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Nomenclatures and Abbreviations

| Abbreviation | Meaning |
|--------------|---|
| ADS | Air Data System |
| AOC | Advanced Operational Capability |
| APV | Approaches with Vertical Guidance |
| ASM | Airport Surface Movement |
| ATC | Air Traffic Control |
| ATM | Air Traffic Management |
| BOC | Binary Offset Carrier |
| BPSK | Bipolar Phase Shift Keying |
| BRNAV | Basic Area Navigation |
| C-RAIM | Carrier phase based RAIM |
| C/A Code | Coarse/Acquisition-Code |
| CAA | Civil Aviation Authority |
| CFMU | Central Flow Management Unit |
| CNS | Communications, Navigation and Surveillance |
| CDMA | Code Division Multiplex Access |
| CS | Commercial Service |
| DGPS | Differential Global Positioning System |
| DME | Distance Measuring Equipment |
| DoD | Department of Defense |
| DOP | Dilution of Precision |
| DOT | Department of Transportation |
| E-GBAS | Extended GBAS |
| ECAC | European Civil Aviation Conference |
| ECEF | Earth-Centred-Earth-Fixed |
| EGNOS | European Geostationary Navigation Overlay Service |
| ESA | European Space Agency |
| FAA | Federal Aviation Administration |
| FANS | Future Air Navigation Systems |
| FMS | Flight Management System |
| FOC | Full Operational Capability |
| FTT | Full Trinomial Tree |
| GBAS | Ground Based Augmentation System |
| GCC | Galileo Control Centre |
| GGTO | Galileo-GPS Time Offset |
| GIS | Geographic Information System |
| GMT | Greenwich Mean Time |
| GNSS | Global Navigation Satellite System |
| GPS | Global Positioning System |
| GSA | GNSS Supervisory Authority |

| | |
|----------|--|
| GSS | Galileo Sensor Stations |
| HA-NAV | High Accuracy Navigation |
| IA | Integer Aperture |
| ICAO | International Civil Aviation Organization |
| ICT | Indexed Combination Traversal |
| IFR | Instrument Flight Rules |
| IGEB | Interagency GPS Executive Board |
| IGS | International GPS Service |
| ILS | Instrument Landing System |
| INMARSAT | International Maritime Satellite Organization |
| INS | Inertial Navigation System |
| IOC | Initial Operational Capability |
| ION | Institute of Navigation |
| IOV | In-Orbit Verification |
| JAA | Joint Aviation Authorities |
| LAMBDA | Least Squares Ambiguity Decorrelation Adjustment |
| MCAR | MultipleCarrier Ambiguity Resolution |
| MCM | Minimum Constellation Method |
| MDB | Minimum Detectable Bias |
| MEO | Medium Earth Orbit |
| MLS | Microwave Landing System |
| NAVAID | Navigation Aid |
| OS | Open Service |
| PA | Precision Approaches |
| PBN | Performance Based Navigation |
| PL | Protection Level |
| PRNAV | Precision Area Navigation |
| PRS | Public Regulated Service |
| RAIM | Receiver Autonomous Integrity Monitoring |
| RINEX | Receiver Independent Exchange |
| RMS | Root Mean Square |
| RNAV | Area Navigation |
| RNP | Required Navigation Performance |
| PRN | Pseudo Random Noise |
| RTK | Real Time Kinematic |
| SBAS | Satellite Based Augmentation System |
| SIS | Signal in Space |
| SISREs | Signal-in-Space Range Errors |
| SPS | Standard Positioning Service |
| SSE | Sum Square Error |
| SV | Satellite Vehicle |

| | |
|-------|---|
| TAI | International Atomic Time |
| TCA | Terminal Control Area |
| TCAR | Three Carrier Ambiguity Resolution |
| TTA | Time to Alert |
| TTB | Trinomial Tree with Barrier |
| USCG | United States Coast Guard |
| UTC | Universal Time Coordinated |
| VFR | Visual Flight Rules |
| VOR | Very High Frequency Omnidirectional Range Station |
| WAAS | Wide Area Augmentation System |
| WGS84 | World Geodetic System of 1984 |

Introduction

Important parts of our national airspace system (NAS) are the precision landing systems which allow aircraft equipped with the necessary electronic hardware (avionics) to land in conditions of limited visibility, thereby increasing the time an airport can operate during poor weather.

The current precision landing system, the instrument landing system (ILS), is scheduled to be replaced with the microwave landing system (MLS) as part of the Federal Aviation Administration's (FAA) ambitious effort to modernize the nation's air traffic control system—known as the NextGen plan.

The Chairman, Subcommittee on Transportation, House Committee on Appropriations, asked GAO to review FAA's implementation of the NextGen plan. As part of this effort, GAO reviewed the NextGen program, addressing the following objectives:

assess the justification and requirements for a new precision landing system to replace ILS and determine and analyze NextGen improvements since NextGen was justified, determine whether FAA has adequately demonstrated NextGen's potential operational and economic benefits, and determine the reasonableness of FAA's NextGen siting strategy.

The basic navigation observable from GNSS such as GPS is the pseudo-range determined from the signal transmission time and the speed of light in vacuum. This observable (either in the stand-alone or differential modes), cannot provide the necessary accuracy required for precision approach and landing. The second

observable from GNSS is the carrier phase which is more complex and difficult to deal with than the code phase from which pseudo-ranges are derived. Double difference based carrier phase methods have been used successfully for many years in surveying for very accurate position determination. Because of its potential for centimetric or even milli-metric accuracy in real time, the carrier phase measurement offers the possibility to determine both aircraft attitude and positional data for precision approaches, landing and surface movement. However, for this to be the case, the reliability of the determination of integer ambiguity on-the-fly (OTF) must be improved by introducing novel ambiguity search and validation algorithms. This requires a thorough understanding of the error sources that affect the measurement and the techniques required to minimize their effects. Furthermore, because of the 'safety-critical' nature of air navigation, estimation of positioning error and failure detection must be addressed. Existing methods are based on code phase observables and carrier phase based integrity monitoring algorithms are at the infant state. Carrier phase based Receiver Autonomous Integrity Monitoring (C-RAIM) algorithms must be implemented, so that a high integrity, high continuity and high availability system is realized, in addition to high accuracy.

This thesis investigates ways of using the new signals (in addition to the development of various models for the error sources) proposed as part of the modernization of GPS and the new systems under development, such as Galileo, to characterize the levels of performance achievable with the carrier phase measurements and to compare this with aircraft precision approach, landing, and surface movement requirements. Novel high performance navigation algorithms for double-difference based GBAS (Ground Based Augmentation System) are designed and implemented in this thesis. Particular emphasis is placed on ambiguity resolution and validation as well as carrier-phase integrity monitoring and validation tools. Simulated data and real data from representative airport environments are used to validate the algorithms. The performance of these carrier phase based algorithms is presented in detail. By using the novel ICT algorithm developed in this thesis, the success rate of fixing ambiguity can reach 92.6% (static OTF). This rate can be further improved to 99.9% by the application of MCM method.

Aircraft navigation has traditionally been achieved by a combination of a variety of systems that are ground based and aircraft based. Ground based systems,

including Instrument Landing Systems (ILS), Microwave Landing Systems (MLS), Very high frequency Omni directional-Ranging systems (VOR), Distance Measuring Equipment (DME), are located mainly in the surroundings of airports to guide aircraft both en-route and in the initial and final phases of flight (e.g. the ILS and MLS). Aircraft based systems, including Inertial Navigation Systems (INS), radar, and Air Data System (ADS), operate autonomously onboard, acquiring measurements and using these to generate the information required for aircraft navigation. The primary limitation of the present ground-based systems is to the need for line-of-sight. That is, electronic, ground based navigation aids can only be used over a limited portion of the earth's surface not blocked by the horizon or high terrain. Hence, to provide the level of coverage to enable flexible use of airspace in order to increase capacity, an extensive network of navigation radio beacons (and the supporting infrastructure) located around the globe would be required. This is impractical for many reasons not least because of inhospitable site conditions. The limitations of traditional navigation systems were recognized by the International Civil Aviation Organization (ICAO) as discussed below.

In 1983, the Council of the International Civil Aviation Organization (ICAO) determined that the traditional technologies and procedures supporting Air Traffic Management (ATM) were fast approaching their limits. Accordingly, ICAO established a special committee on Future Air Navigation Systems (FANS) to develop a plan and program for the future ATM. This resulted in the Communication Navigation Surveillance/ Air Traffic Management (CNS/ATM) concept and the recommendation that a satellite-based system, which must satisfy the Required Navigation Performance (RNP), should be developed as the future navigation system for civil aviation. Hence, more recently and in line with the ICAO's CNS/ATM concept, space based GNSS (mainly the Global Positioning System – GPS and its augmentations) have started to be used for some operations. GNSS consist of satellites and the supporting ground based infrastructure.

Currently, GNSS based systems only provide navigation service for the en-route and initial approach phases of flight, using code phase observables and code-based GBAS architecture currently is under development for CAT III landings .On the other hand, final approach and landing phases are supported almost exclusively

by traditional ground-based systems. A major limitation of the latter (i.e. ground based systems) is that they require a minimum distance between aircraft to avoid signal deflection, while the former (GNSS based systems) have no such limitation. GNSS based systems can also provide much more flexible navigation service supporting 'free flight' to save fuel and minimize the effects of noise and pollution. Moreover, ground based systems cannot provide the high performance (in terms of navigation accuracy, continuity and level of confidence) required for aircraft surface movement under zero-visibility conditions. Given its concept and principle of operation, satellite based navigation using GNSS based systems has the potential to offer this high level of performance and thus support operations during all phases of flight. However, this requires the development of novel navigation algorithms capable of utilizing the more complex carrier phase observable in addition to the code observable. This has the potential to contribute significantly to the efforts to increase airspace capacity in the terminal areas.

At present the ICAO performance standards for the GNSS navigation system are described in ICAO Standards and Recommended Practices (SARPS) Annex 10. The ICAO specifies aircraft RNAV system performance requirements in terms of four parameters accuracy (difference between the estimated position and the actual position), integrity (a measure of the trust that can be placed in the correctness of the information supplied by the total system), continuity (capability to provide a navigation service without unscheduled interruptions during the intended operation) and availability (the portion of time a navigation system provides a reliable navigation service).

In order to be certified, air navigation systems must satisfy the quantities specified for the parameters above. ICAO SARPs specifies the relevant quantities for phases of flight up to Cat-I approach. More recently, research has been carried out to reconcile the main differences in the approaches used in Europe and the United States to specify the requirements for the most stringent phases of flight. This thesis adopts the requirements as specified by the ICAO and those from Schuster *et al.*,. The latter (for the most demanding phases – precision approach, landing and surface movement) are used to quantify the performance of the methods and algorithms developed in this thesis.

The approach phase starts when entering the Terminal Control Area (TCA) around the airport, with the aircraft leaving an airway. Standard Terminal Arrival Routes (STAR) are established at major airports, and may extend up to 100 to 200 nm from the runway. At the end of the approach, the runway must be in sight. If Visual Meteorological Conditions (VMC, usually ceilings exceeding 1000 to 1500ft and horizontal visibility more than 3 nm) are not fulfilled, the initial (and possibly final) approach must be conducted under Instrument Flight Rules (IFR). Precision Approaches (PA) utilize both lateral (course) and vertical (glideslope) information and establish aircraft on a descent onto the runway. The aircraft descends with constant speed, attitude and sink rate on a trajectory that directly intercepts the runway. The landing begins at the decision height and ends when leaving the runway. A landing may be performed manually and based on visual information or by an autoland system. The latter is mandatory for Cat IIIb and Cat III c, while Cat III a approaches may be flown manually. Phase-smoothed code-based airborne GNSS receivers are already being used to support aircraft navigation for the en-route phases of flight, and GBAS-based navigation system architectures for the more stringent phases of flight (CAT III landings) are under development. Currently, only surface movement radar is used for surveillance from the controller's perspective. This does not allow pilots to taxi safely under zero-visibility and leads to airport capacity limitations. Therefore, the development of Advanced Surface Movement Guidance and Control Systems (A-SMGCS) presents a major challenge to the aviation industry. Code-based CAT III GBAS architectures are unlikely to meet the Airport Surface Movement (ASM) navigation performance requirements. Therefore, multi-frequency carrier-phase based Real-Time-Kinematic (RTK) techniques are required

GPS is the only currently fully operational GNSS and is undergoing a process of continuous improvement with the aim of moving to GPS III, which will bring significant performance benefits to a variety of users including the aviation community. Additionally, Galileo, an independent global European-controlled satellite-based navigation system is currently under development. Galileo will have a constellation of satellites complemented by a ground segment providing system and satellite monitoring and control, including an integrity function to broadcast real-time warnings about satellite or system malfunctions. This system has been

designed by Galileo Industries (renamed to European Satellite Navigation Industries for and in conjunction with the European Space Agency (ESA), and has been consolidated through a successful system Preliminary Design Review (PDR) and complementary design activities. Galileo will transmit freely available satellite navigation signals on three frequencies and is anticipated to be fully operational around 2013. With the modernization of GPS and the development of Galileo, a larger number of navigation satellites will become available (about 60), as well as an increased number of navigation signals, offering advanced opportunities for technical innovation. At the same time, the increasing number of satellites and observables will also bring challenges for navigation algorithms, especially for the carrier phase based algorithms.

The basic navigation observable from GNSS such as GPS and Galileo is the pseudorange determined from the signal transmission time and the speed of light through vacuo. Data tests have shown that this type of observable cannot provide the necessary accuracy required for precision approach and landing due to the noise specification. The second observable from GNSS is the carrier phase and navigation methods based on this can provide centimetric or even millimetric accuracy in real time, with a prerequisite of a reliable determination of the integer ambiguity OTF. Significant research has been carried out in this field for decades, leading to a variety of algorithms. However, none of the algorithms are able to meet the requirements for high precision aircraft navigation. This is partly due to the peculiarities of the characteristics of the various sources of error associated with the terminal areas and airports. In addition, none of the algorithms employ an additional search process if the best candidate is verified to be wrong.

In order to realize fast and reliable integer ambiguity resolution, a thorough understanding of the error sources that affect the measurements is required. This is in addition to the need for adequate geometry, measurement redundancy and agreed navigation performance requirements.

An interesting issue here is the potential benefit to be gained from optimal selection of the required measurements and their geometric configuration, and the impact of this on the stringent accuracy, integrity, continuity and availability requirements.

The majority of previous research has focussed largely on empirical integer ambiguity search and validation methods, without direct linkage to integrity monitoring algorithms. However, as shown in this thesis, integer ambiguity validation algorithms are essential to meet the stringent integrity requirements for safety-critical applications, such as air navigation. In this context, this thesis attempts to create a tight link between ambiguity validation and Carrier phase based Receiver Autonomous Integrity Monitoring (C-RAIM).

There are currently two methods utilized to provide integrity information about the GNSS signals; these are the use of external augmentation systems or Receiver Autonomous Integrity Monitoring (RAIM) and its variations. External augmentation systems consist of ground based stations that receive signals from GNSS (e.g. GPS) satellites and generate information to enhance positioning and navigation performance. Ground based or satellite based transmitters are used to broadcast this information to the users. Hence, this requires significant effort in terms of development and maintenance cost to support these systems. Examples of special external augmentation systems are the European Geostationary Navigation Overlay Services (EGNOS), the US Wide Area Augmentation System (WAAS) and the US Local Area Augmentation System (LAAS). EGNOS and WAAS are satellite based augmentation systems while LAAS is a ground based system. The former i.e. EGNOS and WAAS are generally described as Space Based Augmentation Systems (SBAS) and the latter (i.e. LAAS) as Ground Based Augmentation Systems (GBAS). Augmentation can also take place at the user platform level. In the case of aircraft, this is referred to as Aircraft Based Augmentation (ABAS)

RAIM takes the form of an on-board receiver algorithm which checks the consistency of measurements observed by exploiting measurement redundancy, the geometrical configuration of the satellites relative to the user, knowledge of nominal error behaviour and the user requirements. Its operation follows that of the positioning algorithm within the receiver. Compared to the minimum number of measurements for a stand-alone GPS positioning algorithm, an extra measurement is required for a typical RAIM algorithm to be effective. RAIM has traditionally been applied to the code-phase observables. Hence, when carrier

phase measurements and observables are used, a corresponding integrity monitoring algorithm should be employed. Although research on C-RAIM has been patchy to date, its concept is similar to conventional RAIM. One of the difficulties associated with the development of C-RAIM is the common processing approach that uses the double differenced observable to eliminate the influence of common errors and mitigate the effect of those that exhibit a degree of spatial correlation. Related issues also include ambiguity resolution and validation; cycle slip detection and repair; potential failures associated with differencing (e.g. problems with the reference satellite used for differencing); potential simultaneous multiple failures (e.g. due to multipath and incorrect ambiguity resolution) and correlation of errors. Furthermore, as the atmospheric and environmental conditions in the terminal area and at airports are like to change rapidly, it is critical to determine the uncertainty of GNSS observables in real-time in order to adapt C-RAIM algorithms accordingly.

In summary, the preceding brief background points to existing OTF RTK and RAIM having significant weaknesses that prevent them from delivering the required navigation performance for air navigation, particularly in the cases of the most stringent phases of flight. Specifically, there are a number of research questions of relevance to this field. There is no well established GNSS Signal in Space (SIS) performance requirements for Category-II, Category-III approaches and airport surface movement.

- There is no comprehensive approach that uses double differenced GNSS carrier phase observables with fixed ambiguities to provide a navigation service that meets all the requirements of civil aviation.

- There is no official specification of the functional and physical architectures for the augmentation systems needed to support air navigation using carrier phase data.

- There is no existing integer ambiguity search method that is capable of taking full advantage of the future multi-constellation, multi-frequency GNSS environment in such a way that better navigation performance (including accuracy, integrity, continuity and availability) can be achieved.

- There is no ambiguity validation algorithm designed for multi-constellation or multi-frequency systems. Furthermore, the link between integer ambiguity validation and C-RAIM is poorly understood.

- There is no existing integer ambiguity search method that employs an additional search process in the event that the first candidate is verified to be wrong. This is required to maximize the continuity.

- There is no C-RAIM concept or method that monitors the quality of the navigation solution throughout the data processing chain, from end to end, to detect failures or errors as early as possible.

- There is no functional (and physical) architecture specification or algorithm that can provide real-time estimations of uncertainty of carrier phase observables to enable reliable estimation of protection level (essential for integrity monitoring).

- There is no comprehensive carrier phase based and integrity monitoring algorithm that uses combined GPS and Galileo systems for air navigation.

- There is no corresponding performance assessment based on real raw observable data including generating statistics.

Given the background and the research questions identified above, the aim of this thesis is to develop the data processing structure and novel navigation algorithms for aircraft precision approach, landing and surface movement using combined modernized GPS and Galileo, together with augmentation systems. In order to achieve this aim, the following objectives are pursued:

- Carry out an extensive literature review and capture the state-of-the-art in the specification of the required navigation performance for aircraft navigation.

- Characterize the performances of existing (state-of-the-art) integer ambiguity search/validation and integrity monitoring algorithms in the context of multi constellation and multi-frequency positioning, and identify their weaknesses.

- Select and improve the functional and physical architectures for the augmentation systems needed to support air navigation using carrier phase data.

- Identify and provide solutions to address basic underpinning issues, such as time and coordinate reference frames, in the context of GPS and Galileo interoperability.

- Develop advanced on-the-fly ambiguity resolution algorithms with multiple frequency combined GNSS observables.
- Develop advanced ambiguity validation algorithms and establish the link with C-RAIM algorithms.
- Develop advanced ambiguity re-search and re-validation schemes to improve the continuity performance.
- Develop innovative C-RAIM algorithms which can provide fast protection level calculations and failure detection taking into consideration the uncertainty of the observables and the geometry of the constellation.
- Establish a software platform with efficient data processing structures for testing multi-system navigation algorithms.
- Provide a quantitative analysis of the performance of the novel ambiguity resolution/validation and C-RAIM algorithms.

Test the novel algorithms with both static and dynamic data, employing simulated and/or real data where practical.

Given the uncertainty surrounding the Russian Global Navigation Satellite System (GLONASS), this thesis is based on GPS, Galileo and their augmentation systems only. Although, the thesis focuses on the development of algorithms for civil aviation, the algorithms should be easily transferable to other application domains that require real-time differential carrier-phase positioning.

The thesis is organized into nine chapters, focusing on nine topics. Each of the chapters begins with an overview, followed by a number of sub-sections.

1. Civil Air Navigation

Aircraft navigation is the process of piloting an aircraft from one place to another. It includes position determination, establishment of the course and distance to the desired destination, and the determination of the deviation from the desired track. Navigation, together with communication and surveillance systems employing digital technologies, including satellite systems with various levels of automation, are the cornerstones of a future seamless global ATM system.

This chapter highlights the importance of GNSS based technologies to the future of air navigation, and identifies the performance requirements relevant to

precision landing and airport surface movement. The requirements form the basis for the development of novel navigation strategies and algorithms that can be shown to fully support precision landing and surface movement. Specifically, the chapter captures the trend in the growth in air travel over the years and the corresponding evolution in ATM technology in an attempt to provide the capacity required. Furthermore, it looks into the future of both and presents concepts and ideas to be explored to increase airspace capacity. The chapter also addresses the importance of defining and specifying appropriate navigation performance requirements, as a prerequisite for the acquisition and operation appropriate navigation systems.

The chapter concludes by a consolidated table of the requirements for precision approach, landing and Airport Surface Movement (ASM), used subsequently in this thesis.

1.1 The Growth of Worldwide Civil Aviation

According to the ICAO Annual Report of the Council, international tourist arrivals were up by an estimated 6%. According to the United Nations World Tourism Organization (UNWTO), about 898 million tourists travelled to foreign countries, some 52 million more than the previous year (Figure 2.1). The total scheduled traffic carried by the airlines of the 190 Contracting States of ICAO amounted to approximately 2 260 million passengers and some 41 million tonnes of freight. The overall passenger/freight/ mail tonne-kilometres operated increased some 5.5% over 2006, with international tonne-kilometres at about 6.1%. Figure 2.2 shows the trend from 1998 to 2007. In the near future, this trend is expected to last due to the strong demand around the world, though the high fuel price may slow down this increasing trend.

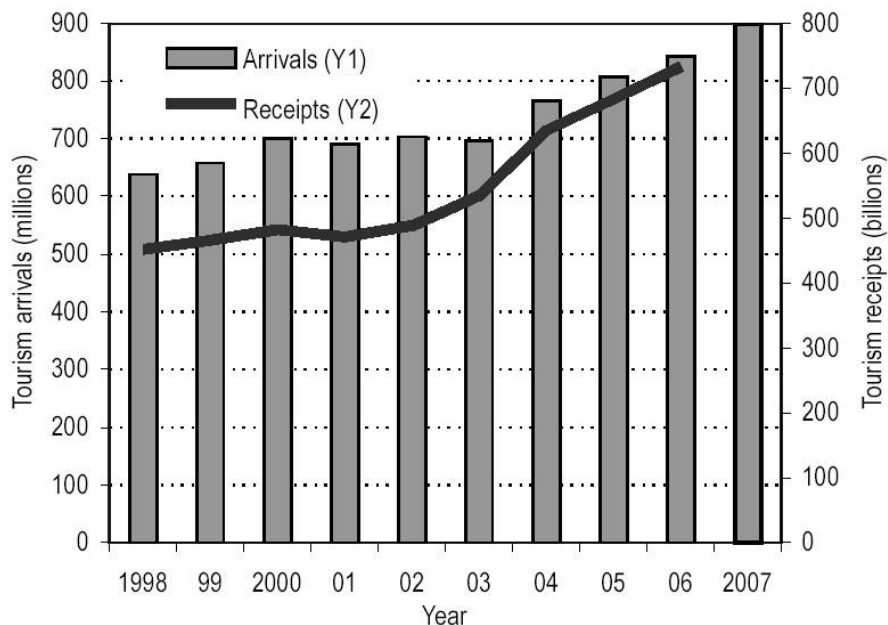


Figure 2.1: International Tourism Receipts and Arrivals, 1998-2007

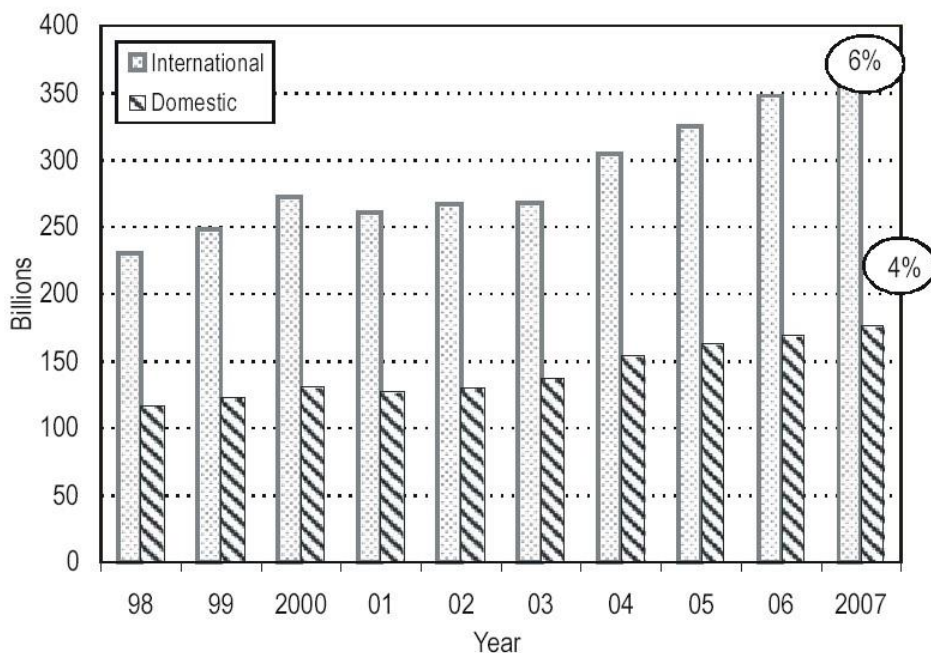


Figure 2.2: Scheduled Traffic Tonne-Km Performance, 1998-2007

In Europe, the number of flights in 2007 surged to 10 million, an all-time high and an increase of 5.3% in 2006. Furthermore, EUROCONTROL forecasts that the number of flights in Europe is to grow by about 4.2% in 2008. Reflecting on the figures, David McMillan, Director General of EUROCONTROL stated that: “Europe saw more than 10 million flights in 2007 – a new record. The overall trend in growth is captured in Figure 2.3 which illustrates the trends for each month between the periods of 2002 to 2007, the daily average number of flights in

the EUROCONTROL Central Flow Management Unit (CFMU) area .As we can see from

Figure 2.3, the increasing trend has been very stable since 2002, despite the European sky being rather busy. Looking to the future, between 2008 and 2015, air traffic in the European Civil Aviation Conference (ECAC) area is forecast to increase by over 30% .The current level of congestion and its consequences in the forms of flight delays, greater safety risk, environmental pollution and noise, suggest that there continues to be a mismatch between growth in travel demand and capacity. One of the two main solutions to this problem (the other being regulation of demand) is to increase airspace capacity, especially in the vicinity of the terminal areas where the traffic density is typically the largest. The Council of ICAO and other organizations have redefined the future requirements of civil aviation operation, especially in the terminal area, as described in the next section.

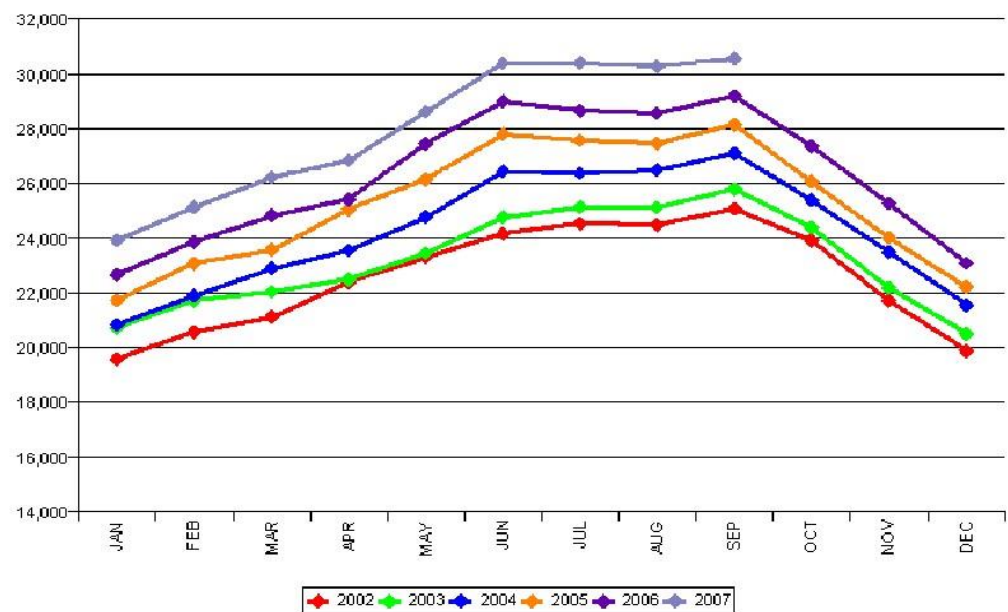


Figure 2.3: Daily Traffic in the CFMU Area (EUROCONTROL, 2007)

1.2 ATM Strategy and Planning

In 1983, the Council of ICAO determined that the systems and procedures supporting civil aviation were fast approaching their limits, and established the Special Committee on Future Air Navigation Systems (FANS).

- Study, identify and assess new technologies, including satellite technology;
- Make recommendations for the future development of air navigation for civil aviation over a twenty five year period.

The committee concluded in 1988 that the current ATC systems were incapable of supporting future civil air navigation needs and that satellite technology has the potential to provide the only viable solution.

In July 1989, the ICAO Council established the Special Committee (FANS Phase II Committee) to monitor and co-ordinate development and transition planning to FANS. This new Committee recognized that the implementation of related technologies and expected benefits would evolve over a period of time. In September 1991, the tenth air navigation conference endorsed the concept for a future air navigation system as developed by the FANS Committees. The FANS concept, which came to be known as Communications, Navigation and Surveillance Systems for Air Traffic Management (CNS/ATM), involves a complex and interrelated set of technologies, dependent largely on satellites.

In Europe, in the late eighties, at the ECAC transport ministers decided on an "ECAC Strategy for the 1990's". In turn, that "first" Strategy was translated into the European ATC Harmonization and Integration Program (EATCHIP). EATCHIP enabled ATM system capacity to keep pace with air traffic growth throughout the 1990s. However, air traffic growth continued inexorably, and ten years later it became clear that without major new initiatives European ATM systems would not be able to keep up with the expected increase of air traffic. Accordingly, in February 1997, the ECAC transport ministers called for a new strategy for ATM to supersede the EATCHIP. The new, "second" strategy was approved in January 2000 with the title 'ATM Strategy for the Years 2000+' (ATM 2000+). This new strategy led to the creation of the European Air Traffic Management Program (EATM). The reorganization of EATM, taking place in October 2006, came in response to developments in the field of air traffic management – including institutional changes and the need to support the successful introduction of the Single European Sky ATM Research (SESAR). The objectives of SESAR are to eliminate the fragmented approach to ATM, transform the European ATM system, synchronize the plans and actions of the

different partners and federate resources. In order to enable the new strategies, new concepts of air navigation and airspace have been developed, such as Area Navigation (RNAV) and Performance Based Navigation (PBN). Some existing concepts have evolved with new meanings, such as the Required Navigation Performance (RNP).

1.2.1 RNAV, RNP and PBN

ICAO defines RNAV as: “a method of navigation which permits aircraft operation on any desired flight path within the coverage of the station-referenced navigation aids or within the limits of the capability of self-contained aids, or a combination of these”. This concept was introduced to allow greater flexibility in the design of routes and procedures, not associated with or constrained by an underlying navigation aid, so that users could select preferred routes that consider factors such as pressure, altitude and wind. In general terms, RNAV equipment operates by automatically determining aircraft position, establishing the desired flight-path, and providing path guidance to the next waypoint. The aircraft position is derived from one, or a combination of, input(s) from various navigation systems e.g. VHF Omni directional Radio Range (VOR), Distance Measuring Equipment (DME) and GNSS.

The RNP concept was defined by ICAO in ICAO Document 9613. An RNP type is used to specify the minimum performance accuracy required within an airspace. Therefore RNP 1 requires that the navigation system ensures the predicted track be within a 1NM lateral containment level of the true track 95% of the time. Basic RNAV (B-RNAV) equates to RNP5 and Precision RNAV (P-RNAV) equates to RNP1. It was envisaged that most operations within airspace designated an RNP type would be RNAV operations but that other operations would be permitted temporarily. This concept would allow aircraft with RNAV equipment on-board to utilize the airspace, but the equipment must be capable of monitoring its performance and alerting the crew if performance is not met. The RNP concept moved away from previous sensor-based requirements which specified particular navigation sensors and equipment models certified for operations within airspace.

In order to bring the RNAV concept within the scope of the performance based navigation concept of RNP, the idea of RNP-RNAV was developed. Following the development of GNSS, a true RNAV capability using omnipresent signals was realizable for the first time without the constraints provided by the range of traditional Nav aids. The benefit of on-board monitoring then enables independent operations with the means to choose both a route and navigation infrastructure to meet operational requirements. In parallel to the conceptual development, the use of RNPRNAV to represent the performance parameters accuracy, integrity, continuity and availability was introduced.

In light of this, RNP-RNAV is an extension of the RNP concept by quantifying the additional navigation parameters of integrity, continuity and availability of the navigation function. This goes beyond the initial RNP accuracy performance parameter. In fact, the original ICAO definition included additional other navigation performance parameters such as coverage, reliability, capacity, time to recover and the now more familiar integrity, continuity and availability. The numerical performance parameters related to each of these concepts was left to appropriate technical bodies. This task was taken upon by the RTCA and led to the definition of the RNP-RNAV performance parameters. In accordance with the ICAO Global Air Navigation Plan for CNS/ATM Systems and international agreements, the concepts of RNAV, RNP and RNP-RNAV are being applied to aircraft operations. B-RNAV is currently implemented within the airspace of several ICAO states, as well as some areas of international airspace.

ICAO's PBN concept aims to ensure global standardization of RNAV and RNP specifications and to limit the proliferation of different navigation specifications in use world-wide. It is a new concept based on the use of RNAV systems. Significantly, it is a move from a limited statement of required performance accuracy to more extensive statements of required performance in terms of accuracy, integrity, continuity and availability, together with descriptions of how this performance is to be achieved in terms of aircraft and crew requirements. The PBN concept represents a shift from sensor-based to performance-based navigation. The move from sensor-based requirement to performance based requirements allows greater flexibility because as the

technologies change existing operations and navigation specifications will cover the application of these Nav aids. This will allow operators to make a cost-effective decision on which Nav aid infrastructure to use for a given navigation application but also allows operators the added responsibility for certifying their aircraft. At present PBN is to be applied within operations with linear lateral performance requirements. ICAO currently suggests that the PBN concept will be extended to angular and vertical requirements.

The PBN concept specifies aircraft RNAV system performance requirements in terms of four parameters: accuracy, integrity, availability and continuity, defined as follows:

- *Accuracy*: is the difference between the estimated position and the actual position. For an estimated position at a specific location, the probability should be at least 95 per cent that the position error is within the accuracy requirement.

- *Integrity*: is a measure of the trust that can be placed in the correctness of the information supplied by the total system. Integrity includes the ability of a system to provide timely and valid warnings to the user (alerts) when the system must not be used for the intended operation (or phase of flight). Specifically, a navigation system is required to deliver a warning (or an *alert*) of any malfunction (as a result of a specified *alert limit* being exceeded) to users within a given period of time (*time to alert*). The alert limit is defined as a position error. *Integrity risk* also referred to as the probability of misleading information, is defined as the probability that the navigation positioning error exceeds the alert limit and that the event is not detected (i.e. missed detection). The *Probability of Missed Detection* is the probability of not detecting a position failure within the time to alert. Given its definition and characteristics, integrity

is the performance parameter that is most directly related to safety *Continuity*: is the capability of a navigation system to perform its function without unscheduled interruptions during the intended operation. Continuity risk is thus a measure of the unreliability of a navigation service .

- *Availability*: availability of GNSS is characterized by the portion of time the system is to be used for navigation during which reliable navigation information is presented to the crew, autopilot, or other system managing the flight of the aircraft.

The availability of GNSS is complicated by the movement of satellites relative to a coverage area under consideration and the potential long time needed to restore a satellite in the event of a failure. Accurately measuring the availability would require many years; therefore the availability of GNSS should be determined through design, analysis and modelling, rather than measurement. Implementation of the RNAV, RNP and PBN concepts and the transition to GNSS based navigation for all phases of flight have been emphasized in the strategies of EUROCONTROL and the FAA.

1.2.2 EUROCONTROL AND FAA Navigation Plans

According to the European air traffic management performance enhancement plans, several main activities were planned for future air navigation related to GNSS. One of the planned contributions is the development of Precision Approach and Landing using GBAS GNSS providing precision approach capability at those airports not equipped with ILS today or by replacing/complementing ILS where operational constraints from the use of ILS or where capacity enhancement can be achieved through the availability of GNSS based landing. The navigation domain plans will support the enabling of GNSS to be used in all phases of flight, together with the implementation of RNAV and RNP concepts. The aim also includes enabling Galileo applications from 2012 to use GNSS to the maximum extent possible commensurate with safety and cost efficiency. GNSS navigation related R & D has been also carried out in system infrastructure, navigation avionic, algorithm design and regulation domains.

The latest “Federal Radionavigation Plan 2005”, released by the FAA, points to an increased emphasis on the use of RNAV and GNSS (Figure 2.4). Figure 2.4 shows that some ground based navigation services will phase out, such as VOR, DME and Non-Directional Beacon (NDB), while some of the ground based navigation services will remain in full use such as the ILS Cat II and III. Planned use of GNSS based navigation systems such as Local Area Augmentation System (LAAS), Wide Area Augmentation System (WAAS) and Nationwide Differential Global Positioning System (NDGPS) is also shown. According to the recently released U.S. Fiscal Year 2009 budget, (Long Range Navigation) LORAN system will be modernized to enhanced LORAN (eLORAN). Furthermore, system responsibility will be placed with the National Protection and Programs Directorate

of the Department of Homeland Security (DHS), which has chosen it as the backup for national infrastructure elements that currently depend on GPS. Moreover, the application of RNAV and GNSS, especially for precision approach and landing, is a key part of the future for future aircraft navigation.

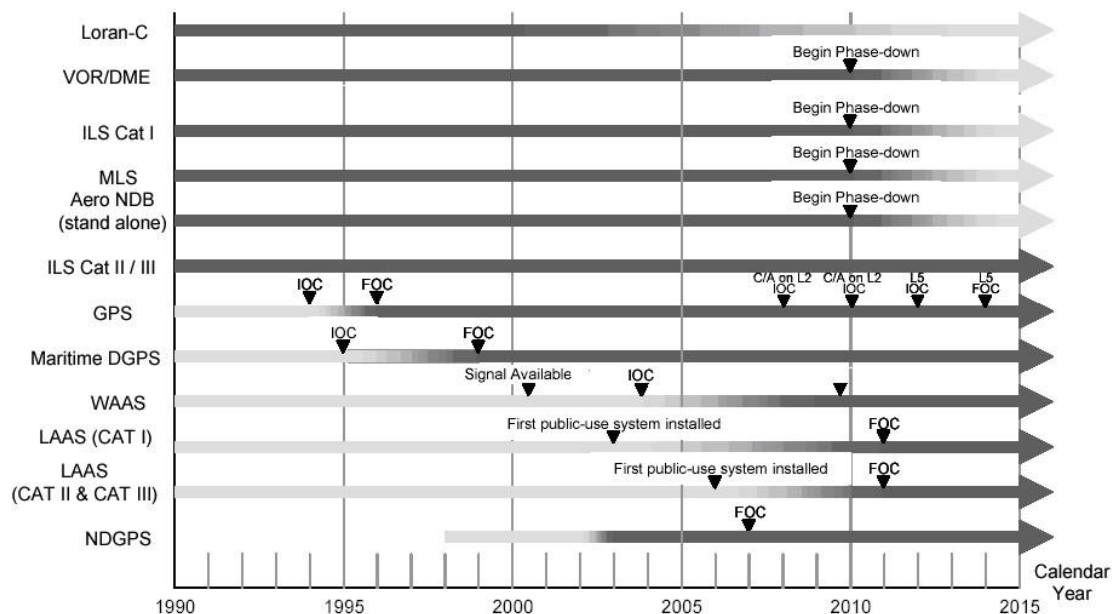


Figure 2.4: Radionavigation Systems Operating Plan (FOC-Full Operational Capability, IOC-Initial Operational Capability)

As shown above, one of the main transition plans from both EUROCONTROL and the FAA is to enable GNSS to support all phases of flight whilst meeting the corresponding RNAV requirements. In order to clarify this transition, the definitions of various phases of flight and existing navigation tools for these phases including their limitations are given in the following section.

1.3 Phases of Flight and Current Navigation

Figure 2.5 depicts the subdivision of a typical commercial air transport mission into different phases of flight. The naming of the phases of flight follows common definition in flight mechanics. From an ATC point of view, the climb segment may also be referred to as the ‘departure’ phase, while the descent and initial approach may be referred to as the ‘arrival’ phase

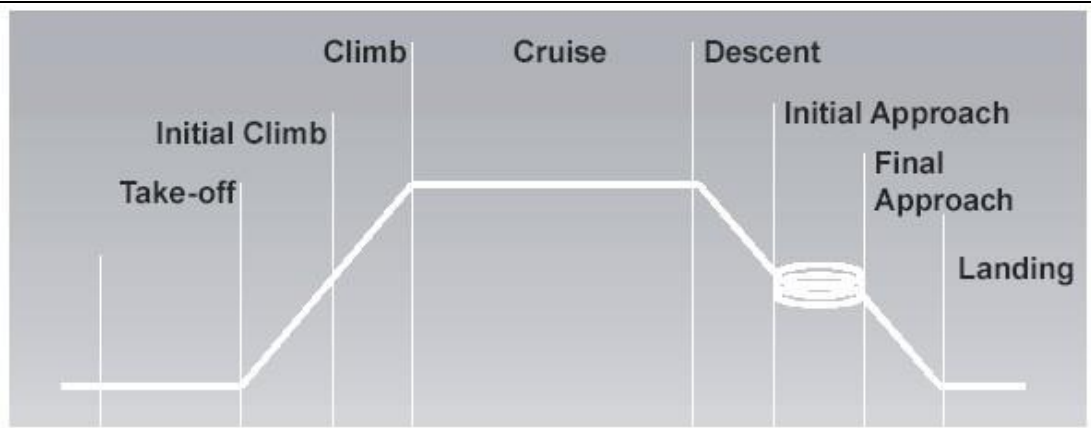


Figure 2.5: Flight Phases for Typical Air Transport Mission

1.3.1 Take-Off and Initial Climb

The take-off begins from the application of take-off power, through rotation and to an altitude of 35 feet above runway elevation. The actual take-off is usually flown manually while the climb-out is performed on autopilot (A/P) coupled to an Inertial Navigation System (INS) or Attitude Heading Reference System (AHRS). During the take-off run, the pilot normally guides the aircraft visually. In poor visibility conditions, ILS localizer guidance is available (at airports equipped with an ILS). For safe operation, aerodynamic speed related measurements of *critical engine stall speed*, *rotation speed*, and *rate of climb*, are crucial.

The current essential navigation equipment for take-off and initial climb is: AHRS or INS.

1.3.2 Climb and Departure

The departure phase begins upon leaving the projected runway centreline and ends when leaving the Terminal Control Area (TCA) around the airport, with the aircraft established on an airway. It includes a relatively complicated climb profile. The departure phase is characterized by relatively high-density, heterogeneous traffic (mix of climbing /accelerating and descending / decelerating aircraft) and frequent manoeuvres. In its early stages, the aircraft is relatively close to the ground and thus navigation errors are potentially more dangerous than during en-route flight. The navigation is based on heading and barometric altitude and may be performed visually (at smaller airports) or using conventional navigation aids like VOR and DME. More complicated routes may be flown with a Flight Management System (FMS) that is capable of RNAV and possibly including GPS

capability. Note that in both cases, barometric altimeter is essential for precise determination of height.

1.3.3 Cruise (En-Route)

Cruise or En-Route flight is from the completion of the Initial Climb through cruise altitude and completion of controlled descent to the Initial Approach Fix (IAF). Until the 1990s, aircraft had to follow airways defined by navigation aids (over land) or waypoints (latitude / longitude fixes, over water). En-Route flight is subdivided into “oceanic” and “domestic” types, where domestic implies the availability of ground based navigation aids such as VOR or DME. Traditional navigation equipments used in the past for the en-route phase of flight are: VOR and DME for short-range positioning; INS, LORANC/ Omega for long-range navigation, and the barometric altimeter for height measurement. Today GPS, combined with INS systems, is more or less universally employed during the en-route phase of flight.

1.3.4 Descent / Approach

The descent phase starts when entering the TCA around the airport, with the aircraft leaving an airway. Standard Terminal Arrival Routes (STAR) are established at major airports, and may extend up to 100 to 200 nm from the runway. At the end of the approach, the runway must be in sight. If Visual Meteorological Conditions (VMC, usually ceilings exceeding 1000 to 1500ft and horizontal visibility more than 3 nm) are not fulfilled, the initial (and possibly final) approach must be conducted under Instrument Flight Rules (IFR) with the following options

- Non-Precision Approaches (NPA) provide course information only. The height is measured barometrically and the aircraft is led to a Missed Approach Point (MAP), at a Minimum Descent Altitude (MDA) usually between 800ft and the absolute minimum of 300ft above the runway, from which the aircraft can be landed normally (if visibility permits)

- Precision Approaches (PA) utilize both lateral (course) and vertical (glideslope) information and establish aircraft on a descent onto the runway. The best known PA NAVAID is the Instrument Landing System (ILS) depicted in Figure 2.6.

An ILS consists of two independent sub-systems, one providing lateral guidance (Localizer), the other vertical guidance (Glide Path) to aircraft approaching a runway. Aircraft guidance is provided by the ILS receivers in the aircraft by performing a modulation depth comparison.

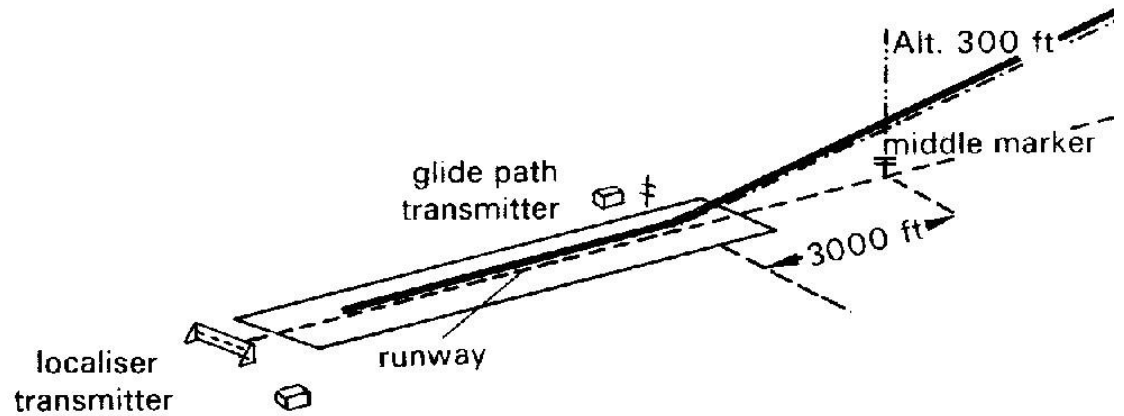


Figure 2.6: ILS System Layout and Approach Path)

The navigation equipment used during approach is

- Non-Precision Approach (NPA): VOR / DME, or INS / GPS, baro-altimeter and localizer approach.

- Precision Approach (PA): in addition to NPA equipment necessary for the initial approach phase, ILS / MLS receiver for the final phase of the approach.

FMS and/or GNSS guided approaches offer the possibility to establish the more economic and environmentally friendly Continuous Descent Approaches (CDA).

An Approach Procedure with Vertical guidance (APV) is a relatively new concept. Designed to be flown under the RNAV concept, this procedure originated at the same time as the introduction of GNSS for air navigation. The procedure was originally named NPV (Non-Precision Approach with Vertical Guidance. From a performance point of view, an APV procedure is located between NPA and PA: It offers vertical guidance in contrast to NPA. However, currently the quality of vertical guidance is not sufficient to fulfill PA requirements. Hence, an APV procedure could be described as “an instrument approach which utilizes lateral and vertical guidance but does not meet the requirements established for PA and

landing operations". Currently and taking into account the different means for vertical guidance, it is possible to classify the procedures in two groups:

1.3.5 Final Approach and Landing

The Final Approach (FA) begins at the Final Approach Fix (FAF) or in the case of ILS with the establishment on the glide slope. The aircraft descends at a constant speed, attitude and sink rate on a trajectory that directly intercepts the runway. The landing begins at the decision height and ends when leaving the runway. It comprises the flare (reduction of vertical speed) and decrab (aligning both aircraft and flight path with the runway centreline in crosswind) manoeuvres. A landing may be performed manually based on visual information or by an autoland system. The latter is mandatory for Cat III b and Cat III c, while Cat III a approaches may be flown manually (although the guidance is exclusively by the Flight Director (FD) and the pilot only executes directions of the FD). Even during visual landings, the height above runway is usually measured by a radio altimeter and communicated to the pilot by callouts.

At the time of writing, the navigation equipment for the landing comprises ILS or MLS receiver for positioning and AHRS or INS for attitude reference, and radio altimeters. GNSS based Landing Systems (GLS) are still in the development phase.

1.3.6 Missed Approach

A Missed Approach (MA) or Go-Around aborts the landing and is initiated either at the pilot's option or at the air traffic controller's request. Typical reasons are poor visibility (runway not in sight at Decision Height (DH) or Missed Approach Point (MAP)), poor alignment with the runway, equipment failures or conflicting traffic. Upon initiating this manoeuvre, the pilot establishes the aircraft in the take-off configuration and climbs to a specified holding fix. Both from an operational and a navigation point of view, MA is comparable to Take-Off / (Initial) Climb and hence uses the same terminal area navigation aids.

1.3.7 Airport Surface Movement (Taxiing)

While the phases of flights described in the previous sections are supported by sophisticated Flight Management Systems (FMS), ground movements today are mostly performed based on visual clues and with paper aerodrome charts as

information sources (or their electronic equivalent, the Electronic Flight Bag - EFB) from the pilot's perspective. Currently, only surface movement radar is used for surveillance from the controller's perspective. This does not allow pilots to taxi safely under zero visibility and leads to airport capacity limitations. Therefore, the development and operation of Advanced Surface Movement Guidance and Control Systems (A-SMGCS) are critical to airports as demonstrated below:

- At major airports, capacity is often not limited by the airborne segment of operations but by safe and efficient handling of ground traffic.
- Runway incursion accidents with hundreds of fatalities, e.g. at Tenerife or Milano, highlight the necessity to increase safety in this phase of operation.
- Landing is possible today in zero visibility but taxiing is not. In very poor visibility, airport capacity is limited (if not completely nullified) by lack of taxi guidance.

ASMGCS is expected to fulfill four primary functions: surveillance, routing, guidance and control, the function with the most stringent requirements being the guidance function. Clearly, the positioning and navigation capability is critical to enable pilots to follow taxiway centre lines in poor visibility conditions. Whilst there may be a number of alternative options to meet the navigation functionality, GNSS with GBAS is an obvious candidate, not only because it has the potential to meet the navigation requirements, but also because it would make use of an already existing (or at least partially existing) infrastructure currently under development for CAT III approaches

From a navigation point of view, surface guidance in poor visibility is extremely demanding because it requires very high accuracy and integrity in a less than benign environment for any kind of radio navigation.

Considering various properties of different phases of flight, the requirements for different phases of flight should clearly be different as well. Defining the performance requirements for a particular phase of flight is a key element of operational safety. The quantified performance requirements for PA, landing and ASM phases will be introduced in the next section.

1.4 Navigation System Performance Requirements for Precision Approach, Landing and Surface Movement

Having discussed the different characteristics of the different phases of flight, this section defines the performance requirements as a pre-requisite to determining whether a given navigation system is suitable for precision approach, landing and surface movement. To illustrate the complete PBN RNAV requirements, Table 2.1 shows the values to be achieved for GNSS during the all phases of aircraft operation, though the precision approach, landing and surface movement phases are of most interest in this thesis. The Signal-In-Space (SIS) performance requirements for Enroute to Category-I approaches are well defined in ICAO SARPS .

While the SIS performance requirements for Category-I approaches are well established, those for Category-II and III approaches have been under debate by the two main technical bodies– the EUROPEAN Organization for Civil Aviation Equipment (EUROCAE – EU) and the Radio Technical Commission for Aeronautics (RTCA – USA) - for several years. Two separate methods were used in the derivation of these requirements, with significantly different results, as shown in Table 2.1. As an example for Cat-IIIb vertical alert limit requirements, 10.0 m was derived by the RTCA and 2.6 m by EUROCAE.

The derivation of the performance requirements in Europe were based upon the so-called *ILS Look-Alike* method, whereas in the USA, performance requirements were derived based upon the *Autoland* method. The "ILS Look-Alike Method" is based upon the concept of matching system performance at the level of the Navigation System Error (NSE) by line arising the ILS performance specifications at a given height, chosen to be the decision height, at which a pilot must make the decision either to continue the approach and land the aircraft, or to abort the approach. The rationale behind using the decision height is that it corresponds to the location at which the performance requirements are most stringent during the precision approach. The "Autoland Method" is based on the idea of evaluating the required performance to protect the safety of the landing operation, rather than by extrapolating the equivalent NSE performance from existing ILS specifications. It is based upon probabilistic requirements that the aircraft must land within a pre-defined landing box a given percentage of landings.

Both methods lead to significant discrepancies in the performance requirements. One of the key differences between these two methods was identified in as being the different assumptions made about the flight technical errors (FTE) of aircraft. FTE describe the accuracy with which the aircraft is able to follow the instructions provided to it by the aircraft navigation system (through the flight management system) and, together with the NSE, make up the total system error (TSE). The ILS Look-Alike method, implicitly assumes FTE that have been validated through many years of operational experience with the ILS. The Autoland method assumes that FTE have improved over the years, hence reducing the stringency of the navigation system requirements. However, the new FTE assumptions have not been adequately validated, and therefore, this thesis will take as a basis the CAT III requirements developed by EUROCAE.

Reviewed and derived the navigation system performance requirements of an ASMGCS to be able to support the guidance function under zero visibility conditions. The derivation of the performance requirements takes as a basis the airport design and operational requirements specified in the ICAO DOC9157. Making use of the travel surface design requirements and aircraft dimensions, Schuster *et al.*, 2007 extracts the allowable TSE, making the assumption that the probability of exceeding the limits of the taxiways should not be any larger than the probability requirements of exceeding the landing box during the landing phase. This assumption seems reasonable since it is based on the idea of guaranteeing at least the same level of safety during the surface movement phase as during the landing phase. Three elements contribute to the TSE when taxiing on an airport surface: NSE, Path Steering Error (PSE) and Aeronautical Data Quality (ADQ). The PSE is the equivalent of the FTE in flight, and the ADQ expresses how accurately the reference points (e.g. centrelines) on the airport surface have been expressed in terms of the GNSS coordinates. With the assumption of typical path-steering errors (PSE) and maximum allowed taxiing speeds as well as assuming that the current requirements on Aeronautical Data Quality (ADQ) are met, Schuster *et al.*, 2007 extracted the NSE requirements. Continuity and integrity risk requirements were derived based upon target-level of safety (TLS) specifications by ICAO, 2002 and making the assumption that pilots are able to mitigate continuity, but not integrity risks. These assumptions are reasonable given

that pilots, when taxiing under zero visibility, do not have any outside reference to mitigate integrity risks, but are able to take the appropriate action in case the navigation system is unable to provide continuity of service. Based upon these derivations, Schuster *et al.*, 2007 reached the conclusion that surface movement under zero visibility conditions can only be supported at airports CAT-D to F. At CAT-A to C airports, a combination of current ADQ and PSE requirements results in potential errors that are larger than the total allowable TSE. As a result, even in the absence of any navigation system error, current ADQ and PSE requirements do not allow surface movement under zero visibility on these airports, For CAT-D to F airports, the most stringent requirements are summarised at the bottom of Table 2.1.

| Phase of Operation | Accuracy | | Integrity | | Continuity | Availability |
|--------------------|-----------------------|--|----------------|-------|---------------------|-------------------|
| | SIS Accuracy (2σ) | Alert Limits | Integrity Risk | TTA | Continuity Risk | |
| En-route | 2 nm (L) N/A (V) | Oceanic/low density 4 nm (L), N/A (V) | 1E-7/h | 5 min | 1E-4 /h – 1E-8/h | 0.99 – 0.99999 |
| | | Continental 2 nm (L), N/A (V) | | | | |
| En-route, Terminal | 0.4 nm (L) N/A (V) | 1 nm (L) N/A (V) | 1E-7/h | 15 s | 1E-4 /h – 1E-8/h | 0.99 – 0.99999 |
| Initial approach, | | | | | | |

| | | | | | | |
|--|--------------------------------|------------------------------------|--------------------------------|------|--------------------------------|--------------------|
| Intermediate approach, NPA, Departure | 220 m (L) N/A (V) | 556 m (L) N/A (V) | 1E-7/h | 10 s | 1E-4 /h – 1E-8/h | 0.99 – 0.99999 |
| APV-I | 16 m (L) 20 m (V) | 40 m (L) 50 m (V) | 2E-7/150 s | 6 s | 8E-6/15 s | 0.99 – 0.99999 |
| APV-II | 16 m (L) 8 m (V) | 40 m (L) 20 m (V) | 2E-7/150 s | 6 s | 8E-6/15 s | 0.99 – 0.99999 |
| Cat-I | 16 m (L) 4 m (V) | 40 m (L) 10 m (V) | 2E-7/150 s | 6 s | 8E-6/15 s | 0.99 – 0.99999 |
| Cat-II | 6.9/6.1 m (L) 2.0/1.4 m (V) | 17.3/17.9 m (L) 5.3/4.4 m (V) | 1E-9/15 s | 2 s | 4E-6/15 s | 0.99 – 0.99999 |
| Cat-IIIa | 6.2/3.6 m (L) 2.0/1.0 m (V) | 15.5/10.4 m (L) 10.0 /2.6 m (V) | 1E-9/15 s | 2 s | 4E-6/15 s | 0.99 – 0.99999 |
| Cat-IIIb | 6.2/3.6 m (L) 2.0/1.0 m (V) | 15.5/10.4 m (L) 10.0 /2.6 m (V) | 1E-9/30 s (L) 1E-9/15 s (V) | 2 s | 2E-6/30 s (L) 2E-6/15 s (V) | 0.99 – 0.99999 |
| Surface Movement (most stringent phase) | 0.5 m | 1.4 | 7.25E-9/90 s | 1 s | 7.25E-5/90 s | 0.999 – 0.99999 |

Table 2.1: RNP Requirements for Phases of Flight (Schuster *et al.*, 2006 and Schuster *et al.*, 2007)

According to Table 2.1, the most stringent phase of aircraft operation is surface movement, therefore, if the GNSS based navigation infrastructure and operational algorithms can meet the requirement for surface movement, it is

expected to be able to support the other flight phases as long as the aircraft is within the coverage of the system. The surface movement navigation system requirements are therefore taken as a basis in the development of the navigation algorithms in this thesis.

In this chapter, the growth of civil aviation is presented together with the trend and evolution of the future ATM system. It has been widely accepted that GNSS based systems will serve as the key navigation systems for all the phases of flight in the medium future and the new navigation concepts to facilitate this transition are being introduced by civil aviation authorities. Performance requirements for all phases of flight have been presented in this chapter. These requirements together with the specification of GNSS signals will determine the infrastructure design, observable selection and algorithm development to support different phases of flight. In the next chapter, the state-of-the-art in GNSS and its augmentation systems are presented and a potential GNSS a potential architecture identified for surface precision approach, landing and surface movement.

2. Microwave landing system



The NASA 737 research aircraft on the Wallops runway in 1987 with the Microwave Landing System equipment in the foreground.

A microwave landing system (MLS) is an all-weather, precision landing system originally intended to replace or supplement instrument landing systems (ILS). MLS has a number of operational advantages, including a wide selection of channels to avoid interference with other nearby airports, excellent performance in all weather, a small "footprint" at the airports, and wide vertical and horizontal "capture" angles that allowed approaches from wider areas around the airport.

Although some MLS systems became operational in the 1990s, the widespread deployment initially envisioned by its designers never became a reality. GPS-based systems, notably WAAS, allowed the expectation of the same level of positioning detail with no equipment needed at the airport. GPS/WAAS dramatically lowers the cost of implementing precision landing approaches, and since its introduction most existing MLS systems in North America have been turned off. GPS/WAAS-based LPV 'Localizer Performance with Vertical guidance' approaches provide vertical guidance comparable to ILS Category I and FAA-published LPV approaches currently outnumber ILS approaches at US airports.

MLS continues to be of some interest in Europe, where concerns over the availability of GPS continue to be an issue. A widespread installation in the United Kingdom is currently underway, which included installing MLS receivers on most British Airways aircraft, but the continued deployment of the system is in doubt. NASA operated a similar system called the Microwave Scanning Beam Landing System to land the Space Shuttle orbiter.

2.1 Principle

MLS employs 5 GHz transmitters at the landing place which use passive electronically scanned arrays to send scanning beams towards approaching aircraft. An aircraft that enters the scanned volume uses a special receiver that calculates its position by measuring the arrival times of the beams.

2.2 History

The US version of MLS was a joint development between the FAA, NASA, and the U.S. Department of Defense, was designed to provide precision navigation guidance for exact alignment and descent of aircraft on approach to a runway. It provides azimuth, elevation, and distance, as well as "back azimuth", for navigating from an aborted landing or missed approach. MLS channels were also used for short-

range communications with airport controllers, allowing long-distance frequencies to be handed over to other aircraft.

In Australia, design work commenced on its version of an MLS in 1972. Most of this work was jointly done by the then Federal Department of Civil Aviation (DCA), and the Radio Physics Division of the Commonwealth Scientific and Industrial Research Organization (CSIRO). The project was called Interscan, one of several microwave landing systems under consideration internationally. Interscan was chosen by the FAA in 1975 and by ICAO in 1978 as the format to be adopted. An engineered version of the system, called MITAN, was developed by industry (Amalgamated Wireless Australasia Limited and Hawker de Havilland) under a contract with DCA's successor, the Department of Transport, and successfully demonstrated at Melbourne Airport (Tullamarine) in the late 1970s. The white antenna dishes could still be seen at Tullamarine up till 2003 before it was dismantled.

This initial research was followed by the formation of Interscan International limited in Sydney, Australia in 1979 who manufactured MLS systems that were subsequently deployed in the US, EU, Taiwan, China and Australia. The Civil Aviation Authority (United Kingdom) developed a version of the MLS which is installed at Heathrow Airport and other airports due to the greater incidence of instrument approaches and Cat II/III weather there. GPS has not yet solved the critical problems needed to match the MLS international standard.



An MLS azimuth guidance station with rectangular azimuth scanning antenna with DME antenna at left.

Compared to the existing ILS system, MLS had significant advantages. The antennas were much smaller, due to using a higher frequency signal. They also did not have to be located at a specific point at the airport, and could "offset" their signals

electronically. This made placement at the airports much simpler compared to the large ILS systems, which had to be placed at the ends of the runways and along the approach path.

Another advantage was that the MLS signals covered a very wide fan-shaped area off the end of the runway, allowing controllers to vector aircraft in from a variety of directions or guide aircraft along a segmented approach. In comparison, ILS could only guide the aircraft down a single straight line, requiring controllers to distribute planes along that line. MLS allowed aircraft to approach from whatever direction they were already flying in, as opposed to flying to a parking orbit before "capturing" the ILS signal. This was particularly interesting to larger airports, as it potentially allowed the aircraft to be separated horizontally until much closer to the airport. Similarly in elevation, the fan shape coverage allows for variation in approach angle making MLS particularly suited to aircraft with steep approach angles such as helicopters, fighters and the space shuttle.



An MLS elevation guidance station.

Unlike ILS, which required a variety of frequencies to broadcast the various signals, MLS used a single frequency, broadcasting the azimuth and altitude information one after the other. This reduced frequency contention, as did the fact that the frequencies used were well away from FM broadcasts, another problem with ILS. Additionally, MLS offered two hundred channels, making the possibility of contention between airports in the same area extremely remote.

Finally, the accuracy was greatly improved over ILS. For instance, standard DME equipment used with ILS offered range accuracy of only +/- 1200 feet. MLS improved this to +/- 100 ft in what they referred to as DME/P (for precision), and offered similar improvements in azimuth and altitude. This allowed MLS to guide the

extremely accurate CAT III approaches, whereas this normally required an expensive ground-based high precision radar.

Similar to other precision landing systems, lateral and vertical guidance may be displayed on conventional course deviation indicators or incorporated into multipurpose cockpit displays. Range information can also be displayed by conventional DME indicators and also incorporated into multipurpose displays.

It was originally intended that ILS would remain in operation until 2010 before being replaced by MLS. The system was only being installed experimentally in the 1980s when the FAA began to favor GPS. Even in the worst cases, GPS offered at least 300 ft accuracy, not as good as MLS, but much better than ILS. Additionally, GPS worked "everywhere", not just off the end of the runways. This meant that a single navigation instrument could replace both short and long-range navigation systems, offer better accuracy than either, and required no ground-based equipment.

The major issues with GPS, namely 2 feet vertical guidance accuracy near the runway threshold and the integrity of the system has not been able to match historical ICAO standards and practices. Additional GPS accuracy could be provided by sending out "correcting signals" from ground-based stations, which would improve the accuracy to about 10 m in the worst case, far outperforming MLS. Initially it was planned to send these signals out over short-range FM transmissions on commercial radio frequencies, but this proved to be too difficult to arrange. Today a similar signal is instead sent across all of North America via commercial satellites, in a system known as WAAS. However WAAS is not capable of providing CAT II or CAT III standard signals (those required for autoland) and so a Local Area Augmentation System, or LAAS, must be used.

2.3 Operational Functions

The system may be divided into five functions: Approach azimuth, Back azimuth, Approach elevation, Range and Data communications.

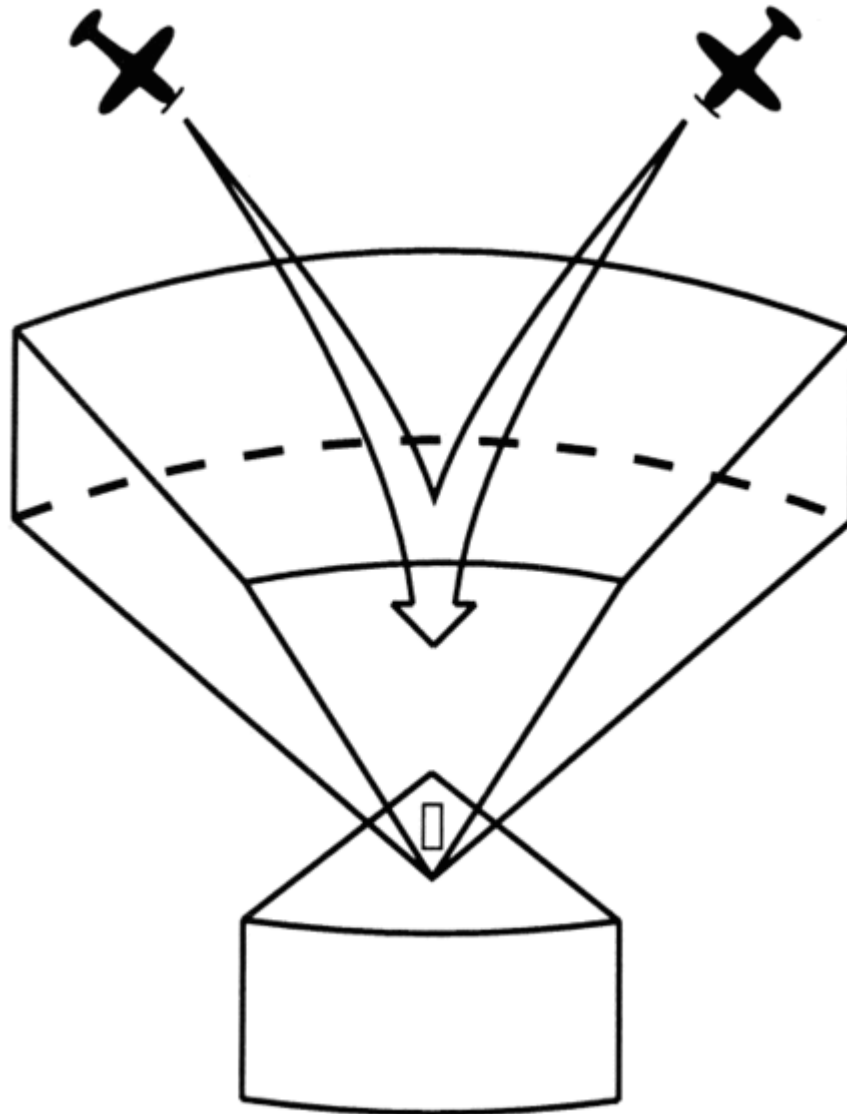


FIG 1-1-10 Coverage Volumes 3-D Representation

2.3.1 Approach azimuth guidance

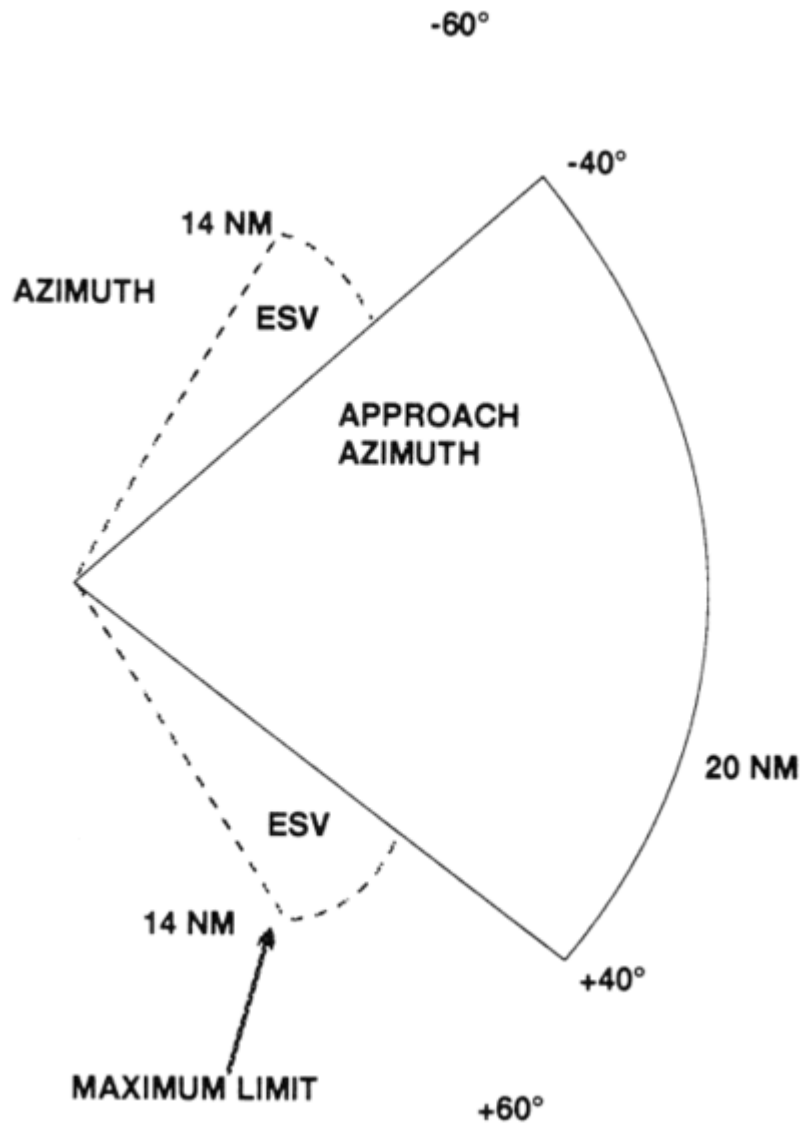


FIG 1-1-8 Coverage Volume of the Azimuth station

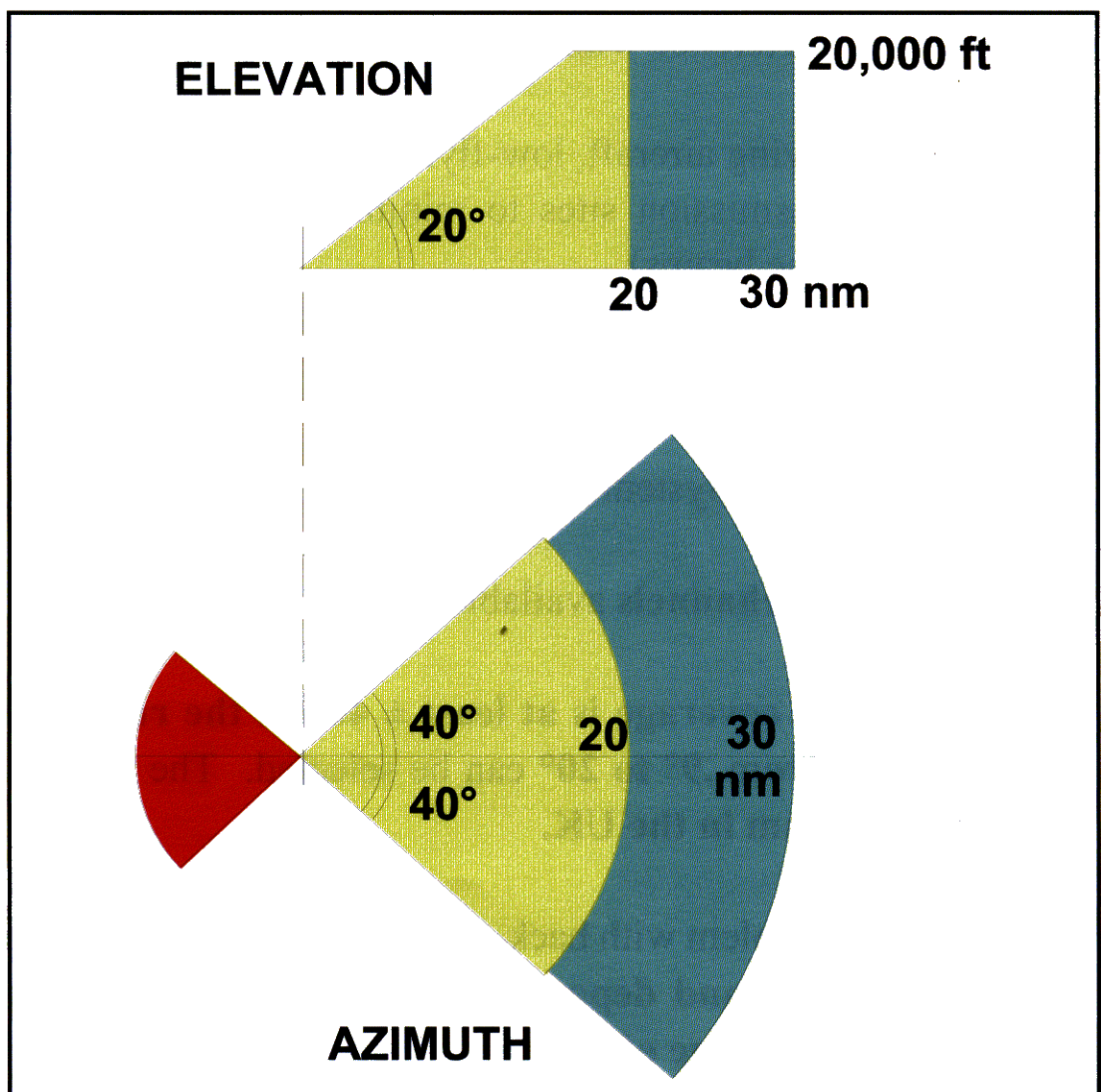


FIG 1-1-9 Coverage Volumes of the Elevation station

The azimuth station transmits MLS angle and data on one of 200 channels within the frequency range of 5031 to 5091 MHz and is normally located about 1,000 feet (300 m) beyond the stop end of the runway, but there is considerable flexibility in selecting sites. For example, for heliport operations the azimuth transmitter can be collocated with the elevation transmitter.

The azimuth coverage extends: Laterally, at least 40 degrees on either side of the runway centerline in a standard configuration. In elevation, up to an angle of 15 degrees and to at least 20,000 feet (6 km), and in range, to at least 20 nautical miles (37 km) (See FIG 1-1-8.)

2.3.2 Elevation guidance

The elevation station transmits signals on the same frequency as the azimuth station. A single frequency is time-shared between angle and data functions and is normally located about 400 feet from the side of the runway between runway threshold and the touchdown zone.

Elevation coverage is provided in the same airspace as the azimuth guidance signals: In elevation, to at least +15 degrees; Laterally, to fill the Azimuth lateral coverage and in range, to at least 20 nautical miles (37 km) (See FIG 1-1-9.)

2.3.3 Range guidance

The MLS Precision Distance Measuring Equipment (DME/P) functions the same as the navigation DME, but there are some technical differences. The beacon transponder operates in the frequency band 962 to 1105 MHz and responds to an aircraft interrogator. The MLS DME/P accuracy is improved to be consistent with the accuracy provided by the MLS azimuth and elevation stations.

A DME/P channel is paired with the azimuth and elevation channel. A complete listing of the 200 paired channels of the DME/P with the angle functions is contained in FAA Standard 022 (MLS Interoperability and Performance Requirements).

The DME/N or DME/P is an integral part of the MLS and is installed at all MLS facilities unless a waiver is obtained. This occurs infrequently and only at outlying, low density airports where marker beacons or compass locators are already in place.

2.3.4 Data communications

The data transmission can include both the basic and auxiliary data words. All MLS facilities transmit basic data. Where needed, auxiliary data can be transmitted. MLS data are transmitted throughout the azimuth (and back azimuth when provided) coverage sectors. Representative data include: Station identification, Exact locations of azimuth, elevation and DME/P stations (for MLS receiver processing functions), Ground equipment performance level; and DME/P channel and status.

MLS identification is a four-letter designation starting with the letter M. It is transmitted in International Morse Code at least six times per minute by the approach azimuth (and back azimuth) ground equipment.[1]

Auxiliary data content: Representative data include: 3-D locations of MLS equipment, Waypoint coordinates, Runway conditions and Weather (e.g., RVR, ceiling, altimeter setting, wind, wake vortex, wind shear).

2.4 Future

There are different requirements when it comes to landing in Europe and the USA. In the USA, if pilots are unable to see the runway due to low visibility conditions, the aircraft can generally divert to another airport. In Europe, due to its smaller land area, low visibility can affect all airports in the vicinity, forcing planes to land in low visibility conditions.

In the United States, the FAA suspended the MLS program in 1994 in favor of the GPS (Wide Area Augmentation System WAAS). The FAA's inventory of instrument flight procedures no longer includes any MLS locations;^[2] the last two were eliminated in 2008.

Many countries in Europe (particularly those known for low visibility conditions) have embraced the MLS system as a replacement to ILS.

2.5 Difference between MLS and ILS

The guidance system for approach and landing now in use is the Instrument Landing System (ILS), which has been the standard system in USA since 1941 and is widely used by civil aviation throughout the world. ILS provides guidance by radio beams that define a straight-line path to the runway at a fixed slope of approximately 3° and extending 5 to 7 miles from the runway threshold. All aircraft approaching the airport under ILS guidance must follow this path in single file, spaced at intervals dictated by standards for safe longitudinal separation and the need to avoid wake vortex. This long, straight-in approach is a bottleneck that reduces the runway utilization rate, especially when fast and slow aircraft are mixed in the approach stream or when arrivals from different directions must be merged on the common final approach path. As a result, the capacity of the airfield under IMC, when the long ILS common approach path must be used, is usually less than under VMC.

The runway utilization rate under IMC could come closer to that attainable under VMC if aircraft could follow multiple approach paths, descend at different approach angles, or aim at different touchdown points on the runway—none of which is practical with ILS. If this flexibility were possible, as it is under VMC, airfield

capacity would be less affected by weather conditions, and throughput would be governed almost exclusively by runway geometry and aircraft performance characteristics.

The Microwave Landing System (MLS), which has been under development by FAA for over a decade, would overcome some of the disadvantages inherent in the ILS. Because MLS uses a beam that scans a wide volume of airspace, rather than the pencil beam of ILS, it permits aircraft to fly any of several approach angles (including two-step glide slopes) and, in the horizontal plane, to approach along curving paths that intersect the extension of the runway centerline at any chosen point. In effect, MLS offers a degree of freedom in using the airspace that is closer to that enjoyed under conditions of good visibility.

The chief motive for FAA in seeking to develop and deploy the MLS is not the potential capacity benefits, however, but its operational advantages —more precise guidance, ease of installation, improved reliability, less susceptibility to electromagnetic interference, and greater number of transmission channels. The capacity benefits are secondary but still of great importance at some airports where the present ILS acts to constrain capacity in adverse weather conditions. In terms of its effect on capacity, the chief advantage of MLS is that, in IMC, it allows pilots and controllers greater flexibility in selecting an approach path so as to shorten the approach time, to avoid air turbulence generated in the wake of preceding aircraft, or to avoid noise-sensitive areas. Another advantage is that MLS can provide guidance for the aircraft during missed approach, allowing a safe exit from the terminal airspace and smooth reentry into the approach pattern. The availability of missed approach guidance could have a significant capacity benefit at those airports with parallel or converging runways that cannot now be used in IMC. A third advantage is that MLS can be installed on runways where ILS is not possible due to siting problems and on short auxiliary runways reserved for commuter and small general aviation (GA) aircraft. On some runways, MLS can increase capacity during IMC by providing lower landing minimums than ILS and thereby allowing the airport to remain open in marginal weather conditions. A fourth advantage of MLS is its capability to provide non-conflicting routes into closely situated airports, where approach or departure paths may mutually interfere and limit capacity utilization.

ILS has limitations:

- It only has 40 channels.
- It only can serve one runway, causing congestion in bad weather.
- It is subject to interference by powerful FM broadcasts.
- It can be blocked by terrain.

Advantages of MLS

- Can be used to land aircraft on aircraft carriers.
- Has 200 channels, instead of just 40.
- Can handle curved and stepped approaches.
- The glideslope is selectable, which can handle steeper approaches that helicopters use.
- Is not subject to interference from FM radio stations.
- Is not subject to blockage from terrain.
- MLS is at very few airports, however. This is because it is anticipated to be replaced by GPS
- Reliability: freedom from FM radio and terrain interference. (allows for more versatile site selection.)
- Flexibility:

Availability of multiple flight paths approaching the same runway.

Lateral guidance can vary as much as 60 either side of centerline with range to 20nm.

Vertical guidance from 0.9 to 15 (helicopters).

Potential for curved and segmented approaches.

Data transfer capability.

MMLS (mobile MLS) portable deployment for military applications.

Disadvantages of MLS

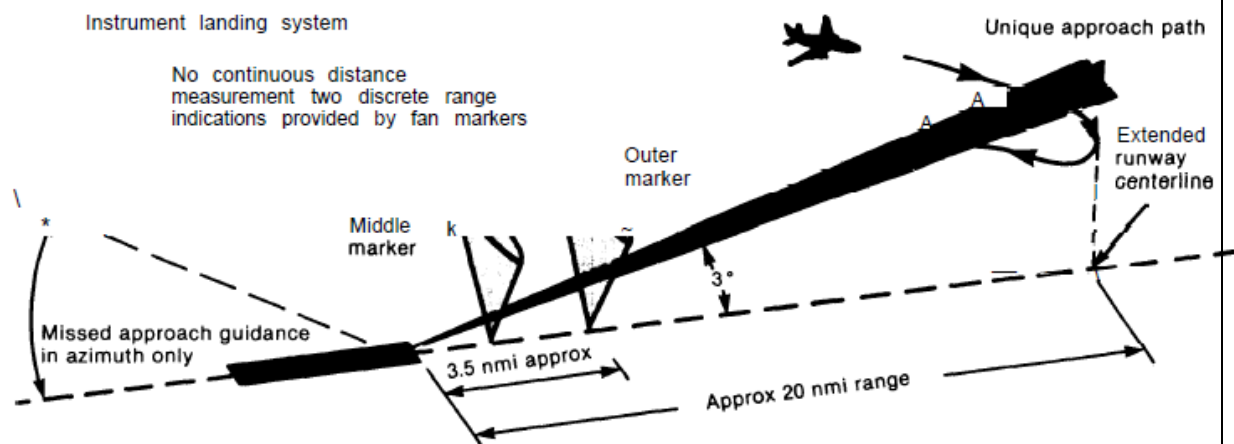
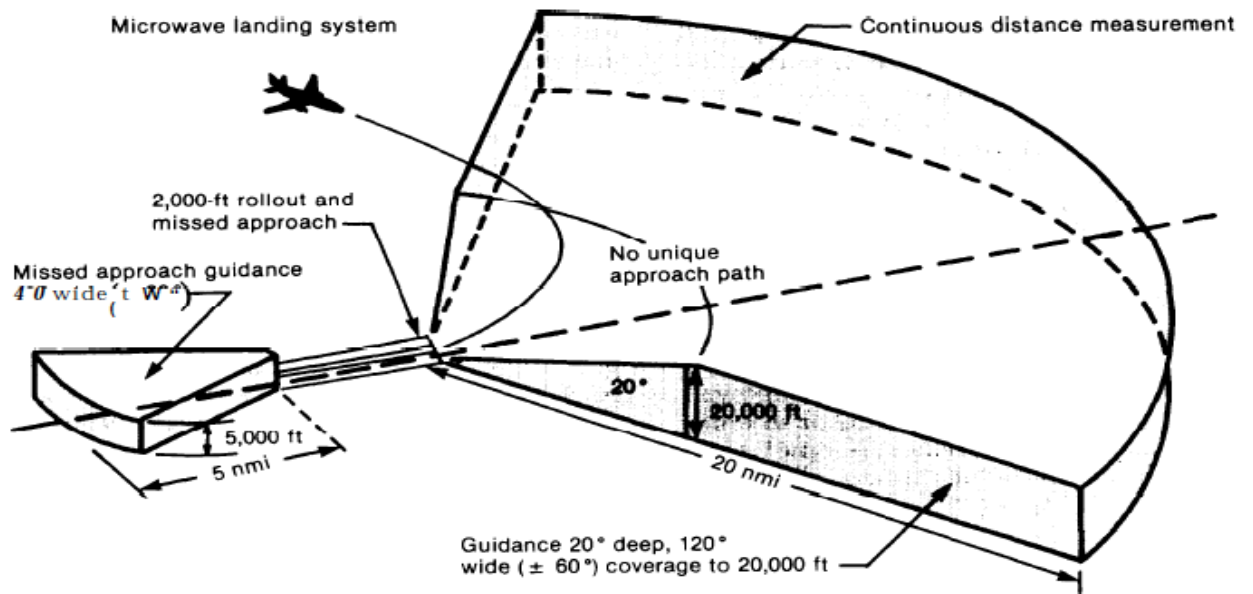
Expensive: the initial expense of infrastructure setup and aircraft equipment installation.

New alternatives: GNSS is emerging as the mainstream RNAV system for civil aviation. It's potential for non-precision and precision approach capability has been

proven. With market forces driving GPS usage it is destined to be the system of the future.

MLS will be limited to specialized applications, such as military MMLS.

Comparison of Microwave Landing System and Instrument Landing System



3. Economic part

Problem of economic development of our Republic is production efficiency increase on the basis of acceleration of scientific and technical progress and economy of all types of resources.

The accelerated introductions of achievements of scientific and technical progress in production and operation of the aircraft equipment are covered by a specific circle of problems among which the extreme importance gets a choice of the most effective directions of research works, expediency of design of these or those models of new aircraft.

At existing speeds and heights it is impossible to carry out flight without stable and reliable information about flight parameters, modes of operation of engines and numerous onboard devices and units therefore the role of aviation devices and automatic systems constantly increases in safety of flights.

Information arriving from onboard systems and sensors of primary information, is processed by means of electronic onboard cars, and automatic devices give out teams for performance of operations on providing all modes of flight.

The salary of dispatchers of the Air traffic control is established

Salary of dispatchers of the Air traffic control according to the Industry, tariff agreement between central committee of labor union of an avia of workers both national airline "Uzbekistan Air Ways" and Situation on compensation of an avia of employees of national airline "Uzbekistan Air Ways".

The tariff agreement is the main for the conclusion of collective agreements, employment contracts (contracts) in structural units the enterprises National Airlines and all additional rights provided by it, privileges, guarantees, compensations, compensation and working conditions is minimum obligatory.

The presents the industry tariff agreement is concluded between the center it committee labor union an epithet to labor unions of an avia of workers of Uzbekistan management of National airline "Uzbekistan Air Ways" for creation to partnership system in regulation of work of all relations, establishments of healthy and safe working conditions and realization of socially economic privileges, guarantees, compensations for workers and their security in questions of entertaining and the population and republic economy in aviation services is directed on ensuring stable work of civil aviation of the Republic of Uzbekistan and satisfaction of requirements.

The agreement establishes additional in comparison by the legislation of the right, a guarantee and compensation privilege, payment and a working condition all structural units and the enterprises of National airline and regulates obligations of the parties.

Calculation of a salary of the Head of flights

The annex No. 1 to the Industry tariff agreement between Central office of labor union of aviaworkers and Management of national airline agrees the Scale of charges of the coefficients, corresponding by the category on compensation of workers, Automated Systems, employees and heads of structural divisions of National airline is entered. According to a scale of charges the official salary of the worker of primary activity is defined by multiplication of tariff coefficient of the corresponding category on fixed a rate accepted in NAC "Uzbekistan Air Ways" for calculation of official salaries.

According to the annex No. 5 to the Industry agreement categories on compensation of employees of the Center are provided. "Uzaero navigation" of National airline "Uzbekistan Air Ways". According to the appendix No. 5 the official salary of the head of flights is charged proceeding from the 17th category on compensation, with application of coefficient 8,28 and raising in coefficient on compensation.

| Table 1 | | | | | |
|-----------------|----------|--|-------------------------|--------------------------------|-----------------|
| Position | Category | Coefficient according to a scale of charges the appendix No. 1 | The raising coefficient | The fixed rate accepted in NAC | Official salary |
| 1 | 2 | 3 | 4 | 5 | 6 |
| Head of flights | 15 | 8,28 | 1,67 | 68655 | 949334 |

According to Situation on compensation of an avia of workers national airlines "Uzbekistan Air Ways" price-work and time wage of work is established: to heads, Automated Systems and employees official salaries, worker official salaries, hour tariff rates and price-work quotations.

According to Situation on compensation the following surcharges for specialists of the Air traffic control are established:

1) To the workers knowing a foreign language not below the 4th level on a scale of IKAO and applying them in work, extra charges to an official salary in the size of 15% from an official salary are established.

2) Taking into account carried-out amounts of works to establish the following class of services and points of Air traffic control of the Uz aero navigation Center;

I class:

Tashkent, Nukus, Samarkand territorial office.

VRTs - Navoi, Termez; Namangan

II class

Territorial offices (control offices with direct Air traffic control) on all the territory Uzbekistan.

Additional payment to a salary for intensive work by the head of flights is established, to the senior dispatchers and the dispatchers of the Uzaero navigation Center having the existing certificate of the aviation dispatcher, from calculation:

- Tashkent, Navoi, Termez – 20%;
- Samarkand – 15%

- Nukus – 10%
- Namangan – 5%

Thus, the total salary of the Head is displayed by flight in a tabular form (tab. No. 2), as follows:

Table 2

| Position | Official salary according to the tab. No. 1 | Extra charge for foreign language, 15% | Additional payment for intensity of 20% | The Salary (sum) in a month |
|-----------------|---|--|---|-----------------------------|
| 1 | 2 | 6 | 4 | 5 |
| Head of flights | 949334 | 142400 | 189866 | 1281600 |

Thus, the salary of the Head of flights will make according to the table No. 1 and the table No. 2, and according to the industry tariff agreement and Situation on compensation of 1281600 bags in a month.

4. Labor safety

Safety requirements on labor protection for specialists of the Air traffic control The Tashkent Center of the Automated System Air traffic control

Persons are allowed to work as the specialist of the Air traffic control not more young 19 years which have passed medical about witnessing, induction on labor protection. After that the specialist of the Air traffic control passes primary examination on labor protection in examination committee of CUAN. Further it passes periodic instructing in labor protection once in six months with confirmation of it in a log-book of instructing on a workplace.

The specialist of the Air traffic control of the Air traffic control AUTOMATED SYSTEM Tashkent Center is obliged:

- to carry out the instruction on labor protection, Center employment policies and procedures

"Uzaeronavigation";

- fire safety regulations;
- not to allow on a workplace of persons not concerning to performed work;
- to have 1 group on electrical safety;
- nobility and carry out rules of personal hygiene, not to smoke in premises of Shopping Center AS ATC and not to use to and to operating time on which was trained;
- to fulfill requirements of signs of safety;
- to be able to use fire extinguishing means.

The specialist of the Air traffic control of the Air traffic control AUTOMATED SYSTEM Tashkent Center, allowed violations of requirements of the instruction on labor protection, is attracted to a disciplinary responsibility according to CUAN employment policies and procedures and if these violations are connected with causing material damage to the enterprise, bears also a liability in accordance with the established procedure.

Safety requirements before work.

To prepare a workplace.

In the course of pre replaceable instructing the specialist of the Air traffic control receives information on availability for service electro, radio and lighting means from Automated Systems of KRTOP, ESTOP and specialists of the Departments of Internal Affairs which are handing over watch and taken measures for elimination of malfunctions, revealed by previous change.

The specialist of the Air traffic control checks serviceability of the equipment.

Safety requirements in operating time.

During the work with the radio engineering equipment to carry out only those operations which are provided by the instruction on its operation for specialists of the Air traffic control of the Air traffic control AUTOMATED SYSTEM Tashkent Center.

It is forbidden to open panels, hatches, telephone sets, sockets and electric sockets, to repair radio and electric equipment, both special, and household appliances.

In case of shortcomings of work of radio engineering means immediately to report on the shift engineer of RTP of the Air traffic control AUTOMATED SYSTEM Tashkent Center.

Movement on the territory of airfield has to be, as a rule, by car PPRP. In movement cases on foot, movement is made according to airfield marking, with observance of precautionary measures and constant discretion.

Not to run across rulezhny paths before driving planes and isn't at planes with working engines, ahead – 50 meters are closer, behind – 100 meters, and also in the plane of rotating screws are closer. Isn't in the sectors which haven't been specified in the admission of the worker.

Not to accept food on workplaces, not to place on panels of the Department of Internal Affairs and other processing equipment and in close proximity to them construction subjects.

Not to carry out functional duties of employees of other services.

Safety requirement in emergencies.

At emergence of the electric short circuits which have led to ignition of an electrical wiring or the equipment immediately to report RP, on the shift engineer of RTO.

At health deterioration during watch it is necessary to report immediately RP and to demand replacement, and RP organizes substitution and immediately calls the doctor on duty on ph. 34-52, 140-28-95.

At emergence of a fire to call the ASS team (by local phone: 69-81, 60-03, 60-11, 10-25 or PGS) and to take measures for elimination of the seat of fire.

Safety requirements upon termination of work.

To order a workplace.

At available shortcomings of equipment work, the specialist of the Department of Internal Affairs has to notify on this RP and dispatchers of taking-up change.

Safety requirements on labor protection for the employees of services of Shopping Center Uzaeronavigation performing works on personal computers and office equipment (the personal computer and FROM)

On the personal computer (PC) and the organizational equipment (OE) it is allowed to work the persons which have reached 18-year age.

The worker passes preliminary medical examination and not having contraindications. Further the worker passes induction on labor protection and primary instructing in labor protection on a workplace.

In the course of work the worker passes periodic instructing in labor protection of 1 time in 6 months. All types of instructing in labor protection are made out in magazines of registration of instructing and are confirmed by signatures of the worker.

Periodic medical examination is carried out once a year with obligatory participation of the therapist, the neuropathologist and the oculist.

The worker has to have 1 qualification group on electrical safety. The mode of work and rest are defined in Employment policies and procedures of employees of the Uzaeronavigation Center.

Factors of danger are:

Tension of electromagnetic fields.

Tension of the visual analyzer and attention function.

The compelled working pose, the monotonian Period.

Aren't allowed to work with the computer equipment of the woman from the moment of establishment of pregnancy and during feeding by a breast.

During the work on the personal computer and FROM the worker it is obliged:

- to carry out the instruction on labor protection, employment policies and procedures of workers, Center of Uzaeronavigation the instruction of the direct head, workers of labor protection and safety measures, a fire service;

- nobility and observe only that work on which was trained, instructing in protection and it is allowed by the head to work performance;

- to fulfill requirements of signs of safety;

- to report to the direct head about the noticed malfunctions of the personal computer and Completely acceptances of the appropriate measures by the head not to start work; - to be able to render the pre-medical help to injured workers, to use fire extinguishing means (the fire extinguisher, an internal fireplug, etc.), at emergence of a fire to cause a fire brigade 01, 16-54, 60-65, 140-28-70) and to participate and fire eliminations.

The worker who has allowed violation of requirements of instructions on labor protection, can be attracted to a disciplinary responsibility according to Employment policies and procedures of employees of the Uzaeronavigatsy Center and if these violations are connected with causing property damage to the enterprise, the worker bears also a liability in accordance with the established procedure.

Safety requirements before work.

The worker is obliged:

- to check external survey serviceability of sockets and food cords. ;
- to adjust illumination on a workplace, to be convinced of lack of patches of light on the display screen;
- to wipe a napkin a screen surface from a dust (at the switched-off computer)
- to be convinced of lack of diskettes in disk drives;
- to check a nezagramozhdennost of ventilating openings in equipment cases;
- at identification of damages to report on it on the direct head.

Safety requirements in operating time.

The worker is obliged:

- to observe service regulations of the personal computer and FROM;
- to observe the established mode of work and rest;
- to watch lack of paper and other combustible materials on the working equipment.

It is forbidden to the worker;

- to start to work wet hands;
- to open the protective case of the system unit;
- independently to make replacement of safety locks;

- to leave the switched-on personal computer and Otpri an emergency shutdown of the electric power;

- to work at faulty personal computers and FROM (at emergence of a smoke, a smell, ashes, sparking, feeling of an electric current at a touch to metal cases of the equipment, etc.);

- to concern at the same time the monitor and keyboard screen;

- to touch the back panel of the system unit at included pitaniye;

- to put and put on the completing equipment which is a part of the personal computer: paper clips, scissors, cups, drinking bowls, etc.;

- to clean the personal computer and FROM, being energized;

- independently to eliminate the appeared malfunctions.

To report on the appeared malfunctions on the immediate superior.

Duration of continuous work on the personal computer and Otbez of the regulated breaks shouldn't exceed 2 hours. The regulated breaks are established by duration of 15 minutes. The general total duration of working hours on the personal computer and FROM shouldn't exceed 4 hours.

The regulated breaks need to be used for performance of a complex of physical exercises (Appendix 1,2,3). The choice of exercises and their time is carried out by the worker individually, depending on feeling of fatigue.

In case of feeling sick the worker has to stop work, inform the immediate superior or the persons working with a row and to ask for the help the doctor, in a health center by phone: 140-27-57; 44-68 Safety requirements in emergencies.

At the noticed malfunctions or ignition in the personal computer and Otpriyvpolneny of works, the worker is obliged:

- to stop works;

- immediately to disconnect power supply of the personal computer and FROM;

- to warn working as a row about danger;

- to use primary fire extinguishing means;

- to inform the immediate superior;

- in case of a fire to cause a fire brigade by phone: (01, 1654, 6065, 140-28-70) and to participate in fire extinguishing.

At unfortunate a case with workers to render them the pre-medical help. immediately to inform the immediate superior, to cause an ambulance car by phone:

3963, 3452, 140-28-95 or, 6481, 140-28-91

Safety Requirements upon termination of work.

The worker is obliged:

- to close all active tasks;
- to be convinced that in the disk drive there are no diskettes;
- to switch off a food of the personal computer and FROM (including to switch off a food of all peripherals);
- to order a workplace;
- to report to the immediate superior about malfunctions if they are available.

When developing the instruction the following documents were used:

Health regulations and norms while work on personal computer video display terminals and office equipment (San Pi of N No. 0224-07).

The provision on development of instructions on the labor protection, registered by the Ministry of Justice of the Republic of Uzbekistan No. 870 05.01.2000г.

Appendix No. 1

1 . Initial position rack of a foot separately. 1 hand back, 2-3 hands in the parties and up to rise on socks, 4-raslably a humeral belt, hands down with a small inclination forward. Will repeat 4-6 times. Speed slow.

2 . Initial position rack of a foot separately, hands are bent forward, brushes in a fist. trunks 1st by turn on the left "blow" right hand forward. 2-starting position, the 3-4-same in other party. Will repeat 6-8 times. Breath not to detain.

3 . Initial position rack of a foot separately, hands forward. 1 turn of a trunk to the right, a move the left hand to the right, right back for a back. 2-starting position, the 3-4-same in other party. Exercises are carried out widely, dynamically.

To repeat 6-8 times.

Speed fast.

Appendix No. 2

Complexes of exercises for eyes.

1 . To close eyes, strongly straining eye muscles, into the score 1-4, then to close eyes, having relaxed muscles of eyes, to look at the score 1-6 lengthways.

To repeat 4-5 times.

2 . To look at a nose bridge and to detain a look into the score 1-4. Not to bring to fatigue of eyes. Then to open eyes, to look afar at the score 1-6. To repeat 4-5 times.

3 . To transfer a look quickly on a diagonal to the right up – on the left down, then directly afar to the score 1-6. Then on left up – to the right down and to look lengthways at the score 1-6. To repeat 4-5 times.

4 . To close eyes, without straining eye muscles, into the score 1-4, widely to open eyes and to look afar at the score 1-6. To repeat 4-5 times. 3 . To transfer a look quickly on a diagonal to the right up – on the left down, then directly afar to the score 1-6. Then on left up – to the right down and to look lengthways at the score 1-6. To repeat 4-5 times.

5 . To record a look on a subject removed at distance to 30 cm into the score 1-4, then to translate a view of the score 1-7. To repeat 4-5 times.

Appendix No. 3

Physical action for improvement of brain blood circulation.

1 . Initial situation – sitting on a chair 1-2 to take away the head back and smoothly to incline back, to incline 3-4 head forward, not to raise shoulders.

To repeat 4-6 times.

Speed slow.

2 . Initial situation – sitting on a chair, hands in the parties, palms forward, fingers are divorced. 1-having clasped itself for shoulders hands it is possible to bend further more strong to the right. 2 – the same on the left.

To repeat 4-6 times.

Speed fast.

3 . Initial situation – sitting on a chair, hands on a belt. 1-2 circle the right hand back with turn of a trunk and the head on the right. 3-4 same left hand.

To repeat 4-6 times.

Speed slow.

4 . Initial situation – sitting on a chair, hands on a belt. 1-to turn the head to the right.

2 – the same on the left. To repeat 6-8 times.

Speed slow.

To execute 2 options from 4 in any combinations.

Safety requirements to flight and to the service personnel

Crew members of the aircraft and the service personnel irrespective of experience and length of service have to in due time and pass in full all types of instructing in labor protection with registration in the special magazine. Persons not passed instructing aren't allowed to work.

Flight and the service personnel passes the following instructing in labor protection:

- the introduction - at revenues to work (the work security service carries out);
- the primary - on a workplace;
- the repeated - is carried out not less often than once in three months;
- the unplanned - is carried out individually to the expert or completely with crew of the aircraft and the service personnel in case of violation of requirements for labor protection in flight you (weed), when performing aviation works, breaks in work more than 30 calendar days, and also at the next check on the admission to types of aviation works.

Primary on a workplace, repeated, unplanned instructing are carried out by the corresponding instructor in the specialty, the commander of an avia squadron, the senior engineer of flight group (service). All persons, instructing have to pass in the air enterprise annual examination on labor protection.

The aviation personnel uses overalls, special footwear and other means of individual protection from influence of harmful and dangerous production factors according to existing rules.

Crew members have to be able to render the first (pre-medical) medical care, to use the onboard medical first-aid kit. Responsibility for violation of safety regulations and labor protection requirements when providing and performing flights

On each violation of the rules of safety measures investigation with identification of the reasons and the perpetrators which have allowed these violations has to be made.

The aviation personnel and the experts of the customer who have allowed violation of the present requirements for labor protection, are made responsible according to RUZ current legislation.

If violations of the rules of labor protection are connected with causing property damage to the enterprise, these persons bear also a liability in the order established by the law.

The order of investigation and the accounting of accidents when performing aviation works is established according to a relevant provision about investigation and the accounting of accidents and other damages of health of workers on production.

Summary

Replacement of the existing ILS poses two problems that may complicate the transition to MLS and delay realization of the full benefits. There are at present about 650 ILS units in commission at some 460 airports and another 150 or so units in various stages of procurement—some as replacements for existing units, others as new installations. The MLS transition plan calls for these ILS units to remain in service for many years to come, until at least 60 percent of the aircraft routinely using the ILS/MLS runway are equipped with MLS. While ILS and MLS can be co located and operated simultaneously without signal interference, there may be procedural difficulties in blending aircraft equipped with ILS (and therefore capable of only straight-in approaches) into a traffic stream with MLS equipped aircraft flying curved or segmented approaches. Thus, the full capacity benefits of MLS may not be attainable at a given airport until all or nearly all aircraft are MLS equipped and the ILS can be decommissioned.

A second factor that may delay taking full advantage of MLS at specific sites is the agreement with the International Civil Aviation Organization whereby the United States is committed to retaining ILS service at international gateway airports until 1995. There are 75 such airports, generally the busiest U.S airports and those most prone to capacity and delay problems. Retaining ILS service at these airports may influence some users to defer purchasing MLS equipment for another 10 years or more.

While the capacity gains attributable to MLS may be rather small for the airport system as a whole, MLS does appear to offer promise at those airports where it could be used to create a more flexible traffic pattern or to provide commuter and small GA aircraft access to an alternate runway in IMC, thereby relieving pressure on the main runway used by large air carrier aircraft. Beyond these direct benefits, moreover, MLS may permit procedural changes that could also increase capacity or reduce delay. These potential benefits of MLs are discussed in a later section on airspace use procedures.

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