GNSS FOR GROUND OPERATIONS

Jaroslav BURSÍK, Jakub KRAUS*
Department of Air Transport, Czech Technical University in Prague Faculty of Transportation Sciences, Horska 3, 12803 Prague 2, Czech Republic
**Corresponding author.* E-mail: kraus@fd.cvut.cz

Summary. The article focuses on possible usage of GNSS navigation in airport surface movement applications. First, basic principles of GNSS navigation are explained. Then the navigational performance requirements for navigation on taxiways are being determined and they're compared with the actual navigation performance of GNSS. As a result of the comparison, solutions for possible improvement are being proposed.

Keywords: GNSS navigation; navigation performance; taxiing; automatic airport surface movement

1. INTRODUCTION

Automation and navigation: at first glance different domains, which are however in the world of civil aviation very important and also in most cases interrelated. With decreasing spacing between aircraft and the growing need to increase airspace capacity, very high importance is placed on navigation and automation in flight. High utilization of airspace is of course accompanied by a high utilization of airports which are also constantly being expanded so as to meet traffic demands. Despite the complicated system of taxiways land navigation is generally still made solely on the basis of visual perception and systems of the aircraft are operated manually by the crew. Increased crew workload subsequently creates an environment in which can easily lead to a critical situation, both in terms of the flow of traffic, as well as in terms of safety.

This article aims to show the possibilities of introducing instrument navigation methods for ground operations, with emphasis on GNSS satellite navigation.

2. NAVIGATION ON TAXIWAYS

The aim of taxiing is to guide the aircraft from stands to take-off position and after vacating the runway back to its stand. [3] For guiding the aircraft, the pilot uses a taxiway signs and markings designed for this purpose and affects the direction taxiing. The aircraft during this activity moves along a track with some error, whose boundaries need to be defined and maintain the required safety coefficient, since taxi is considered as a critical part of the flight.

2.1. Determination of performance parameters

For determining performance parameters needed for navigation on taxiways, firstly taxiway itself must be defined and then the error components, causing a deviation from the desired route. It is very likely that the resulting performance requirements for the navigation system will be very strict, since we consider the operation at zero visibility and therefore it cannot be assumed that the crew will be able to take control of the aircraft and safely manage taxiing by looking out of the cockpit. Strictest requirements are currently defined for approach and their specific numerical values are recorded in Table 1. It is evident at first sight that these values (accuracy and integrity) are not adequate for

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navigation purposes on taxiways and different requirements based on factors that are specific to the taxiing needs to be established.

Table 1 Navigation performance requirements for approach [12]

Horizontal accuracy	Vertical accuracy	Integrity Risk	TTA	HAL	VAL	Continuity	Availability
16 m	20 m	$2*10^{-7}$/APP	10 s	40 m	50 m	$8*10^{-6}$/15 s	0,99

Taxiways connect different parts of the airport and according to the code designation of airports are defined by the specific dimensional parameters. For the purposes of this article, important parameters are shown in Figure 1. This is the travel surface width (TSW), the distance of the outer edge of the main chassis and the edge of the taxiway (TSC, travel surface clearance). These parameters are defined separately for each letter airport code designation, and it's designed just distance between the outer edges of the main wheels (UW, undercarriage width) and wingspan. In the running lanes (part of the apron designated as a taxiway) instead of the TSC defines the distance edge of the wings from the nearest obstacle (WTO). [12]

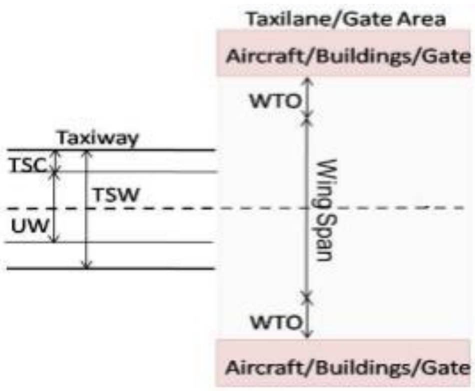

Figure 1 Taxiway parameters [6]

a) Determination of accuracy

The basis of determining the accuracy needed to navigate on a taxiway is the requirement that the total system error (TSE) should not exceed the size of the reserve, separating aircraft from the obstacles (TSC, or WTO). Avoiding of exceeding this reserve obviously cannot be guaranteed in all cases, and therefore it is necessary, as in the case of air traffic to determine the probability of exceeding the specified limits, i.e. the probability of a collision with an obstacle. Given that this article is focused on operations for commercial aviation, only airports codenames C, D, E and F will be taken into account. To calculate the required accuracy of navigation system error (NSE), it is first necessary to determine the requirement for total system error (TSE) because we know that the NSE is one of the components of a TSE, the:

$$TSE^2 = NSE^2 + PSE^2 + NDE^2 \quad (1)$$

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Faculty of Aeronautics, Technical University of Košice

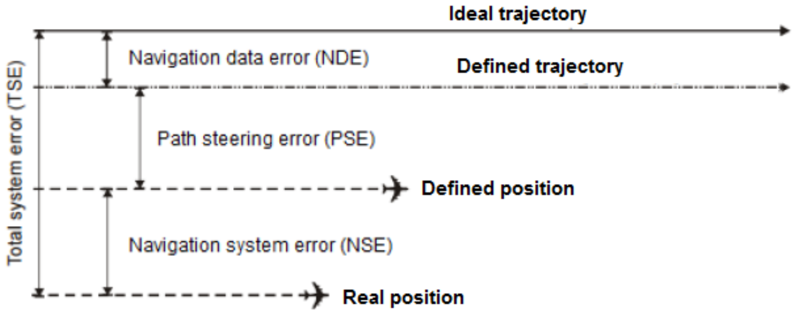

Figure 2 Total System Error

It is necessary to lay down certain default conditions under which the requirement for TSE is established. Here is used appropriate approach, category 3, ie, the probability of exceeding the values defined reserves (TSC, WTO) will be $1*10^{-6}$ in 95% of cases. Determination of the conditions was based on the fact that taxiing must maintain the same level of safety as has any other stage of flight. [3]

To determine the requirement for a TSE, it is necessary to apply probability theory, where we work with a normal (Gaussian) distribution. The following applies [5]:

$$P = 2\frac{1}{\sqrt{2\pi}\sigma_{TSE}}\int_{TSC}^{\infty} e^{-\frac{x^2}{2\sigma_{TSE}^2}} dx \quad (2)$$

And therefore:

$$\sigma_{TSE} = \frac{2TSE}{\sqrt{2}erfc^{-1}(10^{-6})} \quad (3)$$

The resulting requirements on TSE are shown in Table 2.

Table 2 TSE requirements

Airport code letter	C	D	E	F
TSE requirements [m]	1,23	1,84	1,84	1,84

Setting requirements for TSE is only the first step to establish requirements for navigation devices (NSE). The next step is to determine the value of NDE and PSE. For these two specific components of the TSE is not the need to strictly determine the requirements for their value, but to find the current state and consider it when calculating the TSE, because their values are given by the current operating situation.

When determining the NDE for the purposes of this paper we use the worst possible option, i.e. the quality requirements of aeronautical data prescribed by Annex 14. In regulation, the requirement for the accuracy of the coordinate points for taxiway axis is set to 0.5 meters and this value is also used in the calculations. [1, 8]

On the other hand, PSE finding is quite challenging because it is the one component that is highly dependent on the human factor. Because the accuracy that the crew can reach when taxiing to the stand, equipped with the visual guidance, when calculating the requirement NSE conservative value of 1m is used for PSE.

Defined values of TSE, NDE a PSE with (1) allow the calculation of the maximum value of requirement for navigation system error (NSE), whose results are shown in the table 3.

Table 3 NSE requirements

Airport code letter	C	D	E	F
NSE requirements [m]	0,5	1,46	1,46	1,46

b) Determination of integrity

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To determine the integrity requirement, it is necessary to define requirements for the IR (integrity risk), AL (alert limit) and TTA (time to alert). The ideal means for determining the integrity is a method of tree risk analysis, which is described in Appendix A of Aviation Regulation L 10 / I. To use this method, however, detailed knowledge of probability of an accident is required for the failure of each of the elements of the system (avionics, pilots, controls, ground equipment, etc.). Such knowledge requires extensive analysis of individual systems, the implementation of which is not the aim of this paper and integrity requirements will be therefore set out in a simplified manner on the basis of the general safety requirement, taking into account the share of taxiing time in the total flight time. [6]

In RTCA DO-247 (The Role of the Global Navigation Satellite System in Supporting Airport Surface Operations) is stated that the risk of accidents between leaving the stand at the airport and stopping at the stand at the destination should not exceed 10^{-7}, which is called the target level of safety (TLS). For simplicity, it is possible to assume that taxiing time accounts for 10% of the total time of flight. From all statistics [9] about air accidents can be deduced that acceptable risk may be increased five times for taxiing ($5*10^{-7}$). The reason is that only one out of fifty recorded events is the accident. Assuming that the time of taxiing is 6 minutes at zero visibility, the value of loss of integrity (IR) on a taxiway is $2.9*10^{-8}$ and alert limit is 2.8 m. [5] [3]

The determination of TTA (time to alert) can be started from the value of TSC and the driving speed. We assume that for operation in conditions of reduced visibility is taxiing speed lower than at high visibility and whereas the value of TSC is constant for a given category, TTA value is inversely proportional to taxiing speed. For reduction of the TTA value, it is possible to take into account the yaw rate in the event of worsening of any performance parameter of the navigation system. While traveling at normal travel speeds (15 knots), yaw rate could be around a value of 10 degrees per second, and it can be assumed that the maximum yaw angle is less than 30° in normal operation. To determine the TTA we assume that the average speed approaching the edge of the taxiway forms one half speed taxiing. The resulting values for different TTA taxiing speed and TSC = 4.5 m are shown in Table.

Table 4 TTA requirements

Taxiing velocity [m.s^{-1}]	2,6	5	7,7	10,3	12,9
TTA [s]	3,4	1,8	1,1	0,8	0,7

Values in the table are indicative only and are valid for control systems with low latency (fully automatic taxiing). The aircraft, operated by the pilot must take into account the reaction time, which is typically higher than 1 s. From this stems that the requirements for TTA are very limiting.

2.2. Using GNSS without augmentation

By combining new satellite navigation systems (Galileo, GLONASS) with GPS it is possible to achieve favourable performance parameters, and therefore the focus should be also to the use of this combination for ground operations. [13]

Despite significant improvement in accuracy by combining various GNSS navigation systems, it is obvious that the requirement for navigation system accuracy (NSE) will not be achieved. [2] The same limitations are in the area of integrity requirements that are in ground operations rather strict. Currently, the only core GNSS service guaranteeing integrity is safety of life service of Galileo. Values reported directly by ESA themselves do not meet the performance requirements set out above in determining integrity. The issue consists mainly of very high value AL and TTA that are approximately four times higher than for the kind of operation taxiing is. Reducing these values would be theoretically possible by using algorithms to combine all systems. These algorithms are being developed currently, their contribution is, however, questionable as the same issue can be solved by simpler and more reliable manner thanks to the augmentation system (SBAS, GBAS).

2.3. Using SBAS

Satellite augmentation systems (EGNOS in Europe) are in civil aviation widely used to navigate flights in the approach up to category 1 and the number of published approach procedures with SBAS augmentation is constantly increasing. Modern aircrafts are equipped to receive SBAS signals from satellites and therefore its use for ground navigation is possible.

Table 5 EGNOS navigation accuracy [8]

Horizontal accuracy	Vertical accuracy	Integrity Risk	TTA	Continuity	Availability
3 m	4 m	$2*10^{-7}$/APP	≤ 6 s	10^{-4}/15 s	0,99

The table 5 shows the performance parameters of the SBAS augmentation (specifically EGNOS SoL service). Despite the fact that the values are significantly better than in the previous case (non-augmented), they still do not meet the performance requirements. Despite the fact that the combination of existing constellations (GPS, Galileo, GLONASS) of satellite navigation systems can achieve a slight increase in accuracy, integrity is not sufficient in this case. [7]

2.4 Using GBAS

GBAS augmentation is currently at airports expanding relatively slowly, because its installation is accompanied by the high cost for airport operators and comparable benefits can be achieved in many other ways, e.g. using freely available SBAS services. [4] Unlike SBAS, however, the use of GBAS delivers higher performance for the aerodrome (airport and nearby area), particularly in terms of integrity. It is therefore an augmentation with great potential for use for ground operations at the airport.

Table 6 GBAS requirements for CAT II/IIIa [11]

Horizontal accuracy	Vertical accuracy	Integrity Risk	TTA	HAL	VAL	Continuity	Availability
≤ 6,9 m	≤ 2 m	10^{-9}/15 s	1 s	17,3 m	5,3 m	$4*10^{-6}$/15 s	0,99

The table shows the requirements for GBAS navigation performance for approach to landing category II and IIIa (GAST-D), based on the ICAO SARP. The most important requirement is the TTA, which current test equipment of category GAST-D already meet. Desired value of TTA = 1s meets our stated requirements in terms of integrity and GBAS GAST-D is therefore usable as the system for navigation on a taxiway. [10]

3. CONCLUSION

This work is focused on the use of GNSS for ground operations. There are determined parameters needed for this type of operations and evaluated the possibility of GNSS usage. It was found that the requirements for performance for ground operations are relatively high and even exceed the requirements defined by the rules for navigation in the air. The resulting requirements are so strict that they currently cannot be achieved using SBAS augmentation based on too high time to alert (TTA). Requirements are fulfilled, however, in combination with GBAS augmentation, and therefore it can be concluded that the GNSS navigation for ground operation is applicable.

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