia. Its mission is to improve the accuracy of GPS signals during the flight of civil aviation from start to landing.[18]

The system will operate on the same principle as WAAS. GAGAN can determine the accuracy of position to 1.5 meters horizontally and 2.5 meters vertically. In addition to its own signals GAGAN will be able to use timing and signals from GLONASS and Galileo.[19]

3.4.1 Principle of operation

Indian Navigation Reference Earth Stations receive GPS signals. (see Figure 5) They determine the position using the signal versus the position of the receiver. Signals, which need to repair in GAGAN system, are called deltas. Observed deltas are sent to the Master Navigation Control Center thought communication network consisting of optic fibers. Deltas are calculated by computer and their calculation is generated for the entire network. Then they are transmitted via Indian Navigation Land Uplink Stations. They will send corrected data to the geostationary satellite. From there is signal sent to users.[21]

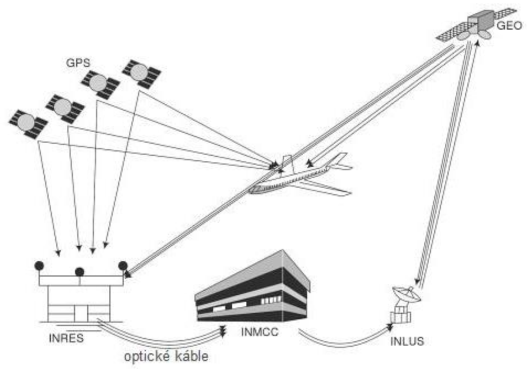

Figure 5 Principle of operation GAGAN [20]

3.5 SDCM

Acronym SDCM stands for the Russian System of Differential Correction and Monitoring. SDCM is developed to increase accuracy and integrity of GLONASS. It is designed to allow monitoring of the integrity of the GPS and GLONASS satellites. Development of the system began in 2002. The system will provide better navigation services. SDCM will determine the position on 1 to 1.5 meters horizontally and 2 to 3 meters vertically. SDCM will be used mainly in the area of the Russian Federation, but it will also be used in some states of Europe and the Middle and Far East.[22][23]

3.5.1 Principle of operation

Signal from GPS and GLONASS is received by Reference Integrity monitoring stations satellites on L1 and L2 frequencies. Then it is sent to the Central processing facility, which calculates a satellite ephemeris, time, integrity and generates the message. Message format is in accordance with the international standard. After that is signal sent to up-link stations. They send signal on geostationary satellites. Users can receive corrected signal from this satellite.

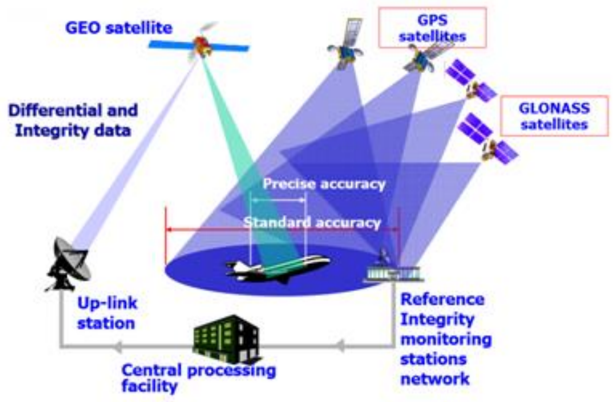

Figure 6 How SDCM works [24]

3.6 Other SBAS

SBAS are developing around the world. Many countries would like to work with their own navigation system. On new regional navigation systems is working South America, Africa and even Malaysia.

4 USING SBAS FOR PRECISION APPROACH FOR LANDING

SBAS systems are used in air navigation. They are used for precision approach for landing. System can provide higher accuracy as GPS, GLONASS and Galileo.

4.1 Use of EGNOS for precision approach for landing

EGNOS can be used to determine the vertical position of the aircraft during approach. EGNOS, as well as the GPS is used for the horizontal guidance on en route and in terminal control area. Using EGNOS in aviation is based on navigation applications published in the ICAO PBN Manual. Approach procedure must be published for the airport. On board the aircraft must be located receivers approved for the operation EGNOS. Now is possible to use EGNOS for precision approach for landing similar to ILS CAT I.[25]

EGNOS will allow flying on path with a constant rate of descent based on GPS augmented with EGNOS. Vertical guidance is used only in the final approach segment. (see Figure 7) EGNOS allows performing approach with vertical guidance with LPV minima. The state shall publish approach procedures. LPV minima constitute of decision height (DH) or decision altitude (DA). EUROCONTROL has established a service that informs about planned outages and the availability of EGNOS LPV operations. The service is called Augur.[26]

4.1.1 Approach with EGNOS

In Figure 7 is precision approach for landing with EGNOS. The aircraft is guided only by GPS to the point of final approach fix (FAF).

From this point is aircraft led by combination of signals from GPS satellites and SBAS. During the approach is aircraft receiving signal corrections from EGNOS satellites. The accuracy of position of aircraft is higher than only using GPS.

There are published approach procedures in approach maps. Inside map are mentioned DA/DH. In some cases they may be lower than 250 ft (76 m). If the aircraft reaches a height of decision altitude or decision height pilot must continue in approach for landing or initiated missed approach.

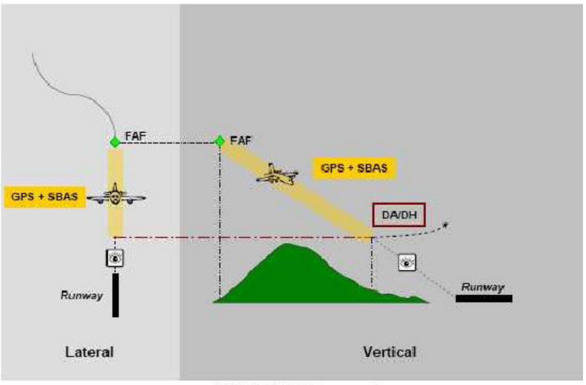

Figure 7 Flight with EGNOS [26]

7. Lateral mode during RNAV approach with LPV minima is displayed as FMS and vertical mode is VGP.
8. Approximately 2 NM from FAF is LPV is displayed green. The aircraft is using angular deviation with high integrity from GPS. GPS provides lateral and vertical guidance to aircraft.
9. When the aircraft reaches the decision height pilot must land or initiate a missed approach.
10. In case of initiation of missed approach pilot push the TO/GA button on throttle. Navigation guidance is automatically transferred from GPS back on FMS.[99]

4.2 Use of WAAS for precision approach for landing

WAAS allows performing approach for landing with localizer performance (LP) minima or localizer performance with vertical guidance (LPV) minima.

By LVP approaches is used flight management system navigation database combined with the signals from WAAS and GPS satellites. It contains additional information for each LPV approach. It is called Final Approach Segment Data Block. It sends vertical and lateral parameters required for RNAV approach with LPV minima. All necessary information is showing on the primary flight display. [99]


Figure 8 Vertical and lateral navigation [27]

4 1.2 Steps of precision approach for landing

1. On display of multifunction control unit is selected the runway for landing.
2. Select the required RNAV approach with LPV minima.
3. Select the load approach in the flight plan.
4. Pilot must verify the approach ID.
5. After loading RNAV approach with LPV in flight plan, LPV on display will indicated in white.
6. After approach clearance is received the final approach fix is active waypoint. Approach mode can be started by pushing the APR button on guidance panel.

5 CONCLUSION

SBAS are able to fill gaps of the traditional navigation systems and increase the accuracy of the positioning of flying objects and air traffic safety. Procedures for precision approach for landing using SBAS are published more frequently. Their use decreases the need to use ground navigation equipment. It also reduces the costs required for their maintenance. We expect that in the near future it will be almost global coverage by satellite-based augmentation navigation systems. It will help to increase the safety of operations.

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