Analysis Of The Navigation Coordinate Systems That I Use Will Solve The Problem Of Finding A Unique Route

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Summary
The article solves the problem of developing a decision support system that provides a solution to problems that arise during flights on four-dimensional routes of four-dimensional navigation. The architecture of the decision support system has been developed, which contains all the necessary elements and connections with external systems to ensure the functions assigned to it. The system consists of three modules, and also interacts with the guidance system, the source of weather data and data on restricted areas.

Keywords:
navigation, Optimal Route Of Movement, technology, Information Technology.

1. Introduction

The global civil aviation community is now closely involved in the development and modernization of the entire air navigation system. To ensure continuous growth in the number of air transportation and destinations constant analysis, development and implementation of new technologies is required both in the work of ground services and in the existing or as additional on-board equipment of an aircraft [6].

Also, the constant growth in the volume of air traffic and the resulting significant increase in the load on the air navigation space on the part of its users - aircraft and helicopters, led to the need to improve the concept of organization and use of air navigation space for all regions of the world, including air navigation space.

Over the past decades, a number of certain changes have been implemented in the air navigation infrastructure, but a significant part of the global the air navigation system is still limited by the conceptual approaches that emerged in the twentieth century. These legacy air navigation capabilities limit the capacity and increase in air traffic volumes [6].

To solve the described problem, a comprehensively harmonized global air navigation system is needed, based on modern performance-based procedures and technologies [7].

To implement such a globally coordinated air navigation system, a plan has been developed that defines the main directions of development and stages of implementation of the necessary technologies for all participants in the system in the form of a methodology for block modernization of the aviation system [6].

One of the directions for the development of air navigation in accordance with this global air navigation plan of the International Civil Aviation Organization (ICAO) [63] is to increase the degree of interoperability [1], the efficiency and capacity of airborne and ground systems to improve coordination between air traffic services through the use of data transmission systems between air traffic management services [1].

The interoperability of on-board and ground systems will allow you to quickly and automatically analyze a large amount of route information in real time, for example:
meteorological data in the area of the arrival aerodrome and along the route [3];
information about the trajectories of other aircraft;
any operational information from air traffic control services [3].

Also, along with the interoperability of airborne and ground systems, one of the main expected results of modernization
of the air navigation system is the possibility of global management of four-dimensional routes.

To implement this opportunity, it is necessary to modernize not only the ground air navigation infrastructure, but also the modernization of existing airborne equipment complexes. One of the main on-board systems that ensure the flight of an aircraft along a given route is the aircraft guidance system (FMS) [45]. It is she who, first of all, should be able to support flights along four-dimensional routes.

Manuscript received April 5, 2022
Manuscript revised April 20, 2022
https://doi.org/10.22937/IJCSNS.2022.22.4.53

But, at the same time, the constant growth of the functionality of on-board systems leads to the need for the crew to analyze more information, which complicates the decision-making process in any emergency.

The presence of an exchange between on-board and ground complexes and an automated possibility of analyzing route information makes it possible to offer the crew solutions in difficult situations that arise when flying along a four-dimensional route, taking into account the ICAO requirements for maintaining navigation characteristics [8], as well as according to the criteria cost and amount of fuel emissions.

The purpose of the article is to increase the level of safety by automating the operational on-board planning of four-dimensional routes, taking into account the influence of wind conditions, restricted areas and areas of adverse weather conditions.

2. Theoretical Consideration

The flight management system, or "FMS" (from the English Flight Management System), which is part of the on-board equipment complex of almost any modern aviation technology, can be considered as the "brain" of the aircraft navigation system. It is fundamental to the operation of modern avionics systems and aims to automate some missions, reducing crew workload and eliminating the need for flight engineers or navigators.

The FMS is designed to improve the safety and efficiency of flights by providing the flight crew and aircraft systems with an on-board electronic equipment data required for efficient operation.

The fundamental function of FMS allows the flight crew to program the route from takeoff to landing. Its appearance made it possible to exclude the navigator from the crew members, reducing its number to two pilots, although the flight engineer was still included in the crew for the first time, and the cabin was made three-seater. Currently some private small aircraft, as well as large commercial aircraft, are equipped with FMS or similar systems. Systems aircraft navigation continued to develop and increase the number of interacting various controls and instrumentation.

The main tasks of the aircraft navigation system are [7]:

determination of the current coordinates of the aircraft location based on the summary data from various onboard navigation sensors;

calculation of the horizontal and vertical flight path according to a given flight plan, as well as support for the operational change of this crew plan;

generation and transmission of control commands to the automatic control system (ACS) to perform automatic aircraft navigation according to a given flight plan [4, 5].

To ensure the formation of the flight path, the FMS interacts with the aeronautical database containing data on aerodromes, their runways and instrument flight procedures, navigation waypoints, ground radio facilities, airways and other aeronautical information. On modern passenger aircraft, automatic navigation can be performed at all stages of flight from takeoff to landing. Using the human-machine interface (HMI) of the system, the crew monitors the air navigation situation, as well as the performance of the flight with automatic control and, if necessary, corrects the route.

FMS calculates flight performance and the most economical route in terms of fuel efficiency, which depends

on parameters such as weight, cruising altitude, actual location of the aircraft, etc.

The traditional FMS architecture is a separate structurally removable unit (KSB) (Multipurpose Control and Display Unit - MCDU), which has its own calculator, software (SW) and HMI, consisting of a small line screen and an alphanumeric keyboard. The FMS HMI in this implementation has only a few lines for displaying information with text in three to four possible colors and typically two capital letter font sizes. The traditional architecture described leads to a large degree of identity between systems from different manufacturers, and an experienced pilot is able to, in a short period of time, time to understand most of the functionality of an unfamiliar MCDU.

Modern FMS can significantly reduce the load on the crew by automating the routine procedures for preparing and performing flights, including including the implementation of automatic calculation of the optimal takeoff and landing characteristics and performance characteristics to build the most economical route, depending on the mission assigned to the crew for the flight.

FMS automatically calculates the required amount of fuel for the flight, taking into account all the necessary reserves and the possible implementation of emergency procedures (failure of one engine, departure to an alternate airfield, etc.), the predicted flight time for which the calculated route will be completed, as well as the most profitable train for cruising flight. For this calculation, a number of parameters are taken into account, including including:

– given cruising flight level;

is the entered takeoff weight of the aircraft;

- a given value of the cost index (from the English. Cost Index (CI)), expressing the numerical ratio of the cost of flight time to the cost of fuel,

– the entered values of the outdoor air temperature along the route (by altitude and with reference to specific points on the route),
– entered values of wind direction and speed along the route (by heights and with reference to specific points of the route).

All the functions of the system described above are basic and have long been provided by the leading developers of modern onboard FMS.

The ever-increasing volume of air traffic has led to the fact that today these functions have become insufficient. In turn, this was reflected in the form of tougher rules and requirements for ground air navigation structure and avionics.

With regard to on-board equipment, the current and forward-looking requirements for navigation accuracy, 4D navigation and avionics functionality require leading FMS developers to continuously upgrade their existing solutions.

Consider the functionality of the aircraft guidance system manufactured by Honeywell, which is one of the leaders among the developers of the system in question in the world market. The main functions are:

automatic tuning of radio facilities, determination of the current location;

route guidance at all stages of flight both in the horizontal (all types of segments in accordance with [5]) and in the vertical plane (altitude, speed);

strategic flight planning. Support for multiple flight plans: active flight plan, modified, two secondary and alternative;

tactical flight planning. Support for procedures: "Direct On", Offset Flight Plan, Holding Areas, Flight Plan Waypoints, Defined user; issuance of information for displaying the flight plan on navigation and flight frames;

support for interaction over the Datalink channel;

prediction of flight plan parameters taking into account the characteristics of the engine models and the environment;

interaction with external aircraft systems;

support RTA function.

For analysis, let's take a closer look at the principle of operation of the RTA function.

To date, to solve the problem of four-dimensional navigation, in particular, the problem of arriving at a route point at a given time is supposed to be as follows.

To perform the function, the crew, first of all, at the stage of pre-flight preparation, must be entered into the system by interacting with the HMI the following minimum required information:

route waypoint - a waypoint in the flight plan at which the arrival time constraint will be defined;

arrival time limit - the desired time of arrival at a given waypoint of the route;

arrival time limit type – time limits to be met by the aircraft. Three types of restriction that are currently supported: AT - at a strictly specified time; AT or Before (AB) - at the specified arrival time or earlier; AT or After (AA) - at the specified time arrival or later.

After entering the minimum required information, the result of the function is the calculation of the time window in which it is necessary to perform takeoff so that the system can ensure arrival at a given route point at a given arrival time with an accuracy regulated by regulatory documentation [1, 2].

This time window is calculated by analyzing the minimum and maximum speed profiles for each flight segment with which the system expects to perform flights along the route.

As part of the process of aircraft execution of a given flight plan, the RTA function monitors the status of its implementation by displaying the following information:

current error (difference between the expected (projected) time of arrival and the specified (RTA) at a given waypoint);

arrival status (represented in the form of three possible options: earlier than the specified time, later than the specified time or on time).

The “On time” arrival status informs that the system was able to determine the speed profile required to complete the task at all flight segments to a given waypoint, which will ensure the arrival of the aircraft at a given time.

The arrival status "Earlier than the specified time / Later than the specified time" informs that the system was unable to determine the speed profile required to complete the task in all flight segments to the specified waypoint, which will ensure the arrival of the aircraft at the specified time.

During a flight along a four-dimensional route, a situation is possible when the error in the time of arrival at a given point on the route exceeds allowable values [7], in this situation, modern FMS will only form informational message about the impossibility to maintain the specified limit.

And if adverse weather conditions or conflict situations with other air traffic participants occur along the formed route, the reaction of the system will not even be of a notification nature.

Thus, having analyzed the general principle of operation of the RTA function, the conclusion is that in the event of an emergency situation, the system will respond only with a notification that the current specified time limit cannot be provided or no reaction will follow [8].

In the context of global management of four-dimensional routes, in the direction of which the global air navigation community of civil aviation is currently moving, such functionality will not be enough [8].

A system that provides support for 4D routes must be resistant to external disturbances that lead to route changes, such as: adverse weather conditions along route sections, conflict situations with other aircraft, restricted areas. The system should simplify the decision-making process as much as possible and provide the crew with the most complete necessary information.

In such situations, today the entire responsibility for decision-making, as well as the maintenance and control of each aircraft lies with on the dispatcher. In conditions of high airspace congestion, such situations will, at best, lead to a violation of the integrity managing the four-dimensional routes of each air traffic participant, and in the worst case, catastrophic situations are possible [11,12,13].
In this regard, in order to reduce the load on the crew, in addition to the existing functionality of the onboard FMS, it is necessary to provide:
solving the problem of finding optimal four-dimensional routes according to several optimality criteria for the possibility of choosing a strategy flight in the event of an emergency;
monitoring the availability of a flight according to the active flight plan and notifying the crew if it is unavailable for further flight, caused by crossing areas of difficult weather conditions or restricted areas;
display and interaction of the crew with information about the existing optimal routes, as well as information about the status flight on an active 4D track.
To solve the problem of air navigation, first of all, it is necessary to choose a coordinate system suitable for it, since the accuracy of calculating the navigation parameters of the aircraft location, as well as the parameters calculated trajectory [4].

An ideal coordinate system must satisfy a number of requirements:
high accuracy solution of the navigation problem;
large area of the earth's surface area or volume of airspace within which acceptable accuracy is maintained navigational computing;
the simplicity of mathematical relationships that describe the process of moving the aircraft.
But in view of the fact that none of the existing coordinate systems meets the above requirements due to their inconsistency, different coordinate systems are used. The choice of coordinate system is made depending on the specific task and the required accuracy of calculations.

Thus, to solve the navigation problem of aircraft movement relative to the earth's surface, currently associated with earth surface local and global coordinate systems [4].
The use of local coordinate systems without sacrificing accuracy due to the neglect of the curvature of the earth's surface is permissible at a distance up to 500 km. But at distances of more than 500 km, the use of local coordinate systems will not allow achieving a sufficiently high accuracy of calculations, which means that in this case they become inapplicable.

But, despite this, mathematical calculations in local coordinate systems are quite simple to implement [2, 4].
To date, there is no coordinate system that would accurately describe the shape of the Earth. Therefore, when describing navigation processes relative to the earth's surface, various approximations of its figure are used. So today, the global ellipsoid WGS-84 (from the English World Geodetic System 1984) is used as the figure of the Earth.
In modern FMS today, when solving a navigation problem, the global geodetic coordinate system or WGS-84 (USA) is used. The aircraft coordinates in this coordinate system are the geodetic latitude (B) and longitude (L), as well as the height above the surface of the ellipsoid (H).

The use of global coordinate systems makes it possible, regardless of distances, to solve the problem of air navigation with high accuracy. In turn, high accuracy is a consequence of a complex mathematical apparatus [9, 10].
Thus, when solving the problem of finding the optimal route, it is necessary to take into account that the aircraft coordinates in their original form are provided in geodetic coordinate system. But solving the problem of finding the optimal route directly in this coordinate system is extremely difficult. Also, at To solve the problem, it is necessary to consider distances over 500 km. In view of the possible application of graph theory methods, where a fixed distance between airspace cells is required, it must be taken into account that the meridians converge at the poles of the Earth, and, therefore, depending on the latitude, the price of dividing a degree of longitude will change in a linear expression. In view of the foregoing, and also to take into account these distortions, the transformation in the Gauss-Kruger projection is used [3, 4, 8].
The use of this projection makes it possible to depict fairly significant areas of the earth's surface with virtually no distortion and, what is very important, to build a system of flat rectangular coordinates on this territory. This system is the simplest and most convenient for engineering and topographic and geodetic works.

Conclusions

As a result of the analysis of the functionality of modern FMS in terms of the ability to support four-dimensional routes, the functional requirements for the decision support system are determined.
by the crew in the event of an emergency situation during a flight along a four-dimensional route.
2. To solve the problem of finding the optimal route, an interface for interaction with the LTH database is defined, which provides accounting for dynamic aircraft characteristics in the process of planning a flight trajectory along a four-dimensional route.
3. The coordinate systems that can be used in solving the problem of finding the optimal route are determined. Selecting a specific coordinate system depends on the trajectory search method.

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