Impact of GPS Navigational Errors on the Required Performance of GBAS Approach Service Type D/F (GAST-D/F)

Ahmad Alhosban[1]

Thesis Booklet for Doctoral PhD Degree

In

Defense Electronic Information Technology and Communication (ITC)

Doctoral School of Military Engineering (DSME)

University of Public Services (UPS/NKE)

Scientific Supervisor: Dr. Farkas Tibor[2]

Budapest, Hungary

2018-2022

[1]*Eng.Ahmad Alhosban: PhD Candidate, University of Public Service (UPS/NKE), Doctoral School of Military Engineering (DSME), Defense Electronic Information Communication Technology, Budapest - Hungary, ahmad_alhosban@yahoo.com, ORCID: https://orcid.org/0000-0001-7494-6067*

[2]*Dr. Farkas Tibor, University of Public Service (UPS/NKE), Signal Department, Budapest - Hungary, farkas.tibor@uni-nke.hu, ORCID: https://orcid.org/0000-0002-8868-9628*

Thesis Booklet

1. Introduction

This thesis booklet covers the following topics: Literature review and motivations, formulation of the scientific problem, the main dissertation questions, the main assumptions, and the main objectives associated with the related research methodology for each objective, the hypotheses answers, the new achieved scientific results of this dissertation, the future suggested recommendations are stated. And finally, the main structure of the dissertation.

2. Literature Review and Research Motivations

In this section, I address the four main motivations behind this dissertation, the research literature review and the speculated objectives based on them.

Firstly, In the Global Navigation Satellite System/ Ground Based Augmentation System (GNSS/GBAS) landing systems' domain, the first version of GNSS CAT I performance in what so called GNSS landing system (GLS) was certified in 2002, it was announced by the International Civil Aviation Organization (ICAO) as per (ICAO Annex 10, Volume 1, Amendment 77, 2002), (ICAOAnnex10, 2002), and it was fully technically detailed in (RTCA245A, 2004), this important event took place just after the Selectivity Availability (SA) had been removed in May 2001, then after, many systems were deployed in CAT I performance and had been operated successfully in France, Germany and USA using the GPS system or the GLONASS Russian System since 2002. The worldwide research had continued for achieving CAT II performance certification since that time, until it has been recently approved in Nov 2020 using the GPS single constellation as per (ICAOAmendment91&92, 2020), and it is still under foreseen for CAT III (or what newly called GBAS Approach Service Type F (GAST –F)), the latest performance of CAT III/ GAST-F is tended to be achieved - only and if only - dual constellation is being used.

Lately, a previous study (Rotondo, 2017) showed that the assumption of having dual constellation is subjected to the evaluation of certain significant factors that would restrict using it, such as: firstly, the delay in time due to phase measurements during phase combination at the receiving antenna, which might cause minimizing the accuracy of the Position Navigation and Timing (PNT) information or/and minimizing the margin below the stringent Vertical Alert Limits (VAL) in the integrity availability. Secondly, the complexity of using the multichannel receivers might also cause further delay in time. Thirdly, and above of all, depending on a nation own GNSS constellation would add a significant value of independency in terms of Politics, Economics and Security, as per fully detailed in (Alhosban A. , 2019). On the other hand, President of the United States of America had recently signed a new Executive Order on Position, Navigation and Timing (PNT) services in Feb. 2020, in which he was encouraging the development of a resilient PNT infrastructure that isn't exclusively reliant on the U. S. Global Positioning System (GPS) only, its aim is motivating all providers to search for alternatives of such critical infrastructure, see (President of USA, (Order, 2020). Moreover, many of the recently published researches has conducted this domain individually for a certain airports, neither in a worldwide coverage manner, nor over Europe sky. In which it doesn't help significantly in the certification process needed by the high organizations bodies such as ICAO or FAA.

Based on above facts and motivations, the first objective of this dissertation was made to examine and evaluate the using of a Single Constellation (SC) in GBAS Landing Systems, particularly the European Galileo system over Europe Space. However, the Multipath error is considered a limiting factor to achieve the needed performance to meet the CAT II/III requirements in terms of Accuracy and yet availability. On the other hand, the BOC signals showed a better anti-multipath and anti-interference over the BPSK, in terms of better MEE. Moreover, the generic BOC modulation has been adopted in the modernized Global Positioning System (GPS) (JW, 2001), and the European Galileo System ((Galileo, 2008), because of its good spectral isolation from heritage signals, its high accuracy, and its multipath interference resistance compared with BPSK modulation. Furthermore, and yet, the Multiplexed BOC (MBOC) modulation has been used for the Galileo E1-B/C and the GPS L1C at frequency (1575.42 MHz) to achieve enhanced accuracy and multipath interference resistance by using multilevel subcarrier symbols or combining different subcarrier symbols. Therefore, the first objective is more refined to assess the impact of these errors and enhancement in achieving CAT III/GAST-D/F performance of the GBAS landing systems.

Secondly; from the interference perspective; the Global Satellite Navigational Systems (GNSS) applications - which are using satellite signals in space - are currently and hugely subjected to

Electronic Attacks (EAs) such as Jamming, Spoofing, and/or Meaconing, if it had not already been interfered unintentionally by other host applications. Many accidents were observed in the past decade especially with the huge dependency on GNSS applications in governmental and private critical infrastructure, in both civil and military aspects. The well-known GNSS discrete frequencies (L1, L2, and L5, etc.) are too vulnerable to EAs, because of their extremely low level of power density, this is due to the reason that they are being propagated from long-distance satellites' orbits of about (22,000 Km) via Troposphere and Ionosphere layers. And they arrive the surface of ground at a weak power level. It's around (-160dBw for GPS L1, -154dBw for GPS L2 (Military), Speculated -155dBw for Galileo E1/E2). Saying that, any non-significant exceeded level of any transmitted power by a jamming transmitter would be harmful to them, this impact ranging either destructively at most, or electronically deceptively at least, consequently, the GNSS signals cannot be acquired or/and tracked anymore by the GNSS receivers.

Therefore, the Electronic Attacks were most critically observed by International Civil Aviation Organization (ICAO) and Federal Aviation Administration (FAA), they are in the GNSS/GBAS Landing systems more critical than other applications, because they are used for final landing phase of flights in both civil and military aviation domains, or during military operations in deployed theaters. However, the GBAS landing systems are satellite-based navigational aids used in the Critical Meteorological Conditions (CMC), such as heavy dust and heavy fog, where the visibility tends to zero in the final landing of an aircraft, in which their loss of service during the Final Approach Segment (FAS) is considered a catastrophic disaster to aviation safety-of-life in terms of assets, human and military operations. At those cases, the capability of service restoring on the proper time has very low probability. It is highly risker in such safety-of-life applications of landing systems when compared with other safety –critical infrastructure applications such as banking or with non-critical applications of GNSS huge usages. Moreover, the GBAS stations are usually located in a well-known surveyed reference sites in the vicinity of the airport near the runways, which makes them more vulnerable to EAs, both the fixed ground reference stations and the downwind moving aircrafts while landing close to runway surface.

Moreover, It was observed a strong link between the concept of multipath and EAs, in terms of accumulating two or more signals at the receiving antenna in the so called technically signal interference. However, the over power jamming seems to be similar to the destructive multipath when the phases of the two signals are 180 degrees out of phase, assuming they were modulated and (authenticated) by the same navigation message of Position, Navigation and Timing (PNT). On other hand, spoofing/meaconing seems to be similar to the electronic deceptive side of the multipath signal with long delay time of the original signal that would cause the GNSS receiver incapable to correlate them in proper time, it might mislead the pilots in terms of PNT information.

Based on that, the second objective of this dissertation was to evaluate the impact of the three different types of EAs (jamming, spoofing and meaconing) on the performance of GNSS/GBAS landing system, and to examine the latest proposed Electronic Protection Measures (EPM) for such EAs, providing the using of the three mitigation methods: the receiver-based mitigation methods, the antenna-based methods and the siting-based methods.

Thirdly, and from the perspective of the Geo-Encryption effectiveness, obviously, since the September 11, the terrorist attacks against the internet and servers' data base have noticeably increased, their tools took another path of the means' curve to achieve their ends and goals. Although the fact they have different levels of skills of hacking and computer knowledge, they were likely able to attack and growing their use of the internet as a digital battleground. As per (Denning, 2001), one of the main man-made cyberspaces is the aviation aspect, evidenced by the September 11 event. From which, it is clear that the aircrafts hijacking is possible anywhere and anytime. However, many data and voice messages transfer from the ground controllers to the aircrafts' computers and pilots could be attacked. Consequently, vast of encryption techniques have been developed using many Advanced Encryption Standards (AES) codes' generation process, most focused in this dissertation is the Denning Geo-Located Model (Denning&Scott, 2003), and its enhancements raised lately.

The Geo-encryption or the Geo-Located model is based on the established cryptographic algorithms to provide an additional layer of security. This added layer is enhancing the conventional cryptography, but not replacing it. It enables data encryption for a predefined place or a given geographic area in time and space. If an adversary, attempts to decrypt the data at different location or time, the decryption process would fail. The decryption device determines its location using some kind of location sensors like a GPS receiver or any positioning system. In all the process, it assumed the use of anti-jam and the anti-spoof receivers.

Based on that, the third objective of this dissertation is to assess the implementation of the geo-encryption (Denning&Scott, 2003) Model or the Mobile (Al-Fuqaha, 2007) Model in the approaching high-speed landing aircraft using GLS, and to examine to which extent the GPS signal is capable to be used in terms of immunity against spoofing/jamming in the geo-encryption aiding and in terms of mobility as well, especially in final approach path in the GBAS Landing system application.

Fourthly and lastly, another perspective point of view, and in order to link the GBAS Landing System (GLS) to the Geographical Information System (GIS), a deeper investigation was performed in this aspect, which is the last objective of this dissertation, Historically, the navigational landing systems era had passed through a long way of developments and enhancements since the early 1970s, the major milestones in this development roadmap are the Instrument Landing System (ILS), the Microwave Landing System (MLS) and the GBAS Landing System (GLS). In early ILSs and MLSs stages, the Approach Instrument Plates (AIPs) were not aided by GIS. Recently, a new approach called RNAV (aRea NAVigation) has been used, it is totally depending on the WGS-84 coordinates system of the used beacons rather than their radiations. Consequently, the new GLS systems would be more effective if they have been used along with GIS-aided Approaches, in terms of accuracy and the capacity enhancing the ATM Management.

Based on that, the fourth objective here is to examine the GIS Aided precise approach trajectory using the signals of the GBAS Landing System (GLS) by comparing with the Non-GIS aided approach trajectories used in the current conventional ILSs. Furthermore, the available GIS infrastructure of the Budapest Airport (BUD) is strongly needed to be detailed, showing the future investment in GBAS landing system to optimize the accuracy, integrity, availability performance, as well as increasing the capacity of the air traffic of the airport handling.

With that is being into considerations, these four motivations have been converted to four objectives of this dissertation, from which this research effort took its importance, and its valuable scientific results so far.

3. Formulation of the Scientific Problem

In the satellite based navigation environment, so called Global Satellite Navigation Systems (GNSS) such as the US GPS, the Russian GLONASS, and the Future European GALILEO constellations, the Signals in Space (SIS) are being transmitted by the satellites vehicles in space and are received by the ground receivers through the ionosphere and troposphere layers, those signals when being used solely are currently not being monitored neither accurate enough to meet the requirement of the precision approach of a landing aircraft as per International Civil Aviation Organization's (ICAO) standards Categories (CAT I to CAT III) of the needed performance to support flight safety Airworthiness. However, the augmentation technique is strongly needed to enhance their availability performance of accuracy, integrity, and continuity of service. The Ground Based Augmentation System (GBAS), which is one of the three Augmentation Systems globally used: Space Based Augmentation System (SBAS) and Airborne Based Augmentation System (ABAS), is intended to be used for precision approach from CAT I to CAT III. Although GBAS is currently been into operation at many airports globally, but to support CAT-I performance precision approaches only (Michael, 2015).

Basically, The Ground-Based Augmentation System (GBAS) provides corrections and integrity monitoring information along with the global navigation satellite system (GNSS) signals to provide navigation guidance for precision approach and landing for both civil and military aviation in all bad weather situations, GBAS is alike to (and will eventually and gradually supplement or/and replace) the currently used Instrument Landing System (ILS), it has been used since many years ago in all the controlled airports worldwide, ILS is used in order to guide the landing aircrafts to the centerline of a runway within a gliding angle (nominally 3 degrees) in the bad weather conditions where the visibility is very low. However, GBAS is based on the differential GNSS technique, where errors in GNSS range measurements are corrected in the range domain or area, the corrections delivered in real time are based on measurements by at least 2-4 ground reference GNSS receivers usually placed at or near an airport with their locations precisely known, those accuracy corrections for each satellite in view (within an elevation angle higher than 5 degrees above horizon) as well as integrity information are sent through VHF Data Broadcast (VBD) stations to (and are used by) the aircraft onboard receiver, then they are been applied to its real time position along the landing path vertically and laterally (Susumu, 2017).

GBAS will increasingly become a safety-critical application of GNSS for civil aviation requiring a high level of availability of (accuracy, integrity and continuity of service), so called performance. The performance requirements are defined by the International Civil Aviation Organization (ICAO) Annex 10 (ICAO 2014). Standards for avionics are further refined by relevant standardizing organizations such as RTCA (RTCA 2008a, b)/EUROCAE, EUROCAE also defined minimum operational performance standards for GBAS ground subsystem (EUROCAE 2013). However, GBAS has been standardized based on the use of single-frequency GNSS (L1, centered at 1.57542 GHz) only (Susumu, 2017). Those performance requirements can be summarized (but not limited to) as follows, knowing that CAT I in ground ILS system is equivalent to GBAS Approach Service Type C (GAST-C) in satellite system, and CAT II is equivalent to GAST-D, and CAT III equals to GAST-F, see figure 1 below:

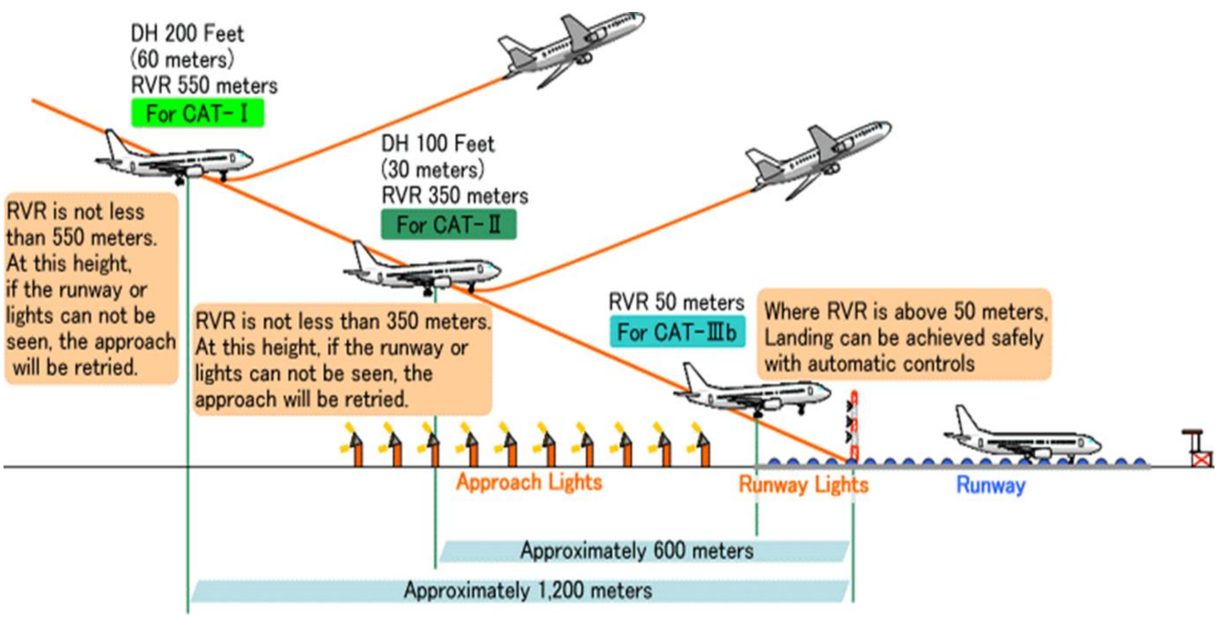

FIGURE 1: THE REQUIRED AERONAUTICAL REQUIREMENTS FOR ILS/GBAS LANDING SYSTEMS [OPEN SOURCE]

- ## Signal in Space Continuity of Service Performance:

The GBAS Signal in Space continuity of service is defined by the probability that a fault-free aircraft subsystem provides valid outputs during any defined period of an approach, assuming that outputs were valid at the start of the period. Outputs are considered as valid if the Navigation System Error (NSE) is lower than alert limits and if there is no warning, and as follows:

- For CAT I operations: shall be greater than or equal to 1 - 8 x 10^{-6} during any 15s period.
- For CAT II and CAT IIIA operations: shall be greater than or equal to 1- 4 x 10^{-6} during any 15s period.
- For CAT IIIB operations: shall be greater than or equal to 1- 2 x 10^{-6} during any 15s period for vertical and greater than or equal to 1- 2 x 10^{-6} during any 30 s period for lateral guidance.

- **Signal in Space Integrity Performance:**

The GBAS Signal In Space (SiS) integrity risk is defined as the probability that the GBAS Ground Subsystem provides information, which when processed by a fault-free receiver, using any data that could be used by the aircraft, results in the position error exceeding the alert limit for a period longer than the maximum SiS time-to-Alert without annunciation, and as follows:

- For CAT I operations: is required to be less than 2 x 10^{-7} in any one operation.
- For CAT II and CAT III operations: is required to be less than 1 x 10^{-9} in any one operation.

- **Signal in Space Vertical Accuracy performance:**

The GBAS vertical accuracy is defined in terms of vertical Navigation System Error (NSE). The vertical NSE is the difference between the measured and true vertical displacement from the final approach path. The probability that the vertical NSE value is within the limits shown below shall be at least 95% per approach. The vertical accuracy limits are given as a function of the height (H) above Landing Threshold Point / Fictitious Threshold Point (LTP/FTP) of aircraft position, (Lateral Accuracy is already identified by not mentioned due its compliance), and as follows:

- For CAT I operation:
    - Between 100ft HAT and 200ft HAT, a constant value of 4 m.
    - Between 200ft and 1340ft HAT, linearly varying from 4 to 17.3m.
- For CAT II operation:

- Between 50ft HAT and 100ft HAT, a constant value of 1.4m.
- Between 100ft and 1340ft HAT, a value linearly varying from 1.4 to 17.3m.

- For CAT III operation:
  - Between 50ft HAT and 100ft HAT, linearly varying from 0.7-1.4m.
  - Between 100 feet and 1340 ft. HAT, linearly varying from 1.4 to 17.3 m.

GBAS Approach Service Type C (GAST-C) stations supporting CAT I operations have been fully developed and already certified with a 200ft decision height for precision instrument approach and landing, the first GBAS stations are currently operational in France, Germany, USA and other countries. Furthermore, the single-frequency GPS-based GBAS GAST-D, which is intended to support operations of CAT II, with lower than 100ft decision height, is still under development including automatic approaches and landings, requirements have been drafted, approved and are currently undergoing validation (Michael, 2015) (Yiping Jiang, 2016). Moreover, with the forthcoming GNSS environment, GAST-F has been designated to the provision of CAT III services using multi-constellation and dual-frequency corrections which will mitigate the issues raised under GAST-D and is being investigated within the European SESAR program (WP 15.3.7) (Yiping Jiang, 2016). Therefore, the dual constellation is the limiting factor for GAST-D/F implementations, especially in the case of Galileo delay.

The Ground Based Augmentation System (GBAS), as a new and alternative approach with high levels of performance in terms of navigation for aircraft, counters systematic errors in broadcast correction ranging measurements associated, such as Ionosphere Delay ID (IrfanSayim, 2017) and Multipath Errors ME (Yiping Jiang, 2016) when using a Global Positioning System (GPS) L1 frequency receiver. In principle, ID can be simply estimated with the aid of dual frequency receivers (GPS L1 and L2) or a new GPS signal (L5), ID is Low-latitude ionosphere disturbances dependent, and frequency depend as well, but the GBAS relies only on the L1 frequency as the L2 frequency is not protected by Aeronautical Radio Navigation Service (ARNS) and L5 is not fully functional yet, neither the new European Global Navigation System Galileo is fully operational yet (anticipated Full Operational Capability (FOC) in 2025 if not beyond, it was supposed to be FOC in Dec 2018 but the remaining 4 satellites out of 30 and the ground stations networking are still not contracted yet, see more details about the three main phases of Galileo navigation project as per (ESA, Galileo Navigation, 2018).

However, beyond Galileo FOC, a period of (5-10 years) anticipated to be needed for the gradually transition phase for the new systems in, and the legacy ones out. Furthermore, and optimistically, the enhanced performance of the Galileo navigation system could enable worse performing aircraft, those with larger Flight Technical Errors (FTE), to meet the requirement, based on the fact that total system performance depends upon both the navigation system error (NSE) and the Flight Technical Errors (FTE) (SARPs 2009).

Mainly, Ionosphere Delay (ID) and Multipath Error (ME) are the most errors challenge for GBAS Approach Service Type D (GAST-D) performance to be achieved using GPS L1, most the recently peer-reviewed published studies by the most experts and working groups in this domain are conducting methods of predictions and estimations of such errors and their effects on GBAS performance especially type D/F (CAT II/III). Moreover, some of those studies were being done and limited for a specific region or for a specific airports, and conducting one type of errors to determine its impact or its associated simulating software. At the same talking, my previous master dissertation study was conducting the user multipath effect on GBAS availability of integrity globally.

Later many multipath mitigation methods of such big threat were developed and did minimize the effect to be closer to achieve type D/F performance, other studies did conduct the ground multipath error impact in some airports due to tough terrain. In addition, and due to the medium term of minimum 5-10 years for the full operational capability (FOC) of Galileo, as the second satellite navigation system using L1, with an added another of 5 to 10 years of gradually transition period, saying that, it has been noticed that most of the studies recently published didn’t conduct a comprehensive evaluation of the total error affecting achieving GBAS Type D/F performance. With that said, the total system performance of GAST-D/F GBAS, depending upon both the Navigation System Error (NSE) and the Flight Technical Errors (FTE), so called the total error budget (NSE +FTE), should be identified, determined and proved globally-wise and regionally-wise in terms of their dependency to achieve GAST- D/F Performance requirements.

From another perspective; the GPS L1C signal is not monitored yet, the signal integrity is not assured, it may mislead the pilots in terms of position information, especially in the final phase of flight landing, in which the probability of error should tend very low values, almost to less than 2 x 10^{-7} failure occurrence in any one operation is required to be for CAT I operations, and less than 1 x 10^{-9} failure occurrence in any one operation is required for CAT II/III, i.e. GAST –D/F. Also the interference impact may add another value for the errors and it should be modelled and identified, moreover, mitigated to its minimum probabilities as well.

Taking into consideration the mentioned motivations in section 1.2 above, and the rationale scientific problem formulation mentioned in section 1.3 above, all the above factors had led to the research objectives, in order to start, with a suitable methodology tools, to search for the best solutions to this scientific problem in the aviation domain. I tried my best to reach at the end of this research dissertation to the ultimate, optimized engineering scientific results.

By this is being taken into considerations, the questions, objectives hypotheses and their associated methodologies of the dissertation were addressed carefully as illustrated in the next sections.

4. Dissertation Questions

Based on the above literature review and motivations as well as the scientific problem formulation, the questions of the dissertation were as follow:

- How efficient the GBAS Landing systems (GLSs) to achieve the required performance of CAT II/III (or newly called GAST-D/F?
- What is the impact of GPS Navigational errors on the required performance of GBAS GAST-D/F Landing systems?
- What is the impact of the Electronic Attacks on the GBAS GAST-D/F performance?
- How far the geo-encryption model and its mobility be implemented in the approaching high-speed landing aircraft using GLS?
- How to optimize and to enhance the use of the GIS-Aiding precision approaches in the GBAS Landing systems?

5. The main Assumptions of the Dissertation

The main assumptions of the dissertation are:

- Using single constellation of the EU Galileo Navigation system.
- Using dual frequency transmission to minimize the effect of Ionospheric and tropospheric errors.
- Using a limited coverage area over Europe with comparison with USA Area.
- Using a validated simulation tool to assess the needed availability for GAST D/F.
- Using a validated Matlab software to assess the Multipath Envelope Error (MEE).

6. Dissertation Objectives and their related Research Methodologies

In order to investigate the feasibility of achieving the GAST-D/F performance using GNSS Landing Systems, the main objectives of this PhD study are as stated and sequenced as below:

1. To investigate and define the impact of GPS/GNSS Navigational errors on the required performance of GBAS GAST-D/F landing systems. This was performed by using:
    a. AVIGA validated Simulation Tool for the availability Assessment.
    b. Matlab Code line programming for the Multipath Error assessment.
2. To investigate and model the impact of the Electronic Attacks on the performance GBAS GAST-D/F landing systems. This was performed by using modelling method for the interference caused by electronic-attacks, with analogy to Multipath errors estimations.
3. To assess the implementation of the geo-encryption model and its mobility in the approaching high-speed landing aircraft using GLS. This objective was performed by examining the model in different flight phases.
4. To optimize and enhance the use of the GIS-Aiding precision approaches. This was performed by a qualitative research method by examining the Budapest Airport (BUD) aerospace using GIS approach plates.

7. The New Achieved Scientific Results

Most importantly to be mentioned is that all of this dissertation achieved scientific results were published in peer-reviewed Journals, the publications were continuously and timely performed as the progress of the research went on. The time schedule of the research during the 4-year research plan was conducted and supervised carefully, trying to mitigate all the difficulties and to overcome all the challenges that faced this work. All the efforts led to the success of showing up the following achieved new scientific results in the domain of GNSS/GBAS landing systems, which contribute directly and seriously to the aviation worthiness and safety.

The new achieved scientific results are:

1. New scientific result # 1a: Global coverage: I have approved that the global availability of the GBAS Landing System in GAST-D/F performance of 99.99% using a single constellation simulator (Galileo or GPS) is not feasible in Single Constellation/ Dual Frequency SC/DF, but Galileo is more visible when CB-DF precision configuration is reached, which is characterized being newly updated result than a recently announced in 2020 by ICAO in Annex 10/V.1/Amendment 92. It is more precise and fully validated than the previously conducted studies.

New scientific result # 1b: Regional coverage: I have innovated a regional coverage selection, and I approved that Galileo constellation is able to fulfil the aeronautical requirements of both 99.99% and 99.75% (GAST-D/E/F) over Europe sky using GBAS precise configuration of CB-DF, and it is very close (99.404%) over USA, but the GPS constellation is not able to fulfil these requirements, which is characterized being a new, approved, validated and efficient regional operational concept of GBAS system not being conducted by any other previously studies except as individual airports.

2. The new scientific result # 2: I have developed a structural Matlab software of nearly 1000 code lines to assess the impact of the new BOC signals and filters on the MEE errors in the GPS receivers based on the theoretical multipath error equations, which is characterized being a new, validated, more comprehensive and more customized software than those being recently used by the Chinese researchers in 2020. It is more capable of being customized to assess any new GPS signal process analysis in the future.

3. New scientific result # 3: I have developed a new methodology in assessing the impact of the Electronic Attacks on the GPS signal using the Multipath analogy approach in terms of power level, time of action and data affecting, which is characterized being a new methodology and more efficient than other empirical assessing methods in GBAS protection domain. It assesses by a simulating tool to which level of protection is needed in each configuration.

4. New scientific result # 4: I have approved that the innovated Denning Geo-Encryption model and its mobility enhancement is not efficient in flight modes, it cannot be characterized to be safely used in approach and landing phases due to the high speed mobility of the landing aircrafts, vulnerable and weak GPS signal, slow navigational message update rate, and the wind-varying descent speed. But it can be used with more added value in stationary or semi-moving modes only, which is characterized being safer and less risky than the similar geo-encryption mobility model created by Alfugaha model.

5. New scientific result # 5: I have approved that there is a feasibility of installing a GBAS station in Budapest International Airport, for the sake of having more accurate approaches and enhanced capacity of its air traffic management, In addition, I have approved that the GBAS system performance will be better than the existing ILS systems in Budapest airport, which is characterized being a new result, validated and geographically approved, it is not being conducted by any other researchers in this domain yet.

8. Hypotheses' Answers

The answers for the dissertation hypotheses are addressed in Table 2 below:

#	Hypothesis	Results after testing
1	Single GNSS GBAS systems are capable to achieve GAST-D/F global performance in landing operations.	No , but Regionally only
2	Galileo/GPS each alone is capable to achieve GAST-D/F regional performance in Landing operations.	• Galileo: Yes, over Europe, and very close globally. • GPS: Neither globally Nor regionally

3	Galileo is more immune to Electronic Attacks than GPS	Yes
4	GEO- Encryption is not efficient with high speed mobility of the landing aircrafts that using GNSS.	Yes
5	GNSS Landing Systems (GLSs) have better performance with Geographic Information system (GIS) approaches plates than conventional ILSs.	Yes

Table 1: HYPOTHESES' ANSWERS

9. Practical Availability of the Scientific Results and Recommendations

This dissertation long study is a continuation of a previous master study in 2006 in France, on the same aspect of assessing the Impact of GPS errors on GBAS landing System, but in Performance CAT II or GAST D. that master study recommended at that time, along with adjacent similar studies worldwide, to certify the GNSS GBAS Landing system to be operated in CAT II/GAST-D performance. Recently, in 2020, ICAO has certified it, and finally it saw the light successfully, but not in CAT III/ GAST-F performance, the CAT III /GAST –F performance is not foreseeable to be certified as per ICAO unless dual constellation (by adding Galileo GNSS system) is being used for this purpose.

Consequently, in this Dissertation research, and based on my achieved and approved scientific results, I recommend ICAO to certify the GBAS Landing system in CAT III/GAST-F performance using a single constellation of Galileo or GPS also. At least, it can be certified to be operated regionally over Europe/or over a Single Airport like Budapest Airport using the European Galileo constellation. In addition, I encourage researchers worldwide to perform similar researches in the same domain to support my findings and recommendations.

Detailed technical recommendations are listed in each chapter in this dissertation, and they are summarized as below:

- I recommend that a further investigations in this aspect is recommended when Galileo system comes to its full operation capability of 30 satellites. As well as the modernized GPS Block III comes to its full 20 satellites capability, this would be anticipated by 2025.

- I recommend to use the developed Matlab software for researches in MEE assessment in GBAS applications. Because it is capable to be customized and improved for more purposes due to its simple structure and its dependency on different sub function that can added easily according to the needed mission
- I recommend using the analogy method of interference between the unintentional multipath error and the intentional electronic attacks in order to assess to which extent the electronic equipment could be affected constructively or destructively.
- I recommend that further investigations of such better concept of geo-encryption in flight phases should be conducted by experimental flight tests, which is beyond the capability of the scope of this PhD Dissertation.
- I recommend that there is a technical feasibility of installing a GBAS station in Budapest International Airport in the performance of GAST-D/F, it can be adopted - as many civil aviation authorities adopted – as an alternative usage of the GLS system side by side with the existing ILS system, in order to make easier the gradual transition to the potentially coming GLS systems. Many benefits can be achieved in terms of cost effectiveness, capacity increase, and enhanced performance.

10. Dissertation Structure

The main structure of this dissertation is detailed in the following table 2, The dissertation chapters were written based on the published papers/articles of each individual objective, each objective was planned to be dealt with during the 4-year research plan of the doctoral program, in which the research phase took place in the 3rd and the 4th years, while the academic phase took place in the 1st and the 2nd years along with some research activity as well.

Chapter No.	Chapter Title/objective	Publication Status
Ch.1	Introduction and Motivations	
Ch.2	**Literature Review**: Balancing the Position in Space between GPS and Galileo	Published

Ch.3	**Obj.1:** Impact of the GPS Errors on the Availability of the GNSS-GBAS Landing Systems in CAT III/ GAST-D/F Performance	Published
Ch.4	**Obj.1:** Effectiveness of the Multiplexed Binary Offset Carrier (MBOC) Modulation on Multipath Error Envelope in GNSS Receivers	Published
Ch.5	**Obj.2:** Impact of Electronic Attacks on GNSS / GBAS Approach Service Types C and D Landing systems and their proposed Electronic Protection Measures (EPM)	Published
Ch.6	**Obj.3:** GPS Characterization in Cyberspace Between Vulnerability and Geo-encryption: Impact on GBAS Landing System (GLS)	Published
Ch.7	**Obj.4:** Assessment of the GIS-Aided Precise Approach Using the GNSS-GBAS Landing Systems	Published
Ch.8	Summarized Conclusions and Recommendations	

Table 2: DISSERTATION STRUCTURE (CHAPTERS VERSUS OBJECTIVES)

The two phases were continuously linked together in a regular basis, and they were mile-stoned by the comprehensive Exam, which was designed to examine the academic knowledge and the research progress too. Figure 2 below shows the whole process of the dissertation building and the research activities.

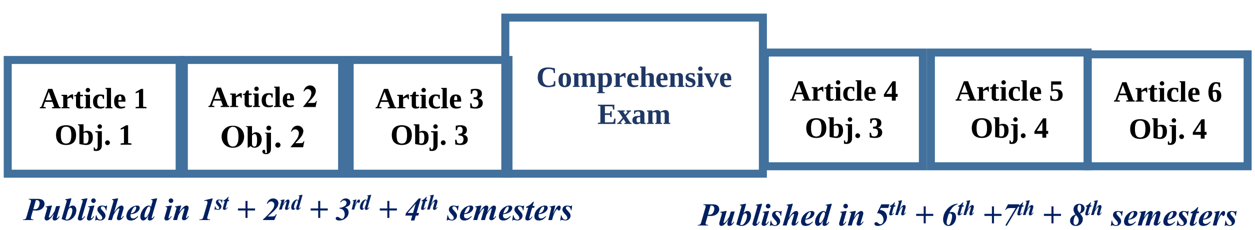

FIGURE 2: DISSERTATION PROGRESS (RESEARCH ACTIVITIES PHASE Vs ACADEMIC PHASE)

With that is being said, I reach to the end of my dissertation for this PhD Degree in UPS/NKE University at Budapest Hungary.

Appendix C: Author CV (Resume)

Mr. Ahmad M. S. Alhosban is a PhD candidate from Jordan, He is an Ex-Air-Force Colonel Engineer, He joined the PhD Program in the Defense Electronic ICT Research field at the KMDI /NKE since 2018, and he has got Excellent grades, 4.98 out of 5. His research topic is the **Impact of GPS Navigational Errors on the Required Performance of GBAS Approach Service Type D/F (GAST-D/F) Landing Systems.** During his PhD program, Mr. Alhosban has successfully published 5 papers, from which 2 of them were abroad in Check Republic and Romania, and 3 in Hungary, 4 of them are in A/B peer-reviewed Journals and 1 in C/D Rank. He still has an extra paper in process, and he wrote a chapter in a book also under publication process. All were in the scope of his topic objectives. Mr. Alhosban also has conducted 5 international conferences, 2 of them were abroad in Slovakia and Austria, 1 was published. Also he was awarded a University level scientific grant, all were in his aspect topic. He had his master degree from ENAC University in France, Toulouse, in 2006, his aspect was Satellite-Based Communication, Navigation Surveillance Engineering for Air Traffic Management, before he had got his BSc in Electrical and Communication Engineering from Jordan in 1994, and both were in a very good grades. Mr. Alhosban was the Chief of Ground Communication Supply Branch, also he was the Founder/Chief of the ATC Engineering B.Sc. program in the Aviation Science Faculty in a Jordanian University, and he was the Commander of the Electronic Workshop's/Labs, His Total years of experience is 24 years, from which 6 years of them were in the teaching activities as a University teacher. Mr. Alhosban has lead and perform many Electronic communications and navigational projects and system installations during his service in Air Force, he also had designed and installed the video streaming system on the air force aircrafts. He supervised more than 30 flight checks of their commissions and periodic maintenance. Colonel Ahmad has joined the Jordanian Engineering Association since 1994, and he has got a consultant rank in his aspect, he also was an effective represented for the GNSS Air Navigation National Strategic Committee, hosted by the Ministry of Transportation and leaded by CARC, Civil Aviation Regularity Commission. Furthermore he represented Jordan in the ICG Expert Meeting in Vienna, Austria, Under UNOOSA, 2015. He also joined the Outer space research Group in Hungary in 2021. His Total Number of training period in U.S.A is (30 weeks). And in France is (30 weeks). And in Germany is (26 weeks). As well as Italy, Sweden and Austria for 2 weeks each. He has got the Royal Legion of Merit 2nd class medal 2016.

Personal Information:

- Name: Ahmad M. S. Alhosban
- Date of Birth: 28 July 1972, Place of Birth: Al-Mafraq, Jordan
- Nationality: Jordanian
- E-mail: ahmad_alhosban@yahoo.com

Profile of Education:

- **PhD Candidate/ 4th Year:** in ICT/Satellite GNSS Navigation Engineering, GBAS Systems, @ National University for Public Services (NUPS/NKE), Budapest, Hungary, since 2018. Excellent, 4.97 out of 5, Rank 1st.
- **Rank: JCE Consultant Engineer in Communication, Since** May 2017, from Jordanian Engineering Association. Rated highest possible degree.
- **Master Degree (MS)/Advanced (Bac+7)** in Satellite-Based Communication, Navigation, and Surveillance SB-CNS/ATM, from ENAC, Toulouse, FRANCE @ 2006, rated Very Good, 1st rank.
- **Bachelor's Degree (BSc)** in Electrical / Communication Engineering, from Mu'tah University, KARAK, JORDAN. @ 1994, rated Very Good, 3rd rank.
- **Diploma Degree** in Military Science from JORDAN@ 1994, rated Excellent.
- **General Secondary Certificate** (Scientific Stream) from Al-Mafraq High school, Jordan, @1989/1990. Rated Excellent, 1st rank.

Languages:

- **Arabic**: Mother Tongue, fluently
- **English**: Second Language, fluently in Listening, Reading, Writing and Speaking.
- **French and Hungarian**: third Languages, Reading only.

Computer Science:

- **Programming Languages** (Matlab, Visual Basic, Fortran): Very Good
- **Spécial Programming** (MD110 Exchange, AXT Exchange, Radios, Vidéo Communications, Navigation networks, GPS networks) : Excellent

Management and Logistics: Projects' management, Personnel management, financial management, Resources management, Electronic Workshop Commander and chief of Com/NAV/Radar Supply

University Education

University/Country	Dates	Certificate	Results
National University of Public Services (NUPS/NKE)	2018-2022 5 years	PhD Candidate ICT-GNSS Engineering	Excellent (4.97/5) 1st Rank/25
Ecole Nationale de l'Aviation Civile (ENAC, Toulouse/France)	2005 – 2006 (1.2 year)	Advanced Master in CNS (Satellite-Based, Communication, Navigation and Surveillance)	Very good (82. 5 %)/1st rank/7
Mu'tah University, Karak/Jordan	1990-1994 (5 years)	Bachelor's Degree in Electrical / Communication Engineering	Very Good (78.48%)/3rd rank/13

College and School Education

College/Country	Dates	Certificate	Results
Mutah Collège, Karak/Jordan	1992-1994	Diploma Degree (Bac+2) in Military Science	Excellent (95%), 20th rank/360
Al-Mafraq High School, Jordan,	1989-1990	General Secondary Certificate (Scientific Stream)	Excellent (91.9 %)/1st rank
Al-Mafraq High School, Jordan,	1987-1988	Basic Elementary School Certificate	Excellent (97.8%)/1st Rank

Special Training

College/Country	Dates	Certificate	Results
Defense Language Institute(DLI), Lackland AFB,Texas,USA	Feb/2004-May/2004	Diploma in Specialized English	Outstanding
Keesler AFB, Mississippi, USA	May/2004-July/2004	Diploma in Expedientiary Communication & Information Training (ECOT)	Distinguished

Professional Job:
Retired in Sep. 2018 as Colonel 4th Year from RJAF as: Chief of Ground Communication Supply Branch and Chief, B.Sc. of ATC Division- Aviation Science Faculty and Electronic Workshop's/Labs Commander, Total years of experience: 24 years, Period: 1994 to 2018
Organization: Jordan Engineer Association, Period: 1994 to present

Details of positions:

Dates	Position	Place
2015-2018 Parallel job	Chief, and founder of the program of B.Sc. of ATC Division- Aviation science Faculty AABU University	Al Al-Bait University AABU
2018-2018	Chief of Ground Communication Branch	Directorate of Electronic Communications
2016-2018	Commander, Electronic Workshops and PMEL Labs	Directorate of Electronic Communications
2014 - 2016	Chief of Electronic Communication Supply Branch	Directorate of Supply
2013 - 2013	Navaids/Radios / 1st Staff Officer	Directorate of Electronic Communication
2007 - 2013	Navaids& Radios Maintenance Senior Field Engineer	Electronic workshops and labs
2005 - 2006	Master SB-CNS France	ENAC, Toulouse, France
2002 - 2005	Navaids Senior Field Engineer & Instructor	Navaids workshop/RJAF
2000 - 2002	Electronics &Communications Instructor(Teacher)	Prince Faisal College

1994 - 2000	Communication/Navigation Site Engineer	Different bases in RJAF /Jordan

Main Performed Projects:

Project	Date	Place
Foundation and Teaching GNSS courses, Advanced GNSS and BPA courses and RNAV courses	2013-2016/ 4 courses	Queen Noor Civil Aviation Technical College(QNCATC)
Establishing Full Motion Video (FMV) Analysis Center in	2013-2015	Squadron 15/RJAF
Adding Metadata Capability to the Video stream.	2014-2015	Squadron 15/RJAF
BMS, video receiving center network over fiber from (4) receiving sites installation (10) ten video receiving sites.	2009-2012	RJAF/ JORDAN
Addressable fire alert systems installation s in three sites	2007+2008	RJAF/ JORDAN
3 ILS/DME and 4 VORs installations	2008-2012	4 bases in RJAF
Telecommunication Cabling Infrastructure installations	2002-2004	KFAB and KA2AB/RJAF

Seminars:

- ✓ International and national Security Conference, Slovakia, Oct, 2019, lecturer
- ✓ Info Communication Conference, Budapest NKE, Nov.2019, lecturer
- ✓ Aviation Conference, Szolnok, Budapest, April 2019, jamming effect on GBAS Systems for CATII/III performance. lecturer
- ✓ ITU Regional Workshop on Terrestrial and Space Radio Communication Services for the Arab States, Amman - Jordan, 29 November – 1 December 2016
- ✓ ICG Expert Meeting in Vienna, Austria, Under UNOOSA, 14-18 Dec 2015, giving a GBAS presentation and publicized in website,
- ✓ GNSS Air Navigation National Strategic Committee, an effective RJAF member/representative in permanent committee to address the GNSS future in Jordan, hosted by the Ministry of Transportation and leaded by CARC, Civil Aviation Regularity Commission.

Special O.J.T.:

- ✓ FAA Flight Inspection for TACAN, VOR, ILS /USAir force, Jordan, 2002 to 2013, 5 weeks /year
- ✓ Total Number of training period in U.S.A and English spoken countries is (30 weeks).
- ✓ Total period in France is (30 weeks).
- ✓ Total period in Germany is (26 weeks).
- ✓ Total period in Hungary: 4 years till now

Outside visits: **Hungary (4year), U.S.A** (20 states) over 25 times (1.5 Year), **France** (1 year and 2 months), **Germany** (6 months), **U.A.E** (Dubai) 2 times, **Italy, Sweden, Austria**.

Medals: Legion of Merit 2nd class medal 2016

List of Publication
Ahmad ALHOSBAN

1. Ahmad Alhosban: „GPS Characterization in the Cyberspace Concept between Vulnerability and Geo-Encryption: Impact on GBAS Landing System (GLS)"
Revista Academiei Fortelor Terestre / Land Forces Academy Review 25: 2. pp. 146-158., 13 p. (2020) DOI 10.2478/raft-2020-0018
https://www.armyacademy.ro/reviste/rev2_2020/Alhosban_Raft_2_2020.pdf

2. Ahmad Alhosban: „Assessing Availability of GNSS-GBAS Landing Systems in GAST - D/F Performance"
Advances in Military Technology 17:1 (2022)
DOI 10.3849/aimt.01540
(accepted for publication)

3. Ahmad Alhosban: „Electronic Warfare in NAVWAR: Impact of Electronic Attacks on GNSS / GBAS Approach Service Types C And D Landing Systems and their Proposed Electronic Protection Measures (EPM)"
Hadmérnök 14: 2. pp. 238-255., 18 p. (2019) DOI 10.32567/hm.2019.2.20
https://folyoirat.ludovika.hu/index.php/hadmernok/article/view/351/54

4. Ahmad Alhosban: „Navigation Warfare (NAVWAR): Balancing the Position in Space between GPS and Galileo"
Hadmérnök, 14: 4. pp. 163–177. 15p. (2019) *DOI 10.32567/hm.2019.4.10*
https://folyoirat.ludovika.hu/index.php/hadmernok/article/view/940/293

5. Ahmad Alhosban: *„Assessment of the GIS-Aided Precise Approach Using the GNSS-GBAS Landing Systems"*,
Repüléstudományi Közlemények 32: 2. pp. 49–65. 17p. (2021) DOI 10.32560/rk.2020.2.4
https://folyoirat.ludovika.hu/index.php/reptudkoz/article/view/1507/4238

6. Ahmad Alhosban: *„Impact of Multipath error on Availability of integrity in GBAS Application"*
In: International Committee on Global Navigation Satellite Systems Experts Meeting on Global Navigation Satellite Systems (GNSS) Services; Abstracts Book; pp.17-22. 6p (Vienna, Austria 15 - 18 December 2015)
https://www.unoosa.org/pdf/icg/2015/2015abstracts.pdf

7. Ahmad Alhosban: *„Assessing the Availability of the Modernized GNSS to achieve GASTD/F Requirements in GBAS Landing Systems"*
In: Repüléstudományi Konferencia 2021. Book of Abstracts; pp.3-4; 2p (Szolnok, Hungary 08. April 2021)
https://ludevent.uni-nke.hu/event/723/book-of-abstracts.pdf

8. Ahmad Alhosban; László Bodnár: *„The Adopted Approach to the disaster management of Covid-19 Pandemic In Jordan /role of the National Center for Security and Crisis Management (NCSCM)"*
In: Fire Engineering & Disaster Management Prerecorded International Scientific Conference 2021. Book of abstracts; pp.489. (Budapest, Hungary 23. February 2021.)
https://kvi.uni-nke.hu/document/kvi-uni-nke-hu/440-konferencia.pdf

9. Ahmad Alhosban: *„GNSS Space Racing Beyond the Cold War Era-Technical Comparative Study”*
   In: „XXIII. Tavaszi Szél Konferencia: MI és a tudomány jövője 2020” Absztrakt kötet; pp.7. (Budapest, Hungary 16. October 2020.)
   https://www.dosz.hu/__doc/dokumentumfile/2020/tavaszi-szel-2020-absztrakt-kotet-i-final.pdf

10. Ahmad, Alhosban: *„NATO EU Nations’ Posture in GNSS”*
    In: Gateway of Science - Poster Contest and Exhibition; Part of the European Cyber Security Month (ECSM) and NATO70 (Budapest, Hungary 5. November 2019.)
    https://www.uni-nke.hu/document/uni-nke-hu/2_NKE%20D%C3%96K_A%20Tudom%C3%A1ny%20Kapuj%C3%A1ban.pdf