УДК 629.7

0580.31 + жс 17-56 661.2

[1]**V.P. Kharchenko,** Dr. Sci. (Eng.)
[2]**V.M. Vasylyev,** Cand. Sci. (Eng.)

DECISION SUPPORT SYSTEM DEVELOPMENT FOR COOPERATIVE AIR TRAFFIC MANAGEMENT

Institute of Information and Diagnostic Systems, NAU, e-mail: [1]kharch@nau.edu.ua; [2]v_vasylyev@ukr.net

This paper presents the conceptual framework upon which a Decision Support System for conflict detection and resolution is expected to develop for Cooperative Air Traffic Management. Intent-Based Adaptive reasoning based on controllability (maneuverability) of dynamic aircraft model and Multiple-choice Analysis with use of Controller-Pilot Data Link Communications is investigated.

Introduction

Decision Support Systems (DSS) are being developed for many Air Traffic Management (ATM) applications such as conflict detection, conflict resolution, evaluation of user reroute requests, and flow management.

Free Flight is a new concept for a future air traffic management system that will provide controllers and pilots with new technologies and procedures that will allow them to increase the safety, capacity, and efficiency of air traffic operations.

Free Flight is “a safe and efficient flight operating capability under instrument flight rules in which the operators have the freedom to select their path and speed in real time.

Air traffic restrictions are only imposed to ensure separation, to preclude exceeding airport capacity, to prevent unauthorized flight through Special Use Airspace, and to ensure safety of flight. Restrictions are limited in extent and duration to correct the identified problem. Any activity which removes restrictions represents a move toward free flight” [1].

Implementation of Free Flight represents a shift from Air Traffic Control (ATC) to Cooperative ATM.

But it is still very unclear how conflicts will be solved in free flight airspace. Free flight traffic, the aim of which is to permit each aircraft to fly its preferred trajectory, results in an unorganized structure, requiring automated computer-based solvers.

The air traffic controllers and flight crew must remain in control of the decision loop, in which decision is initiated by the controller and the flight crew can agree, negotiate or reject, and either the controller or the flight crew can cancel it.

The ensuring of safety would be a shared responsibility of the controllers and the pilots, where controllers would have to provide the long-term (strategic) safety and the pilots the short-term (tactical) safety.

Through the air traffic controllers surveillance systems, the air traffic controllers could monitor this process, and if their assistance would be necessary they could provide directions for a solution of conflicts.

Despite the availability of such flexibility to pilots, controllers will retain the ultimate decision-making authority for air traffic operations. The new concepts of future automated ATM systems development must include elements of artificial intelligence.

The intellectual component of control appears in order to reduce uncertainty level, which can appear due to distribution of objects in space and the corresponding time-delay of information about the objects conditions which is coming to the system; non adequate information about real dynamic characteristics of objects under control; factors due to unpredictable or poorly predictable finite actions of the operators team (pilots and controllers) who realize commands; due to a high level of influence of uncontrollable components which are conditioned by the environment effects.

New Qualities of the Cooperative Air Traffic Management

Nowadays, the controller cannot ask the pilot to accomplish a very accurate maneuver. But when a datalink connection between the ATC and the aircraft becomes available, methods of solving conflicts will change radically. The possibilities offered by data communications, data processing and new display functions (HMI - Human Machine Interface) open the path to a sharing of information through a system-wide information management, which will enable automated assistance, evolution of the tasks and subsequent progress towards Cooperative ATM.

Information sharing and collaborative decisions increasingly rely upon digitized information, used in more automated and integrated ways.

The collaboration decision making aspect relates to the need for all relevant information to be shared between the parties involved in making decisions.

Flight crew will benefit from the availability, in the cockpit, of air traffic information with a level of quality matching the information available to controllers on the ground, in terms of traffic position and intent.

The main purpose of the determination of aircraft relative positions is to ensure their separation by detecting potential conflicts. In addition to the information provided to controllers via radar systems, data link can provide enhanced surveillance capabilities combining typical radar data (aircraft identification, position and altitude) with aircraft downlinked flight parameters (heading, speed, short term intent) and meteorological information, with a view to build an improved image of the real air situation.

Increased use of airborne data will be introduced, principally in the area of flight path intent.

The ATC systems will have the possibility to access the route data contained in the aircraft Flight Management Systems (FMS), in order to perform flight plan consistency checks.

Additionally, flight crew will be able to easily provide controllers with their flight preferences and constraints, with minimum workload increase.

Intelligent Decision Support Systems

Conflict resolution is a very complex mathematical problem involving trajectory optimization and constraint handling. This problem has many objectives: conflict detection, clustering, conflict resolution and optimality of the solution regarding different criteria.

There are three stages of the decision making process for conflict resolution: selection of the aircraft to maneuver, chose of the type of maneuver and specifying details of the maneuver. These decisions imply the examination of the horizontal position, altitude and speed for each aircraft involved in the conflict. Controllers themselves are required to build and maintain a mental picture of extrapolated 4D traffic based on experience and other rather ill-defined heuristics. Having done this, the controller must mentally compare every pair of predicted trajectories to determine whether any pair of aircraft will pass within the minimum permitted separation - in which case he is required to intervene in some way to resolve the potential conflict.

The main purpose in having an intelligent system is to reduce the controller's workload.

Traditionally, artificial Intelligence research has focused on the acquisition of domain knowledge. Artificial intelligence models of expert reasoning often base their reasoning on fixed sets of rules; their design assumes that their rule libraries are complete and correct. However, this assumption may be difficult to realize in air traffic control domain.

Case-Based Reasoning (CBR) methodology has emerged from research in cognitive psychology as a model of human memory and remembering. This methodology replaces the focus on acquiring fixed and final "expert" knowledge with a focus on the process by which expertise is acquired and refined during problem solving.

Case-Based Reasoning solves new problems by adapting solutions that have been used to solve old problems. Case-Based Reasoning is a five-step problem solving process: Representation, Retrieval, Adaptation, Validation, and Update.

The known Intelligent Systems for Aircraft Conflict Resolution ISAC based on CBR assists the controllers only in the first two stages of this decision process [2].

Intelligent Systems for Aircraft Conflict Resolution needs a supporting system (conflict detection module) with the ability to detect and describe the conflict.

When a conflict is detected, its description is sent to ISAC: i.e. the flight plan and performance of the aircraft involved, the shapes of the no-go zones etc.

Using this data, ISAC selects the aircraft to maneuver and the type of maneuver, which it sends back to conflict detection module.

Intelligent Systems for Aircraft Conflict Resolution merely suggests the "best" maneuver, based on the conflict solutions stored in its knowledge base. Case-Based Reasoning can be used in the ATC domain if an adequate case-base is available and if all the cases come from the same sector with solutions given by controllers trained on that sector. The absence of an adaptation mechanism made it necessary to have a case-base with a good coverage.

The most difficult issue is to have a well covered case-base with cases coming from the real world.

Having a lot of conflicts in a case-base is not enough: each conflict needs a solution. However, Intelligent Systems for Aircraft Conflict Resolution based on CBR methodology doesn't find a solution in an optimal mathematical way. Applying artificial neural networks can solve the CBR adaptation problem. Advantages of applying artificial neural networks are generalized from examples, developing solutions faster with less reliance on domain experience, adaptability.

Intent-Based Adaptive Decision Support System

The usefulness of the decision support systems, and hence their capability to provide benefits to airspace users, is strongly dependent on the accuracy of predicted trajectories. For the airspace user, inaccurate trajectory predictions may result in less-than-optimal maneuver advisories in response to a given traffic management problem.

New qualities of the Cooperative ATM system enable to develop the Intent-Based Conflict Detection and Resolution method. The Intent-Based Conflict Detection method uses the aircraft active flight plan as a basis for trajectory prediction and conflict detection. The Intent-Based Conflict Resolution method takes the intent (flight plan) into account when calculating conflict resolution.

Software decision support tools that assist controllers in the management of air traffic depend upon the ability to accurately predict future aircraft positions. Trajectory predictions rely upon the availability of aircraft condition, aircraft performance, pilot intent, and atmospheric data.

Inherent in farther research is the notion of intent. We assume an aircraft is flying a flight plan, or will provide to air traffic control some level of intent whenever an aircraft deviates from its intended flight plan. The process of updating path intent can be greatly aided by use of Controller-Pilot Data Link Communications (CPDLC) for path deviation clearances and the use of Automatic Dependent Surveillance (ADS) for verifying current path intent.

Another important principal decision is to assume that all the aircraft perform Instrument Flight Rules flight. This assumption is acceptable if it is considered that Intelligent Decision Support Systems will assist controllers in future when aircraft will be better equipped and will be able to fly guided by instruments in any phase of flight.

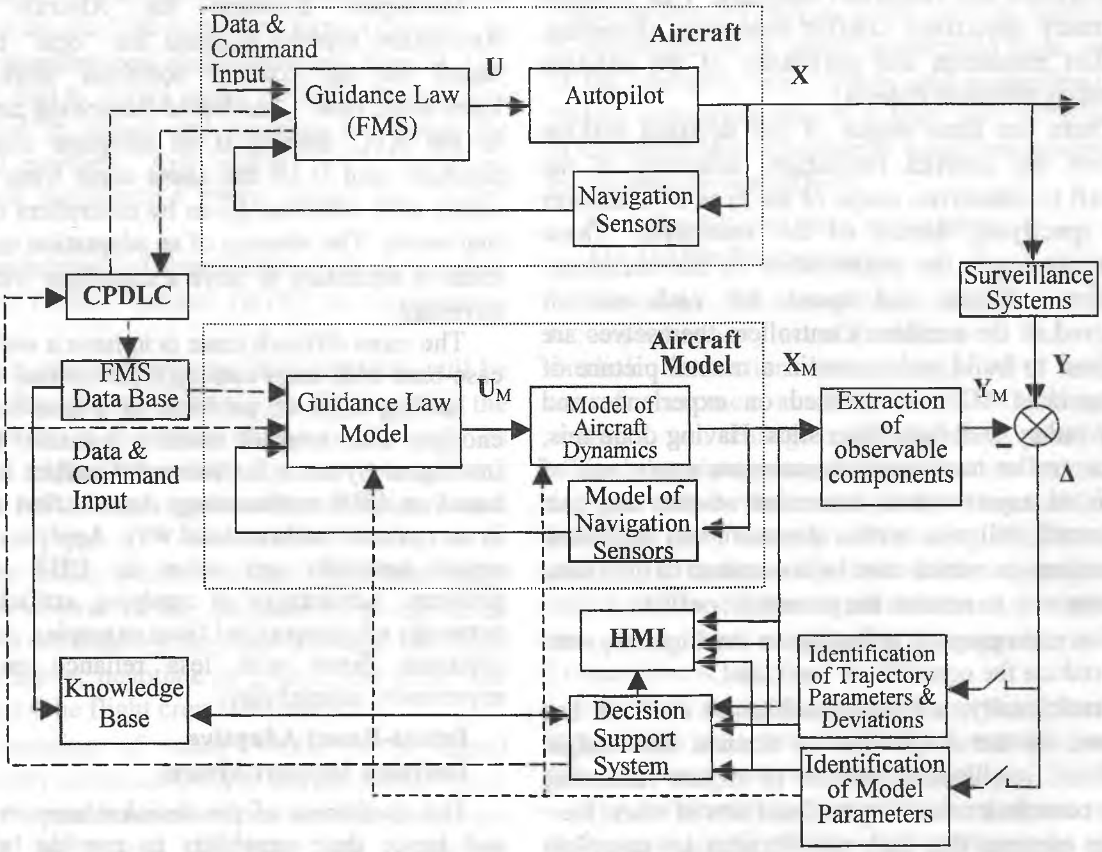
The base of any mathematical prediction method is constituted by process model. The possibility of accessing the data contained in the aircraft Flight Management Systems enables to introduce new type of prognostic model, which include control variable **U** explicitly and has condition of controllability (maneuverability). Generally, this model may be represented by equation $\dot{\mathbf{X}} = f(\mathbf{X}, \mathbf{U}, \mathbf{W})$, where **X** is the aircraft state vector, **W** is the disturbance stochastic vector. In a linear form the model is represented by equation

$$\dot{\mathbf{X}} = \mathbf{FX} + \mathbf{BU} + \mathbf{GW},$$

where **F** – the dynamic matrix.

When stabilize flight direction the control variable is formed via a feedback and may be represented as $\mathrm{U} = c\{\mathrm{X}\}$. Generally, c is a nonlinear bounding function.

If the mode of flight and guidance law is known then the control variable U is calculated by using this law. Figure illustrates interaction of aircraft model with the FMS via CPDLC and with data and knowledge bases.



Intent-Based Adaptive Decision Support System

It is important that even if CPDLC is disabled the control variable may be calculated on the basis of a priori information or on crew report about the mode of flight.

Accurate predictions may require sophisticated flight tracking and conformance monitoring to validate the parameters and guidance laws assumed for the current flight segment.

Controllability enables to solve the problem of identification the deviations from intended trajectory produced by navigation errors and a wind.

Moreover, it enables to identify and tune up the model parameters or incorrect parameters of the guidance law (figure).

Suggested adaptive model-based approach significantly improves trajectory prediction accuracy and diminishes aircraft position uncertainty, e.g. in known conflict alert systems a future position uncertainty is calculated symmetrically relative to heading, but if the stable deviation to the right of intended trajectory is identified that deviation to the left is improbable.

The result of the resolution process is, in general, not one trajectory, but a set of trajectories. A new trajectory assigned to an aircraft should be conflict-free within some time-frame. Furthermore, it must be "flyable" by the aircraft, which is constrained by its own dynamic capabilities. Controllability and model dynamics adapted to the real flight situation satisfies these requirements.

In an automated simulation a solution trajectory can be chosen from a set of trajectories in accordance with optimization criteria. In principle the use of the digital data link between FMS computers in the airliners and the ATC computer allows fully automated air traffic control. It is also illustrated in figure.

The advantage of the Intent-Based Conflict Resolution, besides the incorporation of a recovery maneuver, is that route optimization techniques can be taken into account for time-efficient resolution maneuvers.

Multiple-choice Analysis in Decision Support System

Statistical performance of air traffic flow in control area, distribution of flows according to the sector structure, relative position and aircrafts movement serve as basic data for computer models. Characteristics of controller's dynamic load in air traffic control and interaction with adjacent control sectors necessary for consideration of human factors are integral parts of the model.

The computer models allow considering the factors mentioned and estimate the quality of new air hierarchical navigation system due to the multiple-choice analysis. At that both human errors in management and system failures are taken into consideration.

The revealed risks include, in the first place, violation of separation rules, non-coordination of crews and controllers' activities etc.

The risks analysis features in estimation of rare events and corresponding spectrum of air situations are features of the safety analysis. Consequent models and risk trees help to determine potential events as a whole on the basis of the decision rule chosen including possible collisions in terms of intended track division or estimation of their separation in the air.

The choice of the decision rule of the class of air situation according to the risks level is based on the following. Firstly they determine the reasons for the necessity to use a multiple-choice sequential rule and test hypothesis about situation of class $A_k, k=\overline{1,n}$ [3].

If it is decided to position aircraft in a specific dangerous situation with single surveillance or a series of fixed sample surveillances, classification errors might have been made since aircraft is to be found on the threshold of two dangerous zones. Yet, it is not clear what zone the aircraft positioning refers to.

Mathematically the decision rule does not work here. But physically this means that the case needs extra surveillance to assure classification of the dangerous situation in the air.

This comes for sequential procedure.

Sequential boundary rule is of a less risk than rule of fixed duration.

Sequential boundary rule is similar to optimal. In the relatively low cost of surveillance the average risk is lower for the sample than for the fixed sample.

The sequential multiple-choice analysis lies in the following. Suppose, there are n situation classes $A_1,\dots,A_n$, $n\geq 3$. If random variable x belongs to A_k situation, its density is $\rho_k(x)$, $k=\overline{1,n}$. Let's suppose prior probability of class situations is also given $p_1,\dots p_n$; $\sum\limits_{k=1}^{n} p_k = 1$.

Then if there are ν independent surveillances of a variable x with density $\rho_k(x)$ and sample $x_1,\dots,x_\nu$, combined vector $x=\{x_1,\dots,x_\nu\}$ has got distribution density

$$\rho_k^{\nu}(x)=\rho_k^{\nu}(x_1,\dots,x_\nu).$$

A posteriori probability is as follows:

$$q_k^{\nu}(x)=\frac{p_k\rho_k^{\nu}(x)}{\sum\limits_{j=1}^{n}p_j\rho_j^{\nu}(x)},\quad k=\overline{1,n}\cdot$$

For the given positive thresholds $b_1,\ldots,b_n$ let's consider $0{,}5<b_k<1,\quad k=\overline{1,n}$. After ν independent surveillances of random $\mathbf{x}$ variable the latter is decided to belong to A_k, $k=\overline{1,n}$ situation if

$$q_k^{\nu}\geq b_k,\quad k=\overline{1,n}. \tag{1}$$

The sense of the sequential classification of situations is in the fact that surveillances are continued to the very ν moment when equation (1) is true for a certain class A_k, $k=\overline{1,n}$. While for the ν with each $k=\overline{1,n}$:

$$q_k^{\nu}(x)<b_k,\quad k=\overline{1,n} \tag{2}$$

the surveillance are kept on.

The requirement $b_k>0{,}5,\quad k=\overline{1,n}$, (2) provides unambiguity of decision-making. If the hypothesis A_k, $k=\overline{1,n}$ belongs to the situation is true, due to certain natural requirements related to [3] positive numbers

$$\lambda_{k_j}=\int\left(\ln\frac{\rho_k(x)}{\rho_j(x)}\right)\rho_k(x)dx,\quad k=\overline{1,n},\quad k\neq j$$

with probability of 1,0

$$q_k^{\nu}(x)\xrightarrow{P}1,\quad \nu\to\infty$$

and therefore according to $b_k<1,\quad k=\overline{1,n}$ the decision with probability of 1,0 will be made in the final stage of the surveillance.

However, to make a sequential rule it is necessary to have prior data about prior probability of class situation $p_1,\ldots,p_n$ and apparent distribution density of variable $\mathbf{x}$ in the terms described by situation A_k, $k=\overline{1,n}$.

For estimation of the general risk it is necessary to combine the values of set of local risk of the collisions, obtained in each revealed danger.

Conclusions

The need for development an automated Decision Support System is a serious concern when addressing the issues of Free Flight Airspace.

The use of real-time airborne information under cooperative ATM improves the ground-based trajectory predictions and intent-based conflict resolution.

Introducing mathematical model of aircraft dynamics with controllability (maneuverability) enable to apply optimization criteria and find in real time conflict free trajectories simultaneously minimize the number of maneuver orders, conflict resolution duration and delay due to maneuvers.

References

1. *RTCA*; Report of the RTCA Board of Directors Select Committee on Free Flight, Jan. 18, 1995: RTCA Washington DC.

2. *Bonzano A., Cunningham P., Meckiff C.* ISAC: A CBR System for Decision Support in Air Traffic Control. – Proceedings of the 1996 European Workshop on Case-Based Reasoning, Lecture Notes in Artificial Intelligence, Springer Verlag. – 1996. – Nov. P. 44–57.

3. *Харченко В.П.* Перспективні напрями розвитку аеронавігації початку XXI століття // Вісн. НАУ. – 2003. – №1 (16). – С. 41–49.

Стаття надійшла до редакції 04.11.03.

В.П. Харченко, В.М. Васильєв

Розвиток системи прийняття рішень при кооперативному керуванні повітряним рухом

Розглянуто концептуальну структуру системи підтримки прийняття рішень для виявлення і розв'язання конфліктів при кооперативному керуванні повітряним рухом. Досліджено адаптивне рішення, що базується на інформації про намір, керованість (маневреність) динамічної моделі літака і багатоальтернативному аналізі з використанням цифрової лінії зв'язку "диспетчер – пілот".

В.П. Харченко, В.Н. Васильев

Развитие системы принятия решений при кооперативном управлении воздушным движением

Представлена концептуальная структура системы поддержки принятия решений для обнаружения и разрешения конфликтов при кооперативном управлении воздушным движением. Исследовано адаптивное решение, базирующееся на информации о намерении, управляемости (маневренности) динамической модели самолета и многоальтернативном анализе с использованием цифровой линии связи «диспетчер – пилот».