POLYTECHNIC UNIVERSITY OF BUCHAREST

Doctoral School of Industrial and RoboticEngineering
Engineering and Management

Decision CSUD UPB nr. ……. from …………………..

ABSTRACT
DOCTORAL THESIS

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Conflict detection and resolution in Air Traffic Management

DOCTORAL COMMITTEE

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BUCHAREST 2021

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INTRODUCTION

Conflict Detection and Resolution (CDR) from air trafic involves the interaction of several areas, simulation of aeronautical physical systems, coding of detection algorithms and resolution of air conflicts, operational procedures for resolving detected conflicts. In the Air Traffic Management (ATM) are numerous solutions for detecting and avoidinf air conflicts, having particular simulation algorithm. The similar direction in the case of dynamic systems studied with the CDR, is that a wide range of system agents have a hybrid behavior, so there are a multitude of discrete modes in studies of Flight Management System (FMS). The modalities of detecting and resolving the air conflict begin with the specification and alarm indicated by the ACAS/TCAS systems, abd the study of the probability of occurrence of the conflict which is determined by calculing the position and actual speed of the aircraft in conflict.

The air traffic automation system provides a multitude of solutions for air trafffic decongestion, which is expected in the next 20 years. Automated soving clearly results in increased efficiency, leading to increased aviation safety and security, thus optimizinf the effort of traffic controllers.

The paper proposes a new algorithm for automatic resolution of existing conflicts in real airpace, which considers the problems previously detected, remove random elements, thus resolving new air conflicts and in the absence of a solution, which is based strictly on changing the flight speed on the trajectory.

The paper develops and tests the algorithm for detecting and resolving air conflicts for aircraft with and without a pilot on a board aircraft. A CDR algorithm is developed, subsequently tested, and subsequently this logic is refined in the case of aircraft with a flight deck crew. A useful simulator for testing and evaluating control logic is integrated, thus optimizing air safety in the area considered to be at high risk of air collision. The method of Point of Closest Approach is used, as well as medium-term CD (Conflict Detection), Mid Term Conflict Detection (MTCD) 2D. The algorithm thus aims to determine the minimum distance as well as the time between aircraft that have the same flight altitude.

The doctoral thesis falls into the **Field of Engineering and Management** by addressing issues specific to the field of air traffic of use of air traffic in order to formulate countermeasures capable of preventing the occurrence of aviation incidents and accidents. This requires a methodical study based on sound knowledge and experimental results, numerical methodes and simulations, which have proven to be particularly effective mathematical calculation tools. All this can only be done in a suitable simulation environment, which needs to be constinously developed and updated.

The purpose of the paper focuses on the development and testing of real-time air conflict detection and resolution algorithms.

The general objective of this thesis is the original contribution to the development, but also testing the air collision avoidance algorithm, but also modelling, simulation, intelligent warning standard, as well as the optimization methodology from the point of view of dynamic systems engineering. The personal approach takes into account the multitude of risk factors that appear at each stage of the flight. The development and testing of the original algorithm for detecting and resolving air conflicts it was done from the perspective of the aicraft both without a pilot on board and in the presence of the pilot on board aicraft considered.

The research methodology for the realization of this thesis required the use of the following methods and tools of investigation:

- Research of an extensive bibliography, comparative analysis, descriptive analysis;
- Conceptual modeling, simulation and testing;
- Programming languages: Matlab, Python, Simulink.

The Importance of Flight Collision Avoidance Systems – ACASA/TCAS in the current international context

The structural and functional elements of Air Traffic Management are presented first, starting from the particularities related to the tendencies of the system used on the territory of the European Union, but also that of the United States of America.

The interes in the develpment of air collision avoidance systems can be considered as early as the 1950s, when two U.S. military crashed into the air over the Grand Canyon. Following this event, the FAA focused on the Radiofar Collison Avoidance Systems (BCAS), which is a transponder based system. In 1978 is produced the second air collision, the collision being between a general aviation aicraft and a transport aircraft, which led to the development of the BCAS -Beacon Collision Avoidance System, which in 1981 is renamed TCAS – Traffic Alert and Collision Avoidance System. After producing the third air crash, new legislation was imposed by the FAA, the isntallation of the TCAS system was imposed on all aicraft carrying more than 30 people in United States. The first commercial flight in which the TCAS system was introduced took place in 1990. Safety monitoring and assessement has led to a number of changes that have led to an international version, called Version 7 or the Airborne Collision Avoidance System (ACAS).

In recent years, the development of Remotely Piloted Aircraft Systems (RAPS) has been charesterized by an exponential increase, bot in miliary applications and in civilian and commercial environments. One of the major challenge related to the intensive use of RAPS it is their integration into civil airspace. The results of research conducted in Europe and USA, individualizes Sense and Avoid technology as an essential factor for integration of RAPSs into civil airspace, taking into account an adequate level of safety. One of the most recent and promising proposed solutions is based on the development of Sense and Avoid systems based on the use of ADS-B (Automatic Dependent Surveillance - Broadcast), which has become mandatory since 20020 in the US [1], but also in Europe, for all aicraft flying in Class A, B, and C airspace [2]. Bibliographic references [3] [4] [5] [6] [7] [8] [9] show CASs (Collision Avoidance Systems) based on ADS-B technology. These methods differ both for the mehodes of calculating the collision avoidance maneuver, as well as for in-flight collision detection. A method proposed in the literature, presented in [4], calculates the probability of collision given the uncertainties associated with ADS-B measurements and using Monte-Carlo simulations. Also in this study, the associated computational task is immense, due to the need to use Monte-Carlo simulations to calculate the probability of a collision. The method of collision based on the geometric approach proposed in [5], considers an a priori admitted violation of the initially predefined separation minimuns. In this case, a position control is required to increase the distance provided to the point of closest approach. The method does not have a very high processing calculation, but the cooperation of the intruder planes involved is necessary [2]. Another method whiach takes into account breach of a safe minimum horizontal threshold and the generation of a reference corresponding to the steering angle to restore the minimum permissible separation distance is shown in [6]. Similar to the methodology proposed in [6] and the methods proposed in [8] and [7] formulate the problem of collision avoidance as route planning task, space and separation constraints, height limits and pre-allocated crossing points. Apromising approach based on monocular cameras for collision detection is proposed in [10]; Due to its low weight, small size, but also the low power consumption of the required sensor, can be interesting, but the method may have a slow speed response due to blurred images, especially in dark envirenments, so it may not be suitable for rea-time applications. Bibliographic references [11] and [12] propose a method of collision avoidance for more than two unmanned vehicles. The collision detection condition shall be verified if the distance between the agents is less than the sum of the radius calculated around the aicraft involved in the conflict. The avoidance maneuver is obtained by overwriting a potential output field with an adhoc rotation rate [2]. An approach based on imaging and avoidance is reported in [13]. The approach provides a lateral or vertical separation without estimating the interval and a simple termination criterion is used for the avoidance maneuver. In addition, the Air Force Reseach Laboratory and Lockheed Martin have developed an automatic collision avoidance systems to perform aggressive maneuvers to avoid collisions [14], [15], [16]. The maneuver is calculated by an optimization tool that chooses between the best avaible maneuvers, the best to be applied.

Finally, the Federal Aviation Administration (FAA) has formed a team to develop a new ACAS (Airborne Collision Avoidance System) technology, identified as ACAS X, starting in 2008. The intension is for ACAS X to replace TCAS II (ACAS II); the effectiveness of TCAS II has been demonstrated over many years, and, according to estimates, has reduced the risk of an air collision in Europe by an approximation factor 5. The ACAS X alert logic is based on a set of safety considerations, operational considerations, but also on a numerical lookup table that is optimized in relation to a statistical model for aerspace. Adapting logic to different airspace configurations or certain procedures, the aim is to provide impoved alter performance, a reduction in cost, update deadlines, an improvement for consulting logic and supervision. The new approach takes advantage of current advances in „dynamic programming”, but also by computer technique for generating alerts using online optimization of alert resolution. If TCAS II is based only on transponder surverillance, ACAS X must be compatible with any sourse of surveillance that meets the specifications of the performance criteria. The system will move from TCAS light signal monitoring to plug-and-play surveillance which supports surveillance based on a global positioning system (GPS) data and which can obtain surveillance data from a variety of sources, such as radar surveillance systems, satellite, infrared and electro-optical. The latter sources are particularly needed to support the requirements for UAVs to detect and avoid aicraft which are not equipped with transponder. The new surveillance capabilities will allow collision avoidance protection for new classes of users, including small aicraft, general aviation, which are not currently equipped with TCAS [17].

However, ACAS X is a collision avoidance system for which research is still underway and under development. With regard to the issue of collison avoidance, the Italian Center for Aerospace Research (CIRA) is carrying out specific activities aimed atidentifying a new methodology for calculating the collison avoidance maneuver, suitable for rea-time implementation, thus constituing a promising technological factor fot the safe integration of RPAS Civil Airspace.

Chapter 1

1. The general framwork of Airspace Management

This chapter provides important general information on both the European and American ARM systems, which can be used to explain the multitude of difference between the basic performance indicators. It shows the differences in air traffic management in term of geographical airspace, technolog and command and control equipment. The responsabilities and roles of the ANSP (Air Navigation Service Provider) in ASM (Airspace Management) are highlighted, but also ATFM techniques that are used in different stages and planning scenarious for managing existing demand capacity imbalances in the two study regions, USA and Europe.

The aim is to identify best practices and to understand the differences between the two ASM systems, with the aim of optimizing ATM performance, to the definite advantage of the global air transport system.

The studies are based on a set of comparable performance indicators, reviewed annually and drawn up by mutual agreement, thus creating a solid basis for real comparative studies, between various regions of the world as well as between countries.Specific KPIs (Key Performance Indicators) are based on best practices EUROCONTROL as well as those from Air Traffic Organization System Operation Services, focusing on the comparative study of indicators where areas of performance differ between the USA and Europe.

1.1 Comparativ study on ATM performance in Europe and the USA

In general, Air Traffic Management (ATM) consists of Air Traffic Contrl (ATC), Airspace Management (ASM) and Air Traffic Flow Management (ATFM). The ATCs concern is to ensure the safe separation/staggering of aircraft, and the role of the ATFM is to ensure safety, by warning the rugulation of demand and overloads, given the availability of capacity.

Compared to ATC, ATFM has a longer time to perform operations a few days in advance. Thus, the performance include: Organization of Air Traffic Management, Air Traffic Control (ATC), Airspace Management (ASM), Air Traffic Flow Management (ATFM) and ATFM airport delays influenced by weather conditions.

1.2 Key Performance Areas (KPSs) and Key Performance Indicators (KPIs)

In the manual on the Global Performance of the Air Navigation System, ICAO has identitied eleven Key Areas of Performance, of interest in understanding the overall performance of the ATM system: Acces and Equity, Capacity, Cost Effectiveness, Efficiency, Environmental Sustainability, Flexibility, Global Interoperability, Predictibility, Participation, Safety and Security. The sutdy addresses the Key Performance Areas, which refer to the operational efficiency of the ATM system. There are the KPAs of Capacity, Efficiency, Predictibility and Environmental Sustainability, as it is related to Efficiency, when assessing the combustion of additional fuel, thus decreasing the specific fuel consumtion on the route.

1.3 External factors affecting KPIs

Traffic characteristics in the USA and Europe. This section provides some key features for air traffic in the U.S ATM system compared to Europe. The purpose is to provide some background information and to ensure the comparative study of traffic samples.

Increasing air traffic. In Aeurope, between 2000 and 2017, increased by 23,1%, and at the same timpe in the USA had a decrease of -14,7%. An increase of 2,6% on the main 34 airports was reported by the USA for the years 2015-2917, and Europe grew by 6,6% over the same period.
Air traffic density. In Europe, the “center” consists of the states: Switzerland, Benelux (Netherlands, Belgium, Luxembourg), Germany and the North-East of France which is the most complex airspace and also has the densest area.
Seasonality. The variability and seasonality of air traffic demand could be factors that affect, over time, ATM performance. If air treffic is highly variable, resources may be underrused outside peak hours, but are limited during peak hours.
Air traffic flow. A significant difference between the US and Europe os the share of general aviation, representing 19%, corresponding to 3,5% of traffic in 2017.

1.4 The impactul of weather conditions on airport operations

Weather impact (wind, convective weather, visibility, etc.) on airport operations, so ATM performance can vary significantly, where it depens on a number of factors such as: ATM equipment, and those existing at an airport (radar, ILS, etc.), procedures and rules that are approved, runway configurations (intensification of drafts) and depending on the type of airport. Procedures applied for Low Visibility conditions require increased spacing/staggering between aicraft to maintain the signal integrity of the Instrument Landing System (ILS), which, in turn, reduces transit possibilities. The declaration of runway capacity in Europe is usually based on separation/staggering requirements for weather conditions considered to be „average”. In case of, the actual conditions are better than those taken into account in the capacity declaration process, a higher runway transit that the declared one can be achieved. Meteorological performance analysis provides an indication of how the weather affects systems perforamance and which airport are most affected by changes in weather conditions. The evolution of these values over time can provide a clear indication of how the weather may affect system performance over a period considered [28] [29] [24, 25]. Both groups in Europe and the US use detailed weather reports, known as METAR by both groups that have developed procedures for assessing the impact of weather on aviation performance. A typical METAR conatins data on temperature, wind speed and direction, dew point, precipitation, altitude and cloudiness, barometric pressure and visibility [26] [33]. As weather is a major factor influencing runway flow and airport typicalli issues ATFM restrictions that address on-demand capacity imbalaces when adverse weather condictions occur.

Comparative study of operational performance U.S – refers to Air Navigation Services (ANS) that are provided by the United States in the 48 neighboring states located on the North American continent, South of the border with Canada, including the District of Columbia, but excluding Hawaii, Alaska and the oceanic areas (US CONUS).

Europe – is designated as a geographical area where Air Navigation Services (ANS) are provided by EU Member States, plus non-EU countries, who are members of EUROCONTROL (41 Member States and 2 Agreement States (Israel and Marocco)), excluding the oceanic areas Canary Islands and Georgia.

1.5 The Single European Sky performance scheme (SES)

It is emblematic initiative of the EU (European Union) with a view to reforming the European air traffic architecture, with the fulfillment of future security and capacity requirements usnder SES I and SES II. The initiatives were debated in the late 1990S, but were adopted between 2004 (SES I) and 2009 (SES II). In the first Reference Period (RP1) (2012-2014), targets at EU level have been set on the basis of cost-effectiveness, flight delays per flight and horizontal flight efficiency [23]. Following the increase in traffic in in Europe countries, aispace reconfigured to optimize Air Traffic Flow and Capacity Management (ATFCM) and a considerable reduction in delays. Following the SES regulations in 2004, European Commission reports to Eurocontrol entitled "Mandate on Support for Establishment of Functional Airspace Blocks (FABs)". Regarding the implementation of the Functional Airspace Blocks -FAB, the main idea of the SES is to strengthen regional cooperation with a view to simplifying the effort of air traffic controllers.

1.6 Automation of Air Traffic Management and Air Conflict Managementul

ATM automation and Conflict Management aim to substantially reduce the load, per flight, of the air traffic controller, through a significant increase in integrated support for automation processes, while simultaneously meeting the safety and evironmental objectives of the SESAR Program. Human operators woll remain at the heart of the system, using automated system with an accessible degree of integration and redundancy. Furthermore, this strategic business requirement relates to the evolution of Ground and Airborne Safety Nets (their mutual compatibility) through the use of new means of surveillance, as well as an exchange of information between system components at this level.

Everything will be fully adapted to future trajectory management systems – from the SESAR Program as well as the new aicraft staggering modes, thus ensuring their continued effectiveness as a level of saferty against the risk of in-flight collisions and other imminent hazards [26].

1.7 Conclusions

The study aims to highlight the trends of the system and provides a comparative analysis, particularly interesting between the Unites States and Europe, using KPIs (Key Oerformance Indicators), which have been adapted by both systems.

A total of 14 of the 19 Key Performance Indicators (KPIs) were used, which are found in ICAO GNAP (Global Air Navigation Plan). The study analyzed the common points, but also the differences regarding air traffic management and factors influencing performance, such as: weather and air traffic characteristics.

Regarding the Air Traffic Management system, Europa has a higher level of fragmentation and operates with more physical facilities than the Unites States. The European study region includes 37 ANSPs with 62 route centers and 16 APP units (Approach). In opposition, CONUS United States has an ANSP, 20 ARTCC and 26 TRANCON units (Terminal Area Radar Approach Control).

Chapter 2

2. Air Traffic Control – Modern Radar Surveillance

In this chapter, using the Pofacets program implemented in Matlab, a complex object will be created, and its behavior in the 400 MHz- 30 GHz frecuency band will be analyzed in a monostatic and bistatitc manner. The Pofacets program is a graphical interface for an analysis of the Effective Rflection Surface based on optical approximation.

2.1 The model proposed for study Radar Cross Section

Radar Cross Section (RCS) – is a virtual surface that reproduces the intensity of the reflection of the signal emitted from the target to the radar [18]. The size of Radar Cross Section includes that the target will not be reached bu all radiated energy. Radar Cross Section – target σ, is described as the product of three factors, as follows: $\sigma = A_p \times R \times D$, A_p- for the target is the cross-section area, which is outlined on an orthgonal plane corresponding to the direction of radiation; R-reflectivity; D- directivity.

Of the intercepted power, the reflexivity is a percentage, being reflected by the target. The Effective Reflection Surface for spherical bodies is independent of frequency, only if working at sufficiently high frequencies, where the wavelength λ<< distance and λ<<radius (r).

From an experimental point of view, the signal reflected by a target and which is received by the radar, is compared to the signal received by the same radar, under the same conditions, but reflected by a sphere having a frontal area (or in flat projection) of 1m^2 (a diameter of ≈ 44 in). An airplane, which is considered a target, is extremely complex. It has many elements of reflection and variable shapes. The Effective Reflection Area of a real aicraft must be fully measured. It varies signficantly with the direction of view of the radar [38]. The three-dimensional image of the RCS form the elctromagnetic imprint of the target. These measurement are performed in special rooms and aim to determine the electromagnetic footprint of aircraft that can perform different missions [39].

The Effective Reflection Surface of an object is represented by the (fictious) radar signal intercept area with sufficient power to cause uniform scattering, in alll direction, and produce an echo strong enough to be considered a target by aerial surveillance radar.

2.2 The posibilities and future direction of Radar Cross Section evolution for the case of an aicraft

The evolution of Radar Cross Section can be achieved as follow:

1.Choosing the most favorable conductive geometric configuration of the aircraft, guaranteeing optimal aerodynamic shape and a sufficiently large Cross Section Radar. Due to the need to prioritize aerodynamic design issues, there are limiting ways to increase the Radar CrossSection in this direction.

2.Cover the external aerodynamic surface (if non-conductive) with conductive material or to increase the conductivity of the housing material. If the structure of the tail, the wings, the fuselage is covered with cardon fiber or using high conductivity paint, the Radar Cross Section growth method in direction 2 is possible. These methods can be used independently or simultaneously.

3.Equipping the aircraft with focusing reflective bodies.

2.3 Experimental study

The method of increasing the Radar Cross Section in this direction is limited, as it will strongly affect the aerodynamic quality of the equipment due to the shape and size of the polyhedral reflector. Where such equipement is possible, design solutions with lower costs fot the aicraft may also be offered. With the help of the Pofacets program implementat in Matlab, a coplex object will be created and its behavior in the 400 MHz – 30 GHz frequency band will be analyzed in a monostatic and bistatic manner. The Pofates program is a graphical interface for an efficient analysis of the Effective Reflexion Surface based on optical approximation.

From theory it follows that the Effective Reflexion Surface depends on the ratio between the dimensions of the object and the wavelenght used [40]. The figure below shows a complex rocket-shaped object. It is assumed that where the incident is polarized θ, and the frequency will have different values between 400MHz and 30 GHz. The analysis is performed on the plane $\varphi = 0^o$, the angle θ varies between 0° and 360°, and the step size is 2°. The length of the analysis object is 287cm, the frequency varies between 20MHz and 30GHz, thus the wavelength will be in the range (1-15cm) [31] .

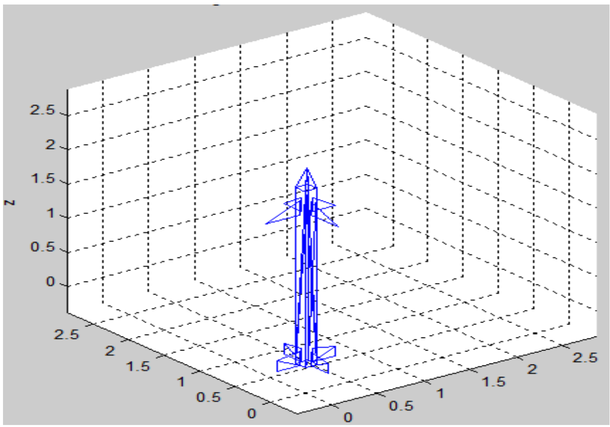


Fig. 2. 1. Object obtained from experimental data

The object to be analyzed is a previously created object and specifies that the faces are considered to be made of materials that are not completly conductive. It is noted that the first 15 faces of the object are illuminated on one side only, and the 11 rear faces on both sides illuminated.

2.4 Efective Reflection Surface for complex targets - SER

A complex targets is considered to includes a large number of object that are independent and which disperses in all directions the energy received from the radar. The most important is the energy scattered in the radar direction. Relative phases and echo signal amplitudes in scattered objects, measured at the radar receiver, determines the total cross section. The phases and amplitudes of each signal can be added to obtain a total cross section or it can cause the complete annulment of the mathematical relations between them. If the separation between the individual scattering objects is large, comparing the wavelength, which is usually true the most radar applications, the phase of a single signal at the input of the radar receiver will fluctuate depending on the position of the radar target, resulting in an oscillatin echo.

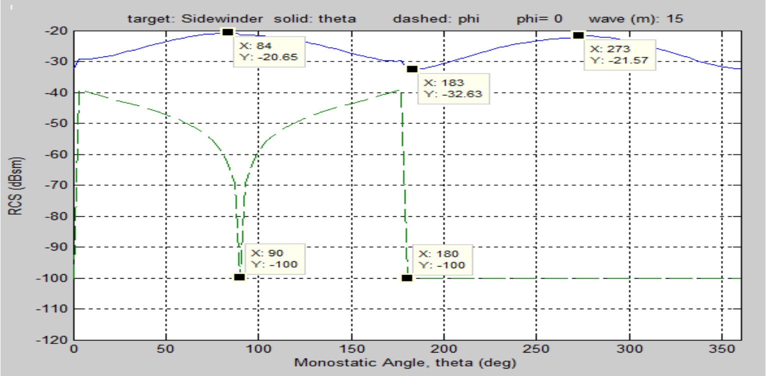


Fig. 2. 2. The angle θ fluctuates 0^o and 360^o with step of 2^o and a frequency 20 MHz

Science the wavelength is much longer than the value of the object to be studied, we are in the Rayleigh reflection zone. There is a slight change in the effective reflection surface, and the value is between -30 and -20 dBsm.

The figure above, Figure 2.2, shows the graph of the effective reflection surface, when the surface of the facets is not fully conductive. The two graph above (Fig. 2.1 and Fig. 2.2), characterize the two of polarization, as follows: the first graph agrees with the liniar polarization, and the second graph agrees with the cross-polarization. Regarding the liniar polarization, on the Effective Refletion Surface there are negative values for the range -30 and -20 dBsm. Reffering to the cross-polarization, the value of the Effective Reflexion Surface is lower than in liniar polarization. At 90^o we have a minimun of -100 dBsm. Effective Reflexion Surface =constant from 180^o, with a value of -100 dBsm, because 15 faces of the object are illuminated on one side.

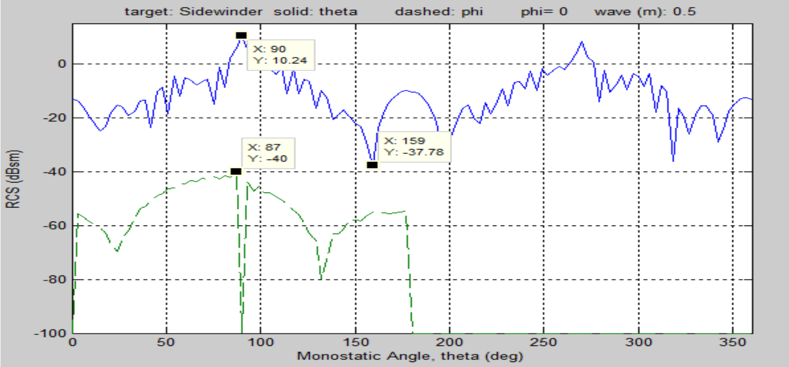


Fig. 2. 3. The angle θ fluctuates 0^o and 360^o with step of 2^o and a frequency 600 MHz

There is an increase, in Figure 2.9, of the Effective Reflexion Surface. In in the case of liniar polarization a maximum was obtained for the angle θ of 90^o, then in the case of cross-polarization the maximum reached for the angle θ is 80^o. With regard to cross-polarization, after a value of 180^o,we have a constant Effective Reflaction Surface value of -100 dBsm.

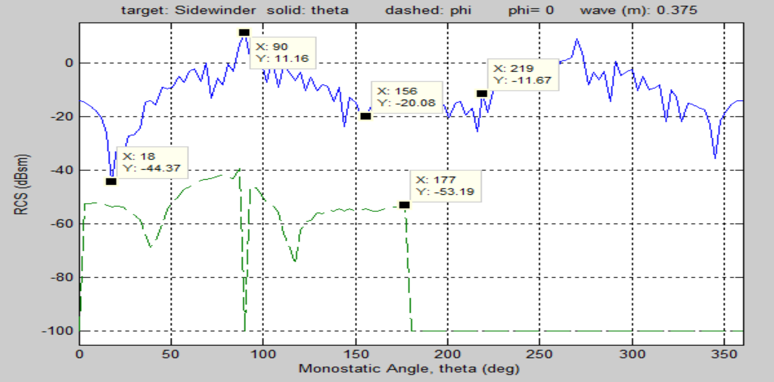


Fig. 2. 4. The angle θ fluctuates 0^o and 360^o with step of 2^o and a frequency 800 MHz

With regard to linear polarization, there is an increase in time compared to the value in Fig. 2.9, above. The maximum value of the Effective Reflection Surface has hardly increased. As the wavelength decreases, in the case of cross-polarization the maximum value of the Effective Reflection Surface exceeds the minimum value of the linear polarization, thus for high frequencies, there will no longer be a big difference between them. The Effective Reflexion Surface is closly related to the angle of incident in monostatic regime, but also bistatic regime. If the incident wave reaches a corner of the object, then the measured SER will be smaller than if it touches a flat face. Also, due the complexity of the object, SER will fluctuate a lot. It will reach its maximum value when the incident wave is reflected from a surface that gives the length of the missile and will have a small value, when reflected from a surface which corresponds to the wing of the aircraft [32].

In bistatic mode, the correct positioning of the receiving antenna is important. If from the component of the analyzed object a flst surface reflects the wave, it is important that the receiving antenna is located on the wave path, otherwise the measured SER will be much smaller than for a favorable position of the receiving antenna. Regarding to frequency with wavelengths greater than the dimensions of the cube under consideration, according to the theoretical statements presented, as expected, an increase of the Effective Reflexion Surface is observed.

2.5 Conclusions

The power level of the reflected field and the directive properties of the reflection also depend significantly on the value of the ratio between the dimension of the target and the wavelength of the incident radiation.

When the target dimensions are smaller than the wavelength we are in the Rayleigh region of the reflections, when they are comparable to the wavelength, in the region of resonant reflexion, the reflected power level is significantly higher than that obtained if the target dimensions are larger than the wavelength of the incident field – optical area of reflection. Therefore, I can say that the Effective Reflection Surface is a complex size, which characterizes the reflection characteristics of an object when it is irradiated by an electromagnetic wave, and its value depends on tha ratio between the size of the object and the angle of incidence, the wavelength of the incident radiation, the roughness, the nature of the surface and the type of radar used, bistatic or monostatic.

Accordingly, Effective Reflection Surface can be reduced in two ways, as follows:

- The first method involves the use of materials or mixtures ob substance which attenuate the incident electromagnetic wave. Attenuation results from the conversion of incident electromagnetic energy into heat, such that the material must have magnetic and electrical losses;

- the second method is to change the shape of the surface, such that the diffusion phenomen dominates the reflection of theincident electromagnetic wave. This it is realizing by dividing the flat surface into areas as small as possible, which are connected at obtuse angles.

Chapter 3

3. Detection and resolution of air conflicts in Air Traffic Management

This chapet proposes a research on the theory, the intelligent air collision warning standard and systems engineering optimization methodology. The ATC decision-making procedure is presented, the improved target for ATC decision-making is set, it is proposed to improve the detection of air conflicts and the resolution of conflicts in 4D space between several aircraft. The long-term and medium-term collision warning strategy is achieved by adjusting altitude and speed, and the short-term collision warning strategy is achieved by adjusting the direction, these strategies make the ATC system an absolute one. The main concern of the ATC is to mmaintain a safe separation between aircraft. The main concern of the ATC is to maintain a safe separation between aircraft. For the realization of conflict detection, uncertainty about the future position of aircraft and the current state of airspace is taken into account, such as likelihood of possible future air conflicts must be assessed. A model is needed for this task, and this model must predict the future.

3.1 Models of conflict

Regarding the future ATM system, to cope with the increase in air traffic, activity based on the 4D trajectory is an important concept, which is defined as an accurate rending of an air route over time and three-dimensinal space. Considering the conflicts between aicraft in a two-dimensional horizontal plane in which the aircraft coming from different direction merges with the waypoint. The wind model is only the stochastic component, which means the inaccuracy of the wind prediction that constitutes the uncertainty in the deterministic meteorological anticipations. In this way, wind speed w_x and $w_y$refer to wind inaccuracies. The aperiodic processes $w_x(x, y)$ and $w_y(x, y)$ are almost like a linear combination of deterministic functions, which are multipled by independent aperiodic variables and using the Karhunene-Loeve (KL) expansion. Therefore, the wind error is presented as the wind error which is spatially correlated with the finite number of independent aperiodic variables using KL exposure. Solving the problem of optimal stochastic control, for conflict resolution, the optimal trajectory is generated, without conflcits, under the uncertainty of the wind.

3.2 Automatic resolution of air conflicts

Using the algoritm, Residual Mean Interacting Multiple Model (RMIMM) as a status estimator, it is intended to solve the problems of tracking several aircraft as well as managing the identify of aircraft in a noisy environment for ATC. From an air traffic control surveillance radar system, clluter (congestion) is a noisy measure; clutter – is defined as measurement resulting from non-targets, such as weather, nearby object, but also electromagnetic interference that are randomin intensity, number, and location. Given the noisy measurements, cannot assume what the trajectory looks like and what number of aircraft are in the surveillance region. The purpose of tracking multiple aircrafts as well as managing the identity of aircraft in a noisy environment is the simultaneous tracking of aircraft identities and trajectory. For the development of an algoritm for detection and resolving conflicts necessary for ATC, a status estimation algorithm is required to track the trajectory of aircraft from the sensor monitoring area (exemple: radar).

3.3 Improved protocol

In the case of several aicraft, **the improved protocol** ensures the security of the inaccurate conflict. In **the improved protocol**, to resolve the air conflict it is necessary to change the direction of the aircraft which increases with the decreases of θ_{min}. There is a possibility that θ_{min} is small, if there are several aicraft in conflcit resolution. Therefore, on the initial trajectory of the aircraft the disturbance will be large, thus keeping a small group to resolve the conflict is desirabile[37]. By applying the conflict warning protocol, the size of the solution group can be reduced. If we have three aircraft, two of the three aircraft are maneuvering to resolve the air conflict, in this way we have less disturbance on the desired routes, unless the three aircraft were maneuvering to resolve the conflict. If we have four aircraft, one of the four aircraft is excluded from the resolution group, such as the remaining three aircraft are involve in the involvement in the conflcit resolution maneuver. If we have ten aircraft, only eight aircraft can avoid air conflcits, and the remaining two aircraft are exluded from the maneuvering group.

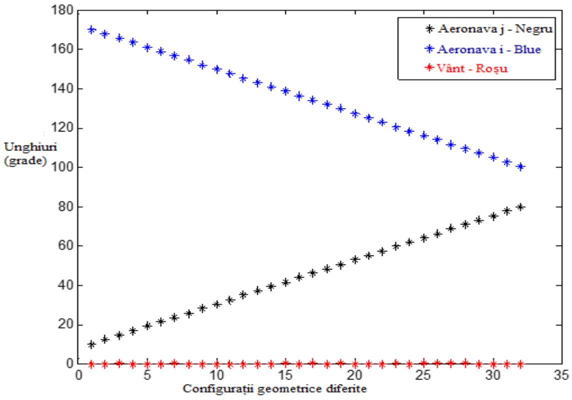


Fig. 3. 1. Aircraft i, j- evolution of wind angles of the maximum Geometric Factor

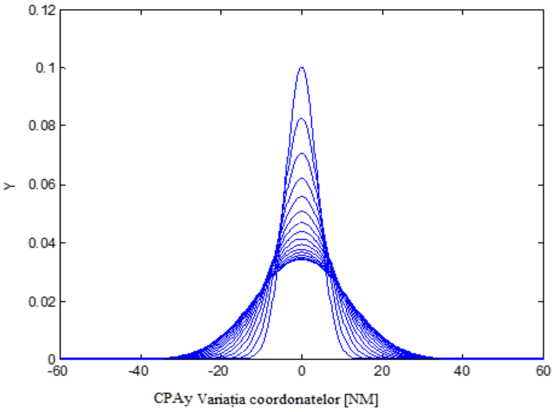


Fig. 3. 2. Probability density function of the maximum Geometric Factor

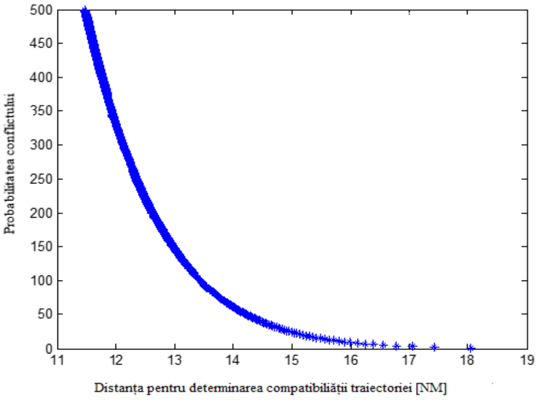


Fig. 3. 3. Resolving the air conflict – Case 3

3.4 Conclusions

In conclusion, I take into account the issues of probabilistic conflcit detection, such as the key element for the fulfillment of future air traffci systems is the verious uncertainties, which are taken into account in flight. Thus an improved stochastic detection algorithm for air conflcits has been proposed.

Chapter 4

4. Optimization of the probabilistic algorithm for resolving conflicts in airspace

In this chapter will propose an algorithm for the automatic resolution of conflcits in real airspace, based on an original algorithm. Standerd Operating Procedures (SOPs) – are oriented in the interest of maintaining efficiency and safety, but also towards a maximum application of the flight authorization. Hpwever, these operating procedures must be satisfactorily flexible to allow pilots to fly even in the event of failure of the automatic functions, or failure of some of the functions, in order to maintain the level of competence, between the recurrent trainings performed by the flight crew, on the simulator. This is extremly important for all airlines that are allowed to extend this sex-month period between flight simulator training.

4.1 Applicable technical requirements fot the automation of air navigation

Change of lateral and sequencing of intermediate flight points.

According to the side profile of aircraft, the flight path consists of several flight segments. The vast majority of flight changes are treated as „flyby” transitions.Early activation of the next control in the vertical flight plane is necessaryto avoid exceeding that segment. The roll of the aircraft is selected based on how quikly the aircraft responds to changes in the position of the ailerons. „Flyby” transitions, which, however, require a course change of more than 135°, are built for a planned overtakinf of the respective flight segment. Initiation of the cornering transition and midpoint sequence, it is not the same all „flyby” transitions. The point is initially sequanced, logically, at the bisector point of the turn, during the transition segment. Roll control is based on the current state of the aircraft, calculate by the navigation function and the side profile, which is provided by the flight path function ans the side profile, which is provided by the flight path prediction functions, the guidance of the aircraft thus produces a control command of the roll angle. This coomand is restricted even by the aicraft’s own performance limits, but it is also influenced by the the need to ensure continuous passanger comfort, but also the airspace that is avaible to perform the maneuver. This command is intended to help keep the aircraft on the correct, preset trajectory. Roll control is usually a simple command, generated due to deviations from the trajectory. Nominal roll angles are calculated for the planned turns. The nominal roll angle is zero for straight flight segments, but correspond to the planned roll angle, which is used to calculate the transition segments, following the execution of the necessary turning maneuvers. $Roll = xtrk\ gain \times xtrk + trkgain \times trkerror + \theta_{nominal}$ (4.3) where: $\theta_{nominal}$ - is the niminal roll angle, which is the planned/set one.

The values required for optimization, which are used for this flight command and control system, are characteristic of meeting the performance criteria of a particular type of aircraft, being specific to that flight control system, which was considered.

The functions of guiding the aircraft in a vertical flight plane.

The guidance function in the vertical flight plane, it provides controls for titlting the aircraft,, but also for the propulsion force level, to control the speed, propulsion and altitude parameters (some FMS – Flight Manangement System offers automatic control only on certain parameters, depending on the aircraft architecture). Similar to the function in the lateral flight plane, the vertical guidance function provides dynamic guidance parameters for the flight segment, to provide the cockpit crew, flight profile in the vertical plane. In contrast to of guidance parameters in the lateral plane, the parameters for guiding the aircraft vertically are dependent on the flight phase, to some extent. In the same way, the time and distance to any point can be calculated, as well as the altitude of that point relative to the ground.

4.1.1 Automatic transition between flight stages

The vertical guidance function controls the exchange between flight phases, depending on certain specific criteria, which must be taken into account.The change from the phase of the boarding procedure to the cruise phase, usually occurs when the aircraft is very close to the altitude specified in the original flight plan.

$$|Cruise\ altitude - current\ altitude| < capture\ gain \cdot current\ vertical\ speed \qquad (4.8)$$

The transition from the cruise phase to the descent phase can be done in several ways. If the crew has initiated the descent phase by lowering the selected flight altitude, then the descent procedure will be initiated automatically, at an optimal distance from the starting point of descent, calculated by the automatic system, in order to allow the airplane to slow down. If the flight crew has not yet started the descent phase by lowering the selected altitude, then the cruise flight stage will continue beyond the starting point of descent procedure, until the altitude that has been seected is subsequently reduced. In general, the flight crew is assisted in initiating the descent phase before reaching the starting point on the descent sequence, by instructions from the air traffic control.

4.1.2 Changing the flight segment vertically

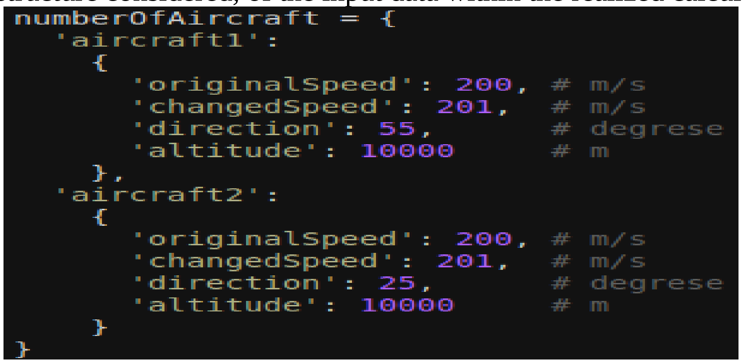
Similar to the previous case presented, namely that of the lateral flight profile, it is now necessary, in the vertical flight plane, to anticpipate the activation of the transition from one segment to another, such as the next segment can be reached without the aircraft being able to overtake it. Thus, it become necessary the existance and correct application of selection criteria for the transitions made between the existing flight segments on the 4D trajectory. These criteria take the form of a relationshio of inequality between the difference in altitude and the difference in speed in the vertical plane of flight.

4.1.3 Automatic control of the pitch axis of the airplane

The pitch command, which is produced by the guidance function in the vertical flight plane, is based on the selected speed, the trajectory calculated by the FMS -Flight Management System, as well as maintaining a certain flight altitutde depending on the respective flight phase, bbut also on the situation considered. Control strategies may very depending on the specific implementations of the FMS [32]. The problem of detecting, but also of resolving conflict in airspace is of an extremely high complexity, taking into account the number of variables that are involved in the study. Resolving these flight conflicts involves modifying the original flight plan as little as possible. For this reason, the most commonly used method is to change the flight level, when this is possible.In additioanl to this method, changing the flight speed of aircraft is also an extremely interesting approach.Currently, conflictresolution by changing the flight speed of aircraft is not used by ATC- Air Traffic Control, who have at their disposal the change of flight trajectory and flight level, methods that are easier to apply to the technical systems currently in use. One or more pairs of aircraft were considered for the testing and correct implementation of the airspace cpnflict resolution algorithm, arranged in a circle with a radius of 100NM, which falying to the center of the circle.

I will consider thefollowing data structure:

Table 1. The structure considered, of the input data within the realized calculation program



```
numberOfAircraft = {
  'aircraft1':
    {
      'originalSpeed': 200, # m/s
      'changedSpeed': 201,  # m/s
      'direction': 55,      # degrese
      'altitude': 10000     # m
    },
  'aircraft2':
    {
      'originalSpeed': 200, # m/s
      'changedSpeed': 201,  # m/s
      'direction': 25,      # degrese
      'altitude': 10000     # m
    }
}
```

In Table 12 it can seen a main object called „numberOfAircraft", which containing two other small pbject, each representing a particular aircraft, having a certain initial speed, but also a speed that was later changed, a certain direction and a level of flight.This object will be provided to the in-flight conflcit resolution algorithm, along with the radius of the circle that I will consider for determining subsequent mathematical calculation [63]. The implementation of the algoritm, entitle Algorithm 1, will run continuously until all air conflicts have already been corrected, and in the end it will return the object containing all the aircraft, so the whole set considered, with absolutely all the information about them, but also the value of the objective function to be calculated. The objective function is considered to be the sum of the speed variations of all the studied aircraft. This amount will be minimized to stay as close as possible to the initial preset flight plan. In additional, the proposed algorithm is limited to resolving flight conflicts strictly by changing the flight speed of aircraft. aaThis limitation could lead to situation where the algoritm cannot correctly determine a solution, such as the air conflict could not be resolved correctly.

4.2 Optimization methods of the applied algorithm

Considering that there is a conflcit between two considered aircraft and, taking into account these possible improvements, an assessmentof an air conflict could be made as follows:

1) The conflict between the two aircraft is determine and the flight speeds of the aircraft are compared; 2) Calculate the new flight speeds, using the maximum permissible coefficients in the range [-0.06, 0.03] to verify that a solution is possible by changing the flight speed of the aircrafts; 3)It is verified if the maximum allowable speeds resolve the air conflict; 4) If the conflict is resolved by simple changing the flight speeds, then the proposed algorithm will automatically calculate the optimal speed change coefficient and provide an optimal solution.

Taking into account these optimizations, four functions have benn defined for: assessment of the number of conflicts and conflicting aircraft, rapid calculation speeds, change of aircraft altitude, rapid optimization of flight speeds of aircraft in potential air conflict.Such tat, these functions will help to improve Algorithm 1, resulting in a new algorithm.

4.3 Conclusions

In this chapter I proposed an algorithm for automatic conflict rezolution in real space, based on an original algorithm, explained in extenso. In this proposed new form, the algorithm takes into account the previously detected problems and proposes to solve all these problems that inevitably appeared in the scientif research process. By removing all random elements from the originally proposed algorithm, the new form of its implementation is expected to be much faster and more efficient in successfully resolving all air conflicts. Also, compared to the previsious form, the new algorithm can resolve conflicts between aircraft and if there is no solution based strictly on changing their flight speed.

Chapter 5

5. Using the Closest Point of Approach method for unmanned aerial vehicles

The content of this chapter focuses on the development and testing an algorithm for detecting and resolving conflicts as regards air aircraft unmanned. Thus, reviewing the history of air conflict detection and resolution is an important step. After a research of the literature, the purpose of this capter is to develop a CDR algorithm, which is based on the Closest Point of Approach method, for the prevention of air conflicts and to evaluate the performance of the algorithm using flight simulator. The current period has been develpment on in-flight collision avoidance systems applicable to unmanned aircraft, but there is also a development if air communications technology, trying to eliminate the human pilot and the make numerous unmanned aircraft that are thus completely autonomous. Autonomous drone aircraft (AUAV) face real problems when they whats to fit into FAA airspace. If on a flight path, an AUAV will trigger an air conflcit involving another aircraft ans violate FAA rules, the AUAV must have the ability to detect and resolve the conflict such as that the separation limits occur in complete safety. Over time, different methods have been implemented for the detection and resolution of air conflicts with different degrees of complexity.

5.1 Equation of motion – development

5.1.1 Position and speed description

The equations of motion are presented, which are used to simulate the trajectory of the aircraft. I consider he aircraft an object as a material point, which has three defrees of freedom of translation, with the positions X, Y, Z being in the inertial frame. I consider the state of the aircraft in a frame alogned with the direction of velocity and the state of inertial velocity North, West, up direction $(\dot{X}, \dot{Y}, \dot{Z})$. The system is known as the speed frame, fixed on the aircraft with the x_V, which is always oriented along the velocity vector. This speed frame is obtained from th einertial frame by a series of two rotations: a rotation of the angle χ which is around the Z axis, then a rotation γ which is around the $-y_V$ axis.

5.1.2 Development of kinetic equations

The development of equations of motion for aircraft begins with the research of the 3DOF model, presented in the paper [70], where the six equations of motion are the kinematic formulas, defined on the Earth considered spherical:

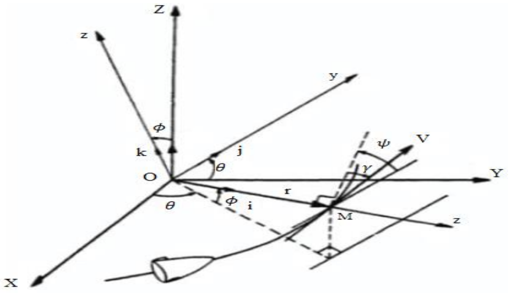


Fig. 5. 1. Coodinate system

5.1.3 Linearisation of kinetic equations. Feedback

To create a 4D trajectory, succeeding an external system with closed loop, there is a need for a closed loop interior systems, to have control over speed conditions. For manual control of the aircraft, the pilot can change the angle of inclunation, the angle of attack, but also the acceleration to have control. An automatic feedback linearization controller is presened to achieve this functionality, having the complementary benefit of generating a kinetic linear model with a closed loop for velosity dynamics.

5.1.4 Transformation of kinematic equations

The determination of the inertial velocity $\dot{X}, \dot{Y}, \dot{Z}$ can be done in one of two ways. Vinh equations [70] can be transformed from centered spherical inertial polar coordinates of the Earth, in cartesian coordinates inertially centered on the flat surface of the Earth.

The figure below shown a block diagram of the development of equation of motion. The model is an open loop systems, despite the fact the name is a closed-liip model, can be seen in the figure below – feedback loop, wherein the effect of the feedback linearisation controller is described. The processing will be entered on a digital computer, and the open loop model is used to establish a 4D Dimensional Path Following – 4PD, which, based on input path commands, will control the position of the aircraft at each point on the trajectory.

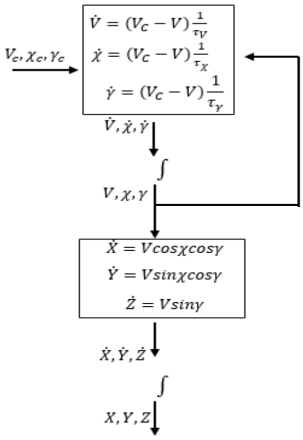


Fig. 5. 2. Block diagram for a closed loop system (open loop)

5.2 Control scheme –overview- CDR algorithm

5.2.1 Control scheme – trajectory tracking

The target aircraft considered is a UAV, thus the mission is carried out autonomously by using the control system that succeeds route; and negative feedback control is the control method used in the system. Negative feedback uses the difference between the current value and the value of the command position, there is an error, but which must be minimized, for the system to have a constant value, and this corresponds to the value of the order. I am more efficient at transforming from the Inertial Reference System in the speed frame, errors, before switching to the control. For transformation, the matrix has been developed in subchapter 5.1, which can be adapted and used to operate over error signals.

Proportional-Integrativ-Derivative is used in signal processing for the controller. For an efficient, easy-to-use system with a powerful controller in which to extend the system in any way desired, compensation strategies are used, which are met by the PID controller. A simple method is *proportional control,* which uses an amplification factor that is applied to the error to produce an output signal, being proportional to the error signal. However, *integrative control* works by integrating the error signal with the multiplication of an amplification factor.

Derivative control uses an amplification factor multiplied by the error derivative to create an output signal. Changes in the values for the amplification factors of the three methods: proportional, derivative, integrative, which affects in different ways the system to be studied. Such as, the increase of the integrative and proportional amplification factors, will contribuite to a decrease of the simulation time of the dynamic system, at the same increasing the value of the limits for the considered time interval. Thus, the increase of the amplification factor will decrease the stationary error of the considdered system.

5.2.2 Formulation of the equation of relative motion

Absolute equations of motion of the inertial frame, for both velocity vectors and position vectors for the conflicting aircraft, but also for the target aircraft. The relative speed and positions of the aircraft compared to the traget aircraft are as follows: $\vec{V_r} = \vec{V_B} - \vec{V_A}$,$\vec{r_r} = \vec{R_B} - \vec{R_A}$ (5.38) (5.38) $\vec{V_r}$ – relative speed vector; $\vec{r_r}$ – the relative position vector

5.2.3 CDR algorithm – forms

Distance and delay time are two important measures in CDR logic. Using the relative motion state, these quantities are compared and calculated with the critical values, which could lead to collision, or can solve current conditions for collision prevention. At each calculate cycle, the conflcit detection component is always up to date and constantly active. The conflcit resolution component is active only when a potential collision is detected. If there is a possible collision, a new trajectory is calculated to detect and resolve the air conflict, thus, after removing the collision hazard, the route of the initial trajectory is resumed. There are countless point on the sphere that will resolve the conflict, but only one point is effective for miving the aircraft.

5.3 Simulator: open loop

To simulate the trajectory of the target aircraft, calculation and simulation software will be used in Matlab, being used for the initial conditions, generation of graphs and reference trajectory, and the Simulink [78] will manage the propagation over time and the simulation of the model. The simulink has several sttings for solving a set of ODEs. ODE4 is the one used, and implements a fourth order Runge-Kutta. The parameters $\tau_V, \tau_\chi, \tau_\gamma$, used in all simulations, are constants having the value 1. Step size ODE4 = ct at 0,001 units of time. With regard to the target aircraft, numerical simulations start with the initial positions at the distance units $X = 0,\ Y = 0,\ Z = 0$. The figure below shows the open loop simulink model, which corresponds to the diagram in the previous Figure 5.6.

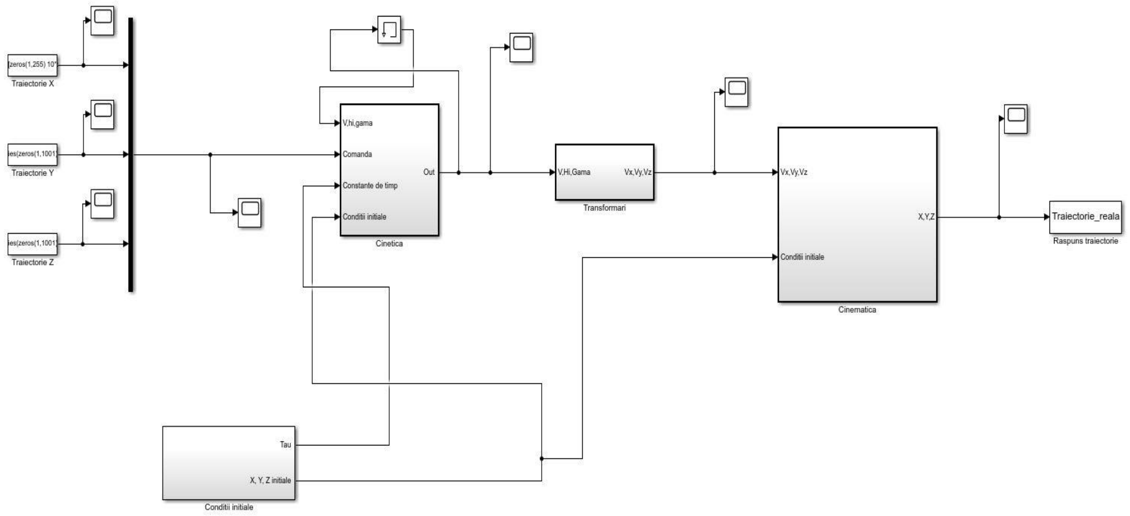


Fig. 5. 3. Simulink: the open loop model

The open loop model accepts the initial values calculated for X, Y, Z and $\tau_V, \tau_\chi, \tau_\gamma$, and accepts V_C, χ_C, γ_C being from the Matlab operating area, but also propagates the kinematics and kinetics of the aircraft in the speed, but also in the inertial frame.

The figure below shows a case 3D simulation of the open loop systems in which level and straight flight is used; the initial speed is $110\frac{d}{s}$, and the initial values χ and γ are 0 rad. After *4* secunds an entry is given $+10\frac{d}{s}$ to the aircraft, and during the numerical simulation it continues at this speed.

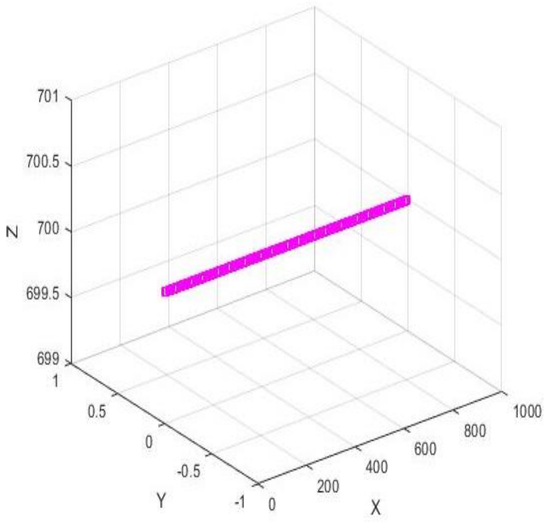


Fig. 5. 4. Open loopmodel, horizontal and straight trajectory $V_c = +10\frac{d}{s}$

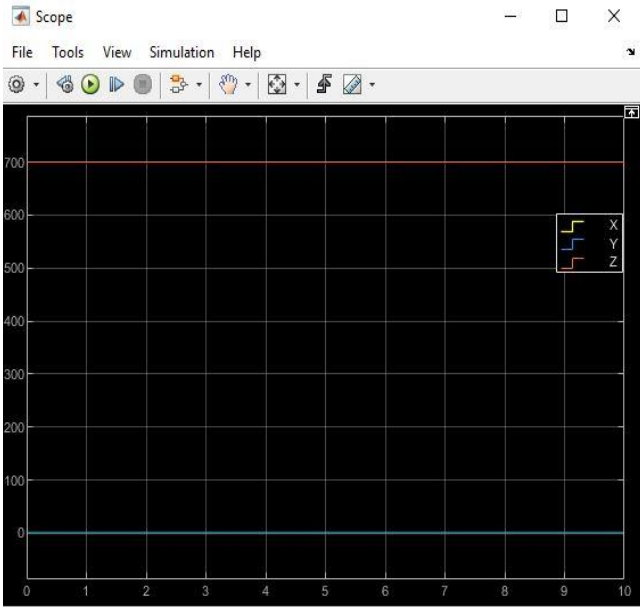


Fig. 5. 5. Open loop, straight and level h=700, $V_c = +10\frac{d}{s}$

In Figure 5.16, it is observed that the y and z command lines are overlapping.

The figure below shows the graph γ and γ_c, depending on the time.

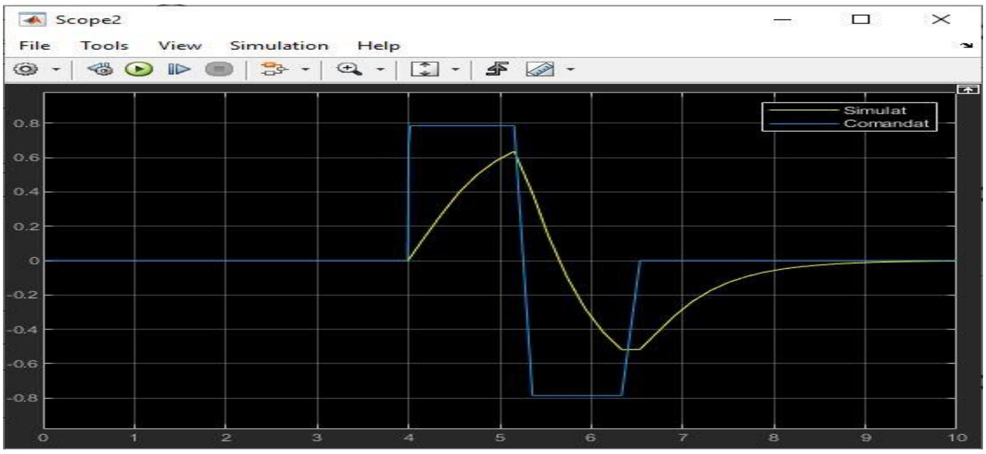


Fig. 5. 6. γ versut t, where $\gamma_C\ din \pm\frac{\pi}{4}$ radian

From the simulation tests, above, it results that the kinematic ans kinetic relations meet the numerical calculation requirements.

5.4 Closed loop simulator with 4PF

After fixing the 4PF control logic, subchapter 5.2.1, an after closing the loop, thus the simulator can take over the initial conditions, the values of the parameters in the operating area according to the Matlab code, the coodinates of the inertial trajectory X,Y,Z, and the propagation of the aircraft in three-dimensional space.

Compared to the open loop model, the initial coordinates in term of trajectory are constant. Figure 5.22 shows the closed-loop Simulink model with 4PF capacity. 4PF admits X_C, Y_C, Z_C, aircraft dynamics ussues speed commands V_C, χ_C, γ_C, and as inputs the feedback signal X, Y, Z and V, χ, γ.

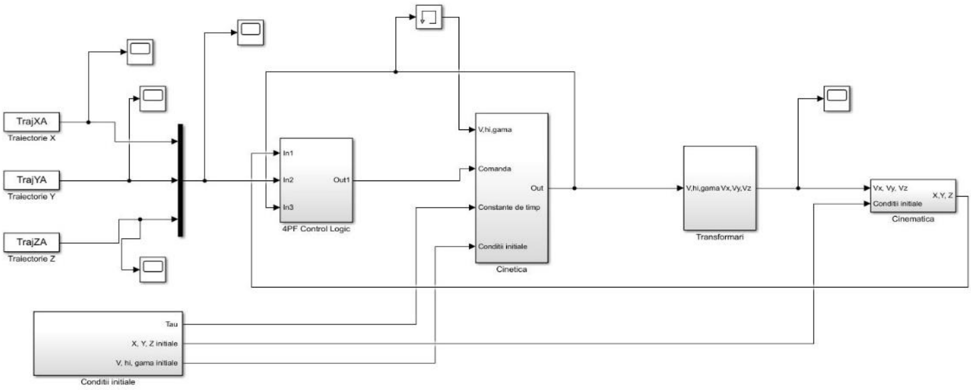


Fig. 5. 7. Block diagram of the closed loop system, which has the integrated 4PF block

5.5 Closed loop simulator with 4PF+CDR

The closed loop block diagram is presented in the figure below, including the Conflict Detection and Resolution (CDR). In the „Closest Point of Approach- Logic" the delay time and the distance vector are calculated, in which the speed and position states are entered for both aircraft, A and B, but also the output r_m and τ_m – Figure 5.34.

Figure 5.30 shows the internal processing of the CDR Logic subsystem with its outputs and inputs, this is the functional block on the air conflcit resolution algorithm.

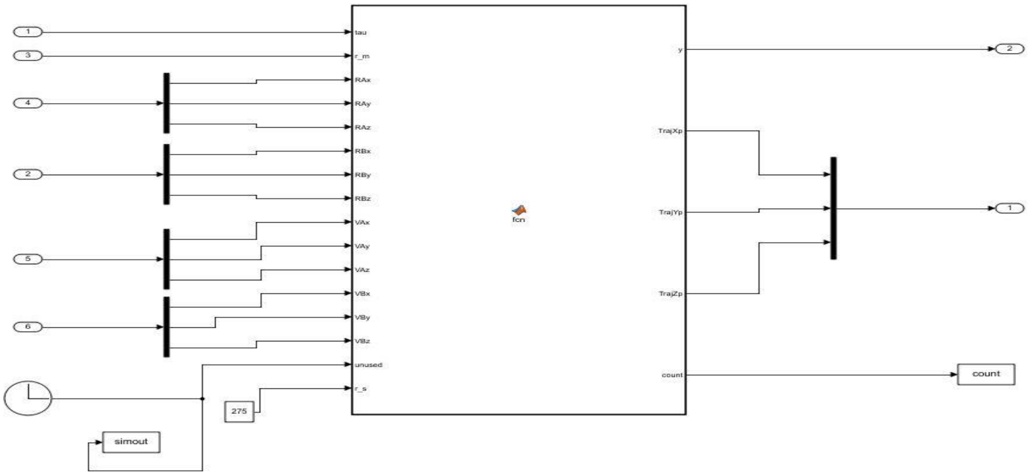


Fig. 5. 8. CDR logic diagram

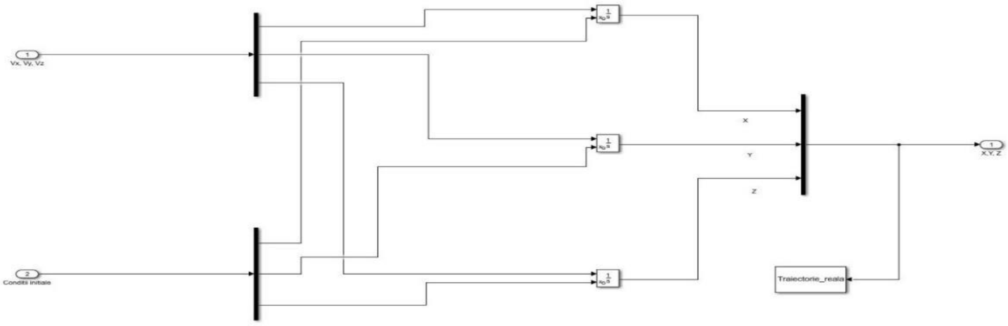


Fig. 5. 9. Kinematics for the closed loop systems with CDR

5.6 Conclusions

The 3DOF simulated aircraft has the ability to accept commands in this framework and can covert these commands into an Inertial Reference System to clearly present the position of the aircraft in any syste, related to the board or the ground.

Using the Simulink, an open-loop simulator was build to test the 3DOFs ability to properly propagate the aircraft trajectory over time. Only the values for the delay constants used limit the ability of the open loop model to follow the instructions V, χ, γ. The feedback linearization of the nonlinear 3DOF ODE kinetic Equations of Motion is validated using this model. Various test cases were performed, with certain values, and which met the expected expectations.

As for case where I have the pool closed, a multitude of block diagrams have benn presented in Simulink. Aircraft trajectory simulation was tested, in which a model for a closed loop system was used under the effect of closed loop tracking control.

PID control was selected because it is efective approach and tested over time, which produces predictable responses when control amplification factors change.

Chapter 6

6. Avoid collision between space objects

In this capter, two methods will be presented in extenso to avoid collision between two or more space objects and a definite answer is formulated to prevent the actual collision. Collision detecyion and avoidance is a fundamental issue for many areas of whether, for any two objects of study, there is a non-zero probability that when they are in close proximity, their trajectory to intersect.

6.1 The importance of in-flight collision avoidance systems

The interest in developing a collision avoidance system dates back to the 1950s, when an air collision occurred between two U.S Army air transport aircraft over the Grand Canyon. In the 1970s, the U.S has developed a system caled the BCAS (Beacon Collision Avoidance Sytem) sstem, which was based on the use of responses received from SSR (Secondary Surveillance Radar). After this catastrophe, a variety of collision avoidance systems have been studied, until 1974 when the Federal Aviation Administration (FAA) focused its attension on the Beacon Collision Avoidance System (BCAS), a air system based on transponder.

6.2 The importance of the in-depth study of the ACAS/TCAS topic

In recent years, the development of Remotely Pilot Aicraft Systems (RPAS) has been characterized by an exponential increase, both in military applications, as well as in civil and commercial environments. One of the latest and most promising solutions proposed is based on the development of Sense and Avoid systems based on the use of ADS-B (Automatic Dependent Surveillance - Broadcast) technology, which become mandatory in 2020 in the U.S [1], but also in Europe, for all aicraft flying in Class A, B and C airspace C [2]. Referinces [3] [4] [5] [6] [7] [8] [9] show CASs (Collision Avoidance Systems) based on ADS-B techology. These methods differ both in the methods of calculating the collision avoidance meneuver, as well as for in-flight collision detection.

6.3 General algorithms for detecting collision between two virtual objects

The collision problem coincides with the determination of the existance of an interior point for two or more objects. The algorithm would consist of verifying the membership of each one of this objects in the spheres determined by any four vertices of the other object, using the fact that a point E is inside the sphere determined by points A, B, C, D if det(A)>0 on the sphere if det(A)=0 and outside it if det(A)<0, where A = (ax, ay, az), B = (bx, by, bz), D = (dx, dy, dz) and E = (ex, ey, ez). The procedure cannot be applied due to the large number of cases to be treated.

Another approach proposed by Gilbert-Johnson-Keerthi [88] which models the problem as a quadratic programming problem in which P points are sought in the first object and Q points in the second object, which minimizes the distance *v* between P and Q (mathematical optimization problem). Also, the procedure cannot be applied due to the large number of cases that need to be treated.

The application developed in this chapter implemets the methods set out below:

6.3.1 Method 1

Collision detection approached as a geometric problem. The geometric method [89]considers that objects are inscribed in convex polyhedra (tetrahedra or parallepipeds). I consider, in the following, two such convex polyhedra P1 and P2 which have been defined by the vertices: v_i , where: $i = \{1,2,\ldots,n_1\}$, $v_i = \begin{bmatrix} v_i^x \\ v_i^y \\ v_i^z \end{bmatrix}$ and w_j , where: $j = \{1,2,\ldots,n_2\}$,$w_j = \begin{bmatrix} w_j^x \\ w_j^y \\ w_j^z \end{bmatrix}$.

The methodology for solving this problem is based on the algorithm called interior-point. The problem can be written in canonical form as follows:

$f = min\,\mu\,\phi$ (6.11) If f = 0, the objects intersect.

6.3.2 Method 2

Collision detection as a problem for analyzing an algebraic equation

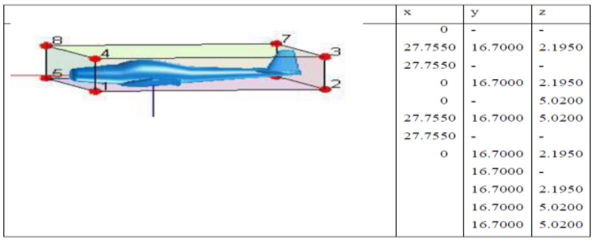
Wang [90], Choi [91] reduce the problem of continuous collision detection to a problem of analysis of an algebric equation. The algebric method [90] considers that objects are inscribed in geometric primitives (ellipsoids or in particular spheres). The implicit equation of the ellipsoid, in cartesian coordinates is: $\frac{(x-xc)^2}{a^2} + \frac{(y-yc)^2}{b^2} + \frac{(z-zc)^2}{c^2} - 1 = 0$ (6.13) where: $(x,y,z) \in [-a,a]x[-b,b]x[-c,c] \subset R^3$, and xc, yc, zc is the center of symmetry of the ellipsoid. If the movement ob object is time dependent, in the case of ellipsoids $A(\ t\ )$ and $B(\ t\ )$ I can write the characteristic equation: $f(\lambda,t) = \lambda^4 + a(t)\lambda^3 + b(t)\lambda^2 + c(t)\ \lambda + d(t)$ (6.25)

6.4 Realization of the application for detection and simulation of in-flight collision between virtual objects

The first model uses the „tips” of his faces as a border for the object. From the analysis of several CAD virtual objects, in STL forma, it was concludend that not all original tips can be used because, being very numerous, they produce a high computational consumption or belong to concave surface. Using some vertices may be build convex polyhedra or other basic geometric primitives: parallelepipeds, spheres, ellipsoids, cylinders and cones to include the object. If the tips of the original objects are used, it would be necessary to check the convexity with one of the specialized algorithms (Andrew, [92], Myszkowski95, or Quickhull). The model that uses the algebraic method considers that objects are inscribed in geometric primitives described analytically. In this case the application uses ellipsoids. The design phase establishes the architecture (components, interfaces and their behavior). The application code is written in Matlab, and the application has been tested. To verify algorithm that implements Method 1, different animations were made taking two or three similar/different object whose movement was independent and random [49].

The convex polyhedral surface that borders the object is created using the extreme values of the coordinates of the vertices extracted from the objects stl, or, for particular cases it can be easily constructed by a few points. The polyhedral surface divides the space into two distinct regions: inside and outside. The collision event analysis application based on the algorithm uses only the vertices of the polyhedra as objects. It was used to verify the algorithm and the offline result of a JSBsim simulation for an aircraft with the following data: time, v, altitude, phi, theta, psi, longitude, latitude, and the other data were randomly created within acceptable limits.

6.5 Test application method 1



x	y	z
0	-	-
27.7550	16.7000	2.1950
27.7550	-	-
0	16.7000	2.1950
0	-	5.0200
27.7550	16.7000	5.0200
27.7550	-	-
0	16.7000	2.1950
	16.7000	-
	16.7000	2.1950
	16.7000	5.0200
	16.7000	5.0200

Fig. 6. 1. The aircraft inscribed in the convex polyhedron determined by the coordinate peaks (x,y,z)

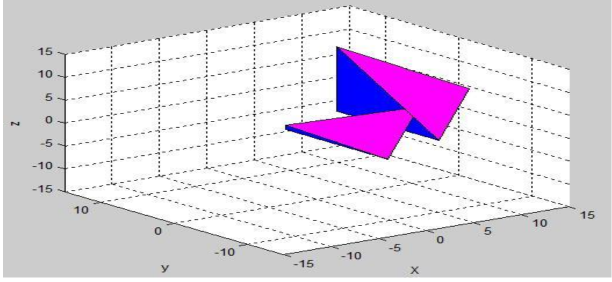


Fig. 6. 2. Graphical representation of the collision between the considered tetrahedra

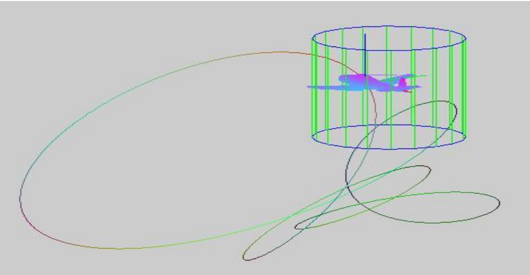


Fig. 6. 3. Graphical representation of the random evolution of an aircraft that is considered to be inscribed in space in a cylindrical virtual volume

6.6 Test application method 2

$$\frac{(x-xc_i)^2}{a_i^2}+\frac{(y-yc_i)^2}{b_i^2}+\frac{(z-zc_i)^2}{c_i^2}-1=0, \quad i=1,2 \tag{6.27}$$

a1=5;b1=5;c1=5; xc1=0;yc1=0;zc1=0;

a2=3;b2=2;c2=4; xc2=0;yc2=0;zc2=0;

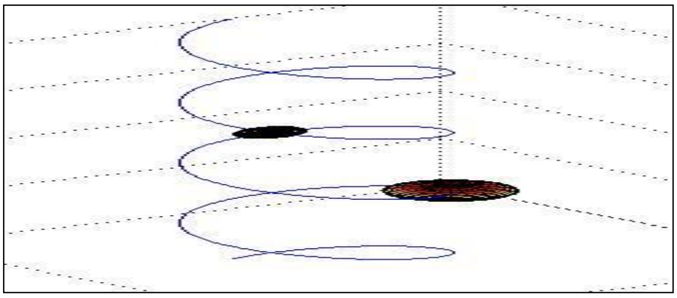


Fig. 6. 4. Graphical representation of evolution in the case of ellipsoids, for which the trajectories are analytically defined

6.7 Conclusions

A linear programming approach was developed, in which two methods of avoiding collision between two or more space objects have been presented. If designing algorithms to detect collisions between different geometric objects has not been very difficult, the real challenge came when collision detection was required in an environment with moving objects at arbitrary speeds - Continuous Collision Detection.Recent developments in hardware and software have allowed virtual reality technology to provide very powerful tools for the construction of the interactive virtual environment common to the user and the objects, in which the most realistic scenarios can be created for different types of analyzes. This study ended with the development of a software application for simulating the collision of objects whose position and orientation in three-dimensional space change. The application can only be used for analysis and simulation, cannot be used for implementation on real embarkable systems, because it lacks communication between the computer system and objects or interobjects, which represents a future direction of research and development of the work.

Chapter 7

7. General Conclusions, Original Contributions, Future Reseach Direction and Syntesis of the Papers

7.1 Generale Conclusions

The research addresses an area of maximum interest and topicality,being in a continuous development, which contributes to increasing the safety of aircraft flight in flexible airspace. The approached topic pursues the following established objectives:

- *Chapter 1*

- highlighting current trends in the ATM system in Europe and the USA;
- Europe has a higher level of fragmentation and operates with more physical facilities than the United States;
- analysis of common points, differences in terms of air traffic, as well as factors influencing aerospace performance.

- *Chapter 2*

- presentation of the model proposed for the Radar Cross Section study;
- detailing the evolution of the Radar Cross Section;
- realisation the experimental study, in which a complex object was created, being analyzed in a monostatic and bistatic manner;
- presentation of the coordinates of the points that define the object;
- were analyzed at different angles and frequencies, thus the Effective Reflection Area can be reduced in two ways: the use of materials or mixtures of substances which attenuate the incident electromagnetic wave, and changing the shape of the surface so that the diffusion phenomenon dominates the reflection of the incident electromagnetic wave.

- *Chapter 3*

- presentation of conflict models and proposal of an improved algorithm;
- simulation of two aircraft in which the wind also acts, using the new improved algorithm;
- analysis and decision-making when air conflict is detected, immediately the system initiates the resolution of the conflict organized in four stages;
- identification of the intruder in the Protected Airspace Area, conflict detection, a new trajectory for conflict resolution is calculated, the flight plan being restored as soon as the separation took place in conditions of safely;
- the analysis of the probabilistic detection problem is determined the key element, the different uncertainties are included, which are taken into account during the flight.

- *Chapter 4*

- highlighting the technical requirements regarding the automation of air navigation;
- creation of an input data structure within the realized calculation program, as well as the description of the way of working;
- description of algorithm 1 and objective function, as well as its implementation;
- description of optimization methods for the applied algorithm, and according to these methods were defined and the functions necessary to rewrite the proposed algorithm;
- the analysis of the new form of the algorithm denotes that, it can resolve conflicts between aircraft even if there is no solution based strictly on changing the flight speed.

- Chapter 5

- the 3DOF study aircraft has the ability to allow commands and to convert these commands into an Inertial Reference System to clearly determine the position of the aircraft in any system related to the aircraft or the ground;
- applying the Simulink, an open loop simulator was implemented to assess the ability of the 3DOF model to extend the trajectory of the aircraft over time;
- the delay constants used limit the open loop model to satisfy the instruction V, χ, γ.

- Chapter 6

- the calculation of linear programming, was performed by two methods of avoiding collision in flight;
- generating algorithms for detecting the collision between geometric objects, collision detection in a perfectly moving object environment, but with arbitrary speeds - Continuous Collision Detection;
- software developments have allowed virtual reality technology to provide dynamic systems for developing the interactive virtual environment common to the user and the objects to be studied, thus being able to make scenarios as close as possible to reality for a multitude of case studies;
- realisation a software application for simulating the collision of moving objects in three-dimensional space;
- the analysis can also be used for a multitude of new numerical simulations on real embarkable systems, for which the communication between the considered computer system and the new objects or interobjects must be made, which can be developed in the future.

7.2 Original Contributions

1. From the analysis of a significant number of bibliographic information from multiple managerial and technical fields I conducted a comparative analysis on the differences between the two ASM (Airspace Management) systems in the US and the European Union, presenting the utility, optimizing the performance and limits of each system, to the advantage of the global air transport system.

2. Proposing a mathematical model for the Radar Cross Section study,

where with the help of the possibilities and directions of evolution of the RCS for an aircraft it was realized:

- experimental study in which a complex object was created;
- performing simulation experiments for various cases, at different angles and frequencies.

3. Proposing an improved algorithm in terms of air conflicts

- resolving a wide range of cases for resolving air conflicts;
- intruder recognition in the Protected Airspace Area, air conflict detection, determining the new trajectory for resolving the conflict, updating the flight plan after avoiding the conflict and restoring safety conditions;
- study of the application of probabilistic detection, implementation of new models that include various uncertainties, these being specified throughout the flight.

4. Proposing an algorithm for the automatic resolution of conflicts in real airspace (based on an original algorithm):

- creating an input data structure;
- creating methods for optimizing the applied algorithm;
- creation of optimization functions;
- realization of a new improved algorithm.

5. Analysis and creation of a new rotation matrix in the chosen SC:

- creation of an open loop simulator, to verify the capacity of the model realized;
- creation of the closed loop simulator with CDR and 4PF.

6. The virtual object collision simulation software application was developed:

- realization of the application arhitecture;
- performing testing by two methods to avoid collision between two or more space objects;
- obtaining new algorithms for detecting the collision between geometric study objects;
- implementation of software according to virtual reality technology to allow dynamic systems new developments in the virtual environment corresponding to the user, but also study objects, analyzing scenarios very close to reality for a multitude of applications;
- development of a software application for simulating collisions between moving objects located in three-dimensional space.

7.3 Future research direction

Resumption and deepening of the closed loop with CDR and 4PF, the curved trajectories will be simulated, 2D and 3D linear trajectories, or any association between these inputs.

From the materials studied for the problem of collision avoidance, the issue of returning to the initial course after avoiding the collision is not addressed, unresolved issue in the context of congested airspace, which can introduce new collision hazards.

The next steps try to solve the global problem of avoiding the in-flight collision and returning to the initially desired route. Therefore, the space must be divided into horizontal surveillance zones, distributed vertically according to the air routes and having interspersed, in the vertical plane, temporary sorting areas necessary to solve the global problem of collision danger.

1. Delimitation of an area in the current horizontal flight plane, which depend on the speed of the aircraft concerned;
2. Depending on the direction of movement of the aircraft, two aircraft formations are created: some that can be entered in a left turn (turn less than 90 degrees) for framing in an ad-hoc roundabout on the left and others that can be entered in a right turn (turn less than 90 degrees) for framing in an ad-hc roundabout on the right. Maintaining the protection distance in the roundabout is done by varying the speed;
3. The trajectory of the target aircraft must not intersect with the trajectories of the intruder aircraft and can register in the direction required by the flight path.

7.4 Synthesis of the Papers

The doctoral student has published 18 scientific papers in the Field of Engineering and Management, all were developed during doctoral studies, of which: 8 (eight) articles / studies (4 in progress) published in **ISI** listed journals; 8 (eight) articles / studies published in **BDI** listed journals; 2 (two) books at a **CNCSIS** accredited publishing house as co-author.

Selective Bibliography

[22] „COMPARISON OF AIR TRAFFIC MANAGEMENT-RELATED OPERATIONAL PERFORMANCE U.S./EUROPE,” 2019.

[28] G. J.-P. D. V.Duong, „Sector-Less Air Traffic Management,” *4th USA/Europa Air Traffic Management R&D Seminar*, p. 158, 3-7 December 2001.

[26] EUROCONTROL, „The impact of fragmentation in European ATM/CNS,” Belgium, 2006.

[23] G.STROE, **M-L.COSTEA,** MANAGEMENTUL SPAȚIULUI AERIAN, vol. I, MATRIX ROM București, 2020.

[37] G.STROE, **M.-L.COSTEA**. MANAGEMENTUL SPAȚIUL AERIAN, vol. II, București: MATRIX ROM, 2020.

[39] H. J.J.Browman, Methods of Radar Cross-Section Analysis, New York: Academic Press.

[41] B. R.Mahafza, MATLAB Simulations for Radar Systems Design, CRC Press LLC.

[42] G.STROE, **M.-L.COSTEA,** A.SEMENESCU „MODERN SURVEILLANCE RADAR FOR AIR TRAFFIC CONTROL,” *Journal Fiability and Durability,* vol. 2, 2020.

[43] Gabriela STROE, **M.-L.COSTEA,** A.SEMENESCU „DEVELOPMENT AND PERFORMANCE EVALUATION OF A RADAR SURVEILLANCE SYSTEM,” *Journal Fiability and Durability,* vol. 2, 2020.

[46] I. W.Liu, „Probabilistic aircraft mid air conflict resolution using stochastic optimal control,” în *IEEE Transactions on Intelligent Transportation Systems,* 2014.

[45] I. W.Liu, „Probabilistic trajectory prediction and conflict detection for air traffic control,” *Journal of Guidance, Control and Dynamic,* vol. 34, nr. 6, pp. 1779-1789, 2011.

[31] G.STROE, **M-L COSTEA**, A.SEMENESCU, „STUDY OF AUTOMATIC TRAFFIC ALERT AND COLLISION AVOIDANCE SYSTEM,” *Journal Fiability and Durability,* vol. No.2, pp. 83-92, December 2020.

[63] „B772, San Francisco CA USA, 2013,” SKYbrary, San Francisco, 2013.

[64] G.STROE, **M.-L.COSTEA,** A.SEMENESCU „OPTIMIZATION OF THE PROBABILISTIC ALGORITHM FOR RESOLVING AIRSPACE CONFLICTS,” *Journal Fiability and Durability,* vol. 2, 2020.

[75] N.X.Vinh, Flight Mechanics of High-Performance Aircraft, Cambridge: Cambridge University Press, 1993.

[81] B. N. B. K. M. Yiannis Papelis, „On The Feasibility of Using Sub-Scale Aerial Vehicles For Testing Full-Scale NAS Concepts,” în *AUVSI Unmanned Systems 2015 Conference,* Atlanta, Georgia, 4-7 May 2015.

[95] Y.-K. C. B. M. W. W. Xiaohong Jia, „An Algebric Approach to Continuous Collision Detection For Ellipsoids,” vol. 28(3), pp. 164-176, 30 November 2011.

[96] YI-King Choi, Jiaye Wange, Myung-Soo Kim, „Efficient Collision Detection for Moving Ellipsoids Using Separating Planes,” *Computing,* 2004.

[97] W. W. H. S. Baciu George, „RECODE: an image-based collision detection algorithm,” vol. 10, Journal of Visualization Computer Animation, 1999, pp. 181-192.

[49] **Mihaela-Luminia Costea**, C. NAE. N. A., F.COSTACHE, I.ANDREI. G.-L.STROE. A.SEMENESCU, „Automatic Aircraft Collisions Algorithm Development for Civil Aircraft,” în *2020 10th International Conference on Advanced Computer Information Technologies (ACIT),* Deggendorf, Germany, 2020.