UDC: 681.518:656.7.022

Aleksey Izvalov, Senior Lecturer, Sergey Nedelko, Doctor of Science, Professor, Vitaliy Nedelko, PhD, Associate Professor
Kirovograd Flight Academy of the National Aviation University

Set of Software for Automatic Control System of the Air Traffic Modeling Complex

The set of software which automates the control process of dynamical air-traffic situations generation is considered in the article. The functional scheme of its work is given. The set includes: airspace sector editor, catalogue searching tool, dynamic air-traffic situation generator and editor. The input and output data is formalized. Reducing the generation time and increasing the quantities and variety of practical tasks due to automation enable implementation of individualized learning approach.
air traffic controller, software, automatic control system, dynamic air-traffic situation, exercise design

А.В. Извалов, ст.преп., С.Н. Неделько, проф., д-р техн. наук, В.Н. Неделько, доц., канд. техн. наук
Кировоградская лётная академия национального авиационного университета
Комплекс программного обеспечения для автоматизированной системы управления комплексом моделирования воздушного движения

В статье приводится состав и функциональная схема работы комплекса програмного обеспечения, автоматизирующего процесс управления генерацией динамической воздушной обстановки для практической подготовки авиадиспетчера. Комплекс включает редактор воздушных зон, инструмент поиска в каталоге, генератор и редактор динамической воздушной обстановки. Формализованы входные и выходные данные Снижение затрат времени и увеличение объёмов и разнообразия учебных заданий благодаря автоматизации позволяет внедрять индивидуальный поход к обучению.
авиадиспетчер, программное обеспечение, автоматизированая система управления, динамическая воздушная обстановка, разработка упражнений

1. Statement of the problem. The simulator training of air traffic control (ATC) specialists is the primary means for development of the professional abilities and skills. Thus, this process ensures the flight safety provision. Typically the training is based on the dynamic air-traffic situation (DATS) modeling complex. Nowadays various means of automation are implemented in DATS modeling, but, nevertheless, the exercise design for the ATC simulator remains the most time-consuming task. Designing a 2-hour duration scenario for modeling the air traffic of average intensity including conflicts and unusual and emergency situations (UES) takes 5-6 hours of training centre staff activity.

This limitation prevented the full implementation of individualized approach for the professional training. According to such a concept, each trainee should complete his/her own sequence of tasks and exercises to reach the required level of professional skills and abilities. As such sequence can be subject to changes resulting from the trainee's current results, there is an urgent need in a set of software tools for the automatic control system of the air traffic modeling complex.

2. The analysis of recent publications and research. The individualized approach in the context of ATC professional training was considered in [1, 2]. In [3] the integration of different elements of automatics control system of ATC professional training was proposed. The student model applicable for ATC training was described in [4]. The models and algorithms of generating separate elements of DATS and the required data structures were described in [5, 6].

3. Objective of the research. The requirements to the software are derived from the workflow of ATC training process. The tasks of DATS design, editing and storing must be fulfilled. Two exercise design modes must be available: the automatic and the human-controlled ones. As the automatic exercise designing is expected to take place right before the actual student's procedural training according to the individual programme, the duration of the design process should be less than 10 minutes. Thus, the DATS should be generated while the student will be reading the instructions and taking the preliminary theory test.

4. The presentation of the material. At Kirovograd Flight Academy of the National Aviation University (KFA NAU) the appropriate models and algorithms were elaborated, the required software was developed and the individualized approach was realized in the ATC professional training. The functional scheme of the automated control system of DATS generation is shown in fig.1. Three major processes can be differentiated: initial data processing, DATS generation and providing DATS for the modeling complex.

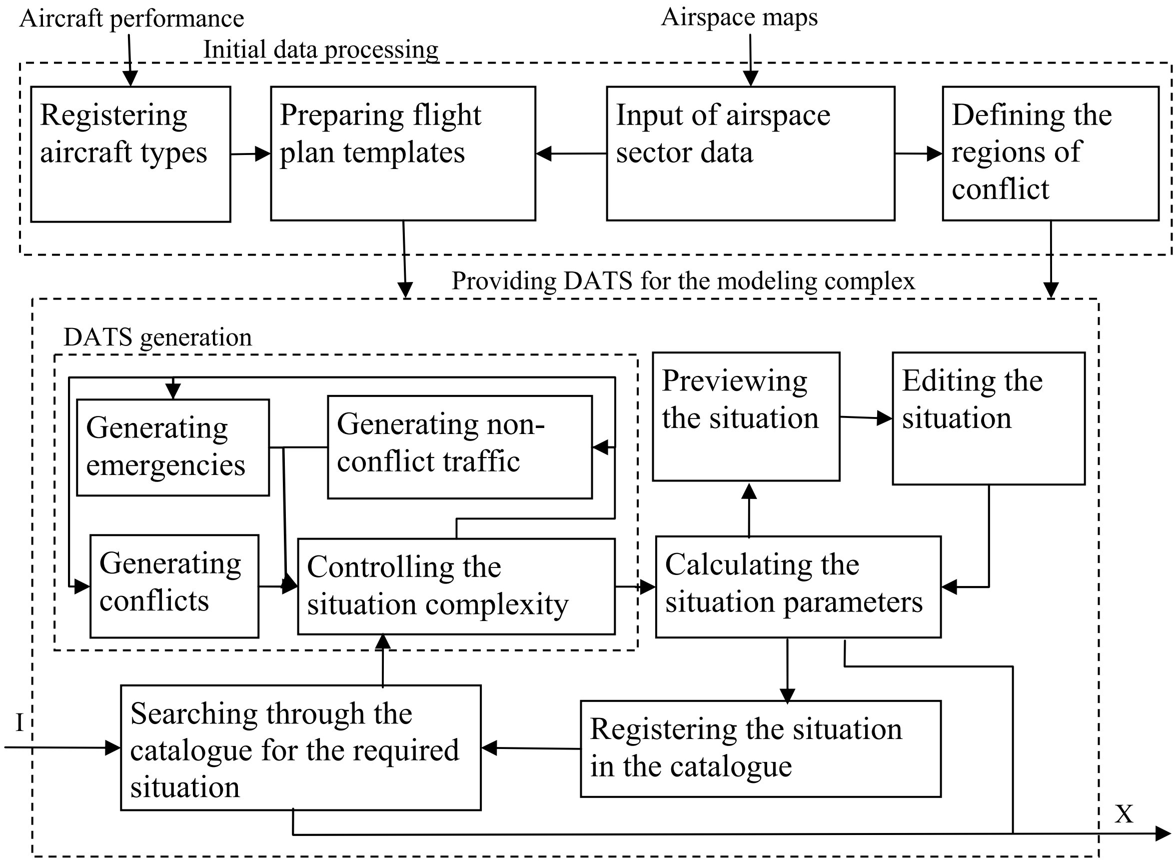

Figure 1 – The functional scheme of the automated control system of DATS generation

The airspace sector is stored in a relational database. The main objects are:

- the graph of air traffic routes with the vertices as navigational points and the edges as the airways segments;
- spatial boundaries: horizontal and vertical;
- regular routes of flights through the airspace with the possible airports of departure/arrival;
- possible vertical flight profiles for the routes;

- regions of conflict, that is regions where the spatial separation of the aircraft can be violated;
- aircraft performance, such as: cruising speed, maximum flight level, accelerating and decelerating characteristics, possible gradients of climb and descent, behaviour of the aircraft in the emergency conditions;
- flight plan templates, being the basic elements for building the DATS. Each template is the pair “Flight profile” – “Aircraft type”. Adding the actual flight plans to the DATS is picking up a flight plan template and specifying the sector entrance time for it.

The initial data processing is performed by the training centre operator. During this stage the aircraft performance data and the airspace structure data are input into the database using the visual editor (fig.2). This tool is capable of loading the array of points’ coordinates from air navigational databases and provides the easy way for their adjustment. Since not each simple route in the graph of air routes represents the regular flight route over the airspace, the regular routes are drawn manually or (for the existing airspace sectors) can be deduced automatically from the list of daily flight plans for this sector.

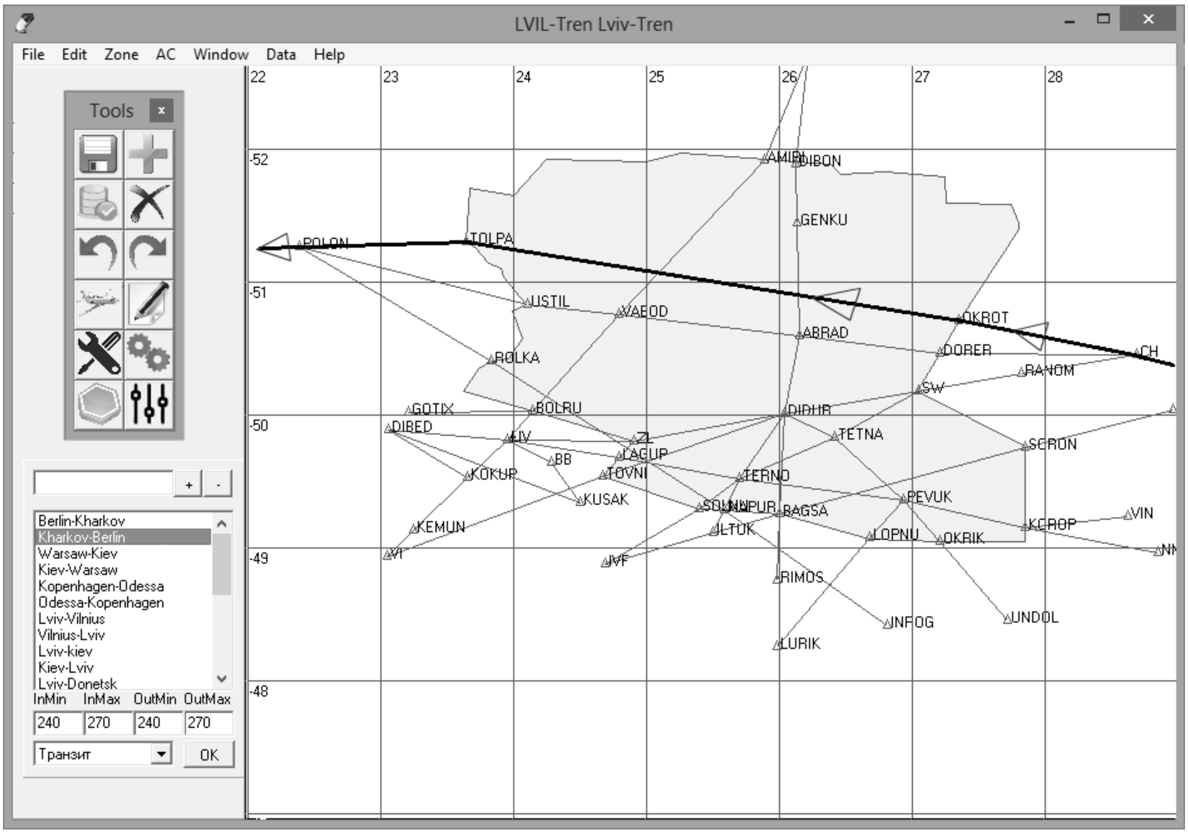

Figure 2 – Airspace editor interface

Having the airspace routes’ and points’ data, the flight profiles are generated automatically, taking into account odd and even flight levels for western or eastern flight directions and the altitude change at the climb/descent route segments. It is possible to apply country-specific vertical separation rules to the calculation if they are different from the international standards.

The map uses Lambert conformal conic projection which ensures that the scale errors are less than 0.1% in case the usual airspace sector lateral dimensions are within 5-10 degrees. The regions of conflict are found by solving the equation of geometry analysis. To reach the reasonable compromise between the amount of data stored and DATS generation time the regions of conflict where the horizontal separation can be violated are to be stored, and the vertical separation between the aircraft in the conflicting regions should be calculated on-the-run during the actual DATS generation.

The flight plan template is the pair "Flight profile" – "Aircraft type". The possible flight profiles are built from the routes data using the minimum and the maximum flight levels of the incoming and exiting traffic. The correspondence between the flight profiles and the aircraft types is defined taking into account such flight characteristics as cruising altitude and climb/descent gradients.

The input requirements "I" for DATS generation can be formalized as

$$I = \left\langle Z, T_{\mathrm{mod}}, P^I, K^I, E^I, C^I \right\rangle, \qquad (1)$$

where Z is the airspace sector in which the modeling takes place;

T_{mod} – duration of DATS modeling;

$P^I = \left\langle N_{AC}, \left\{\left(N_i^{ext}, T_i^{ext}\right)\right\}, D^I \right\rangle$ – requirements to the air traffic during DATS modeling, where

$N_{AC} = [n_{\min}; n_{\max}]$ – interval of number of aircraft, which should pass sector Z within the time T_{mod};

$\left\{\left(N_i^{ext}, T_i^{ext}\right)\right\}$ - extreme values of the function $n_{AC}(t)$ which describes the number of aircraft in the sector at given moment. These extreme values are intervals of extreme values $N_i^{ext} = [n_{i\min}^{ext}; n_{i\max}^{ext}]$ of air traffic and moment $T_i^{ext} = [t_{i\min}^{ext}; t_{i\max}^{ext}]$ of high or low air traffic;

$D^I = \left([d_{\min}^{in}; d_{\max}^{in}], [d_{\min}^{out}; d_{\max}^{out}], [d_{\min}^{tr}; d_{\max}^{tr}]\right)$ – intervals of arriving, departing and transiting air traffic ratios in the generated DATS;

$K^I = \left\{\left(T_i^{conf}, TP_i^{conf}\right)\right\}$ – requirements to the conflicts in the DATS where $T_i^{conf} = [t_{i\min}^{conf}; t_{i\max}^{conf}]$ is the interval of time during which the separation violation mush take place and TP_i^{conf} is the type of conflict (the conflicts are classified basing on the mutual location of the conflicting aircraft regarding their horizontal and vertical speed vectors);

$E^I = \left\{\left(TE_i, T_i^{evt}\right)\right\}$ – requirements to the UES during the DATS modeling, where TE_i is the set of possible UES types, one of which must happen at time interval $T_i^{evt} = [t_{i\min}^{evt}; t_{i\max}^{evt}]$;

$C^I = \left\{\left(C_i^{ext}, T_i^{ext}\right)\right\}$ – requirements to the extreme values of the ATC complexity function of time during the DATS modeling.

Before generating the DATS which would apply to the requirements "I" the system should first search through the catalogue of the already generated DATS. The tool was developed for manual searching through the catalogue, the instructor's interface is shown in fig.3. For storing in the catalogue the DATS is tagged to describe its key features: time of modeling, airspace sector, air traffic, complexity, conflicts, UES. These tags are used for search. Pre-reviewing of the air traffic, complexity function graph, the conflicts and UES is enabled.

Generation of the new DATS "X" takes place in two cases.

a) The appropriated DATS which will be applicable to the requirements "I" is not found in the catalogue.

b) The student controller for training needs new DATS which he has not encountered before to ensure that the situation will be new for him while the situation's parameters are applicable to the requirements for the previously completed exercises.

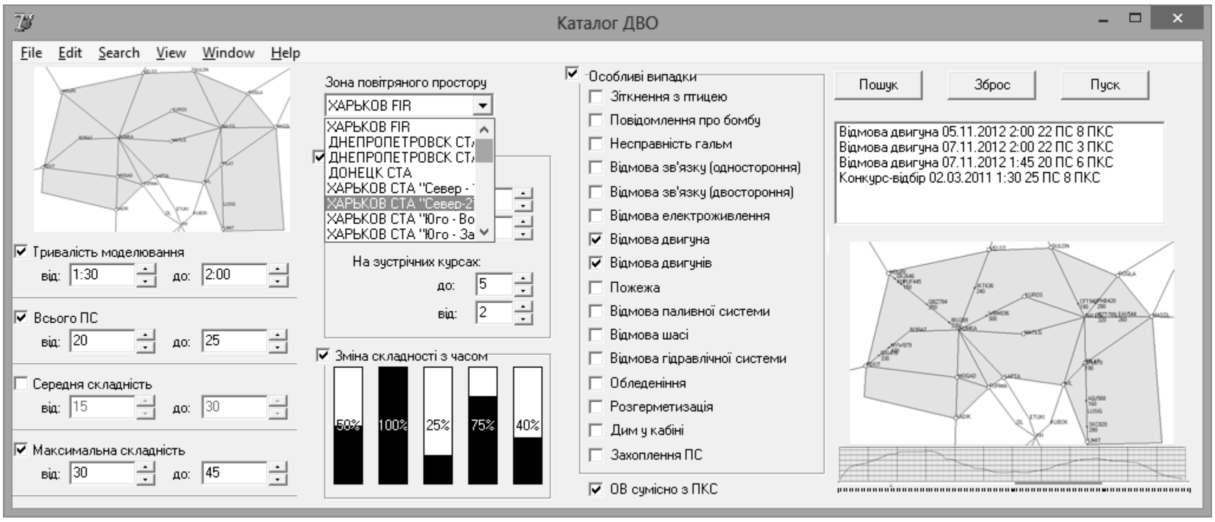

Figure 3 – Searching through the DATS catalogue

DATS "X" can be formalized as:

$$X = \langle Z, F, E, T, M \rangle, \tag{2}$$

where Z is the airspace sector;

$F = \{f_i\} = \{\langle T_i^{in}, L_i, \{\Delta t_j\}, TP_i, A_i \rangle\}$ is the set of flight plans of aircraft through the sector Z.

The flight plan f_i properties are:

T_i^{in} – moment of entering sector Z;

L_i – flight route and profile;

$\{\Delta t_j\}_1^k$ – moments of passing each of k nodes of the flight route.

If j = k, the moment of leaving sector Z can be derived as follows:

$$T_i^{in} + \Delta t_k = T_i^{out}; \tag{3}$$

TP_i – aircraft type;

A_i – other attributes of the aircraft, such as call sign, applied language, using the reduced vertical separation minima, etc.;

$E = \{e_i\} = \{\langle et_i, te_i, oe_i, \Delta t_i^{assist}, \Delta t_i^{effect} \rangle\}$ – set of events which are planned to take place during the DATS modeling, where:

et_i – event type (e.g. engine failure or cumulonimbus progress);

te_i – start moment of the event;

oe_i – object related to the event, which could be an aircraft or a region of the airspace sector;

Δt_i^{assist} – time after te_i during which the controller must react to the event according to the instructions;

Δt_i^{effect} – time after te_i during which the event will exist;

$T = [T_{start}; T_{start} + T_{\text{mod}}]$ – duration of DATS modeling.

M is the meteorological situation model which occurs during the DATS modeling.

The conflicts are not separate elements of X, as they can be defined using the graph K over set F with the incidence boolean function *ConfFPL(f*i*, f*j*)*. This function returns “TRUE” value if and only if the following statement is true:

$$\exists\tau\left(\left(\tau \in \left[T_{start}; T_{start} + T_{впр}\right)\right) \wedge Conf\left(f_i, f_j, \tau\right)\right). \quad (4)$$

Here the boolean function $Conf\,(f_i, f_j, \tau)$ is true if and only if the spatial separation between the aircraft which perform flights according to the flight plans f_i and f_j is violated at the moment τ.

The interface for inputting the requirements “I” for the DATS generation was developed (fig.4). The automatic DATS generation consists of 3 main phases.

1) UES generation. Each time one new flight plan is generated for the aircraft which is going to be the target of the emergency situation.

2) Conflict generation. Each time a pair of flight plans is generated; their flight profiles and the moments of entering sector Z are selected in such a way that the separation violation will take place at the specified moment and in the specified segment of airway.

3) Generating non-conflicting traffic. Flight plans are added one-by-one ensuring they will not violate the separation with already existing flight plans.

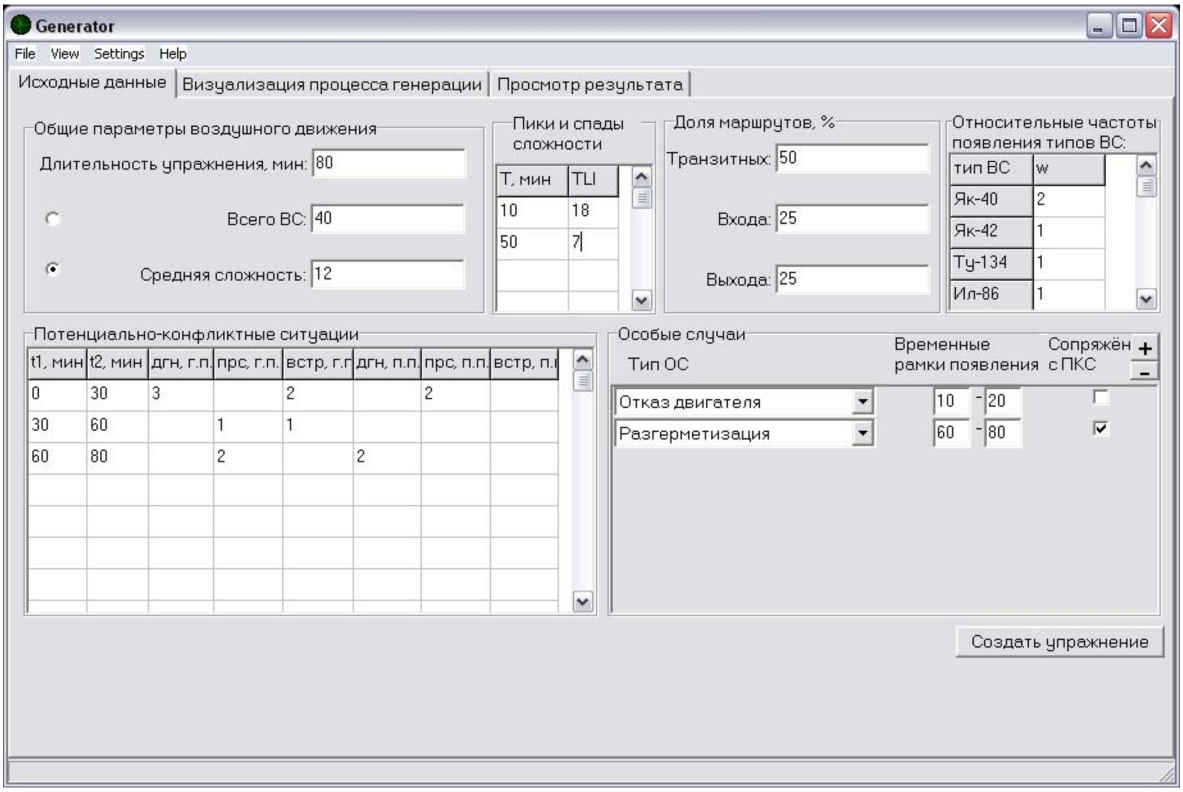

Figure 4 – Input interface of the requirements for DATS generation

During all these stages the situation complexity is controlled constantly and the process is halted when it is impossible to add any new flight plans without breaking the maximum complexity condition.

The visual DATS editing tool was developed (fig.5) which provides easy DATS previewing and editing its elements. Adding the flight plan consists of the following steps.

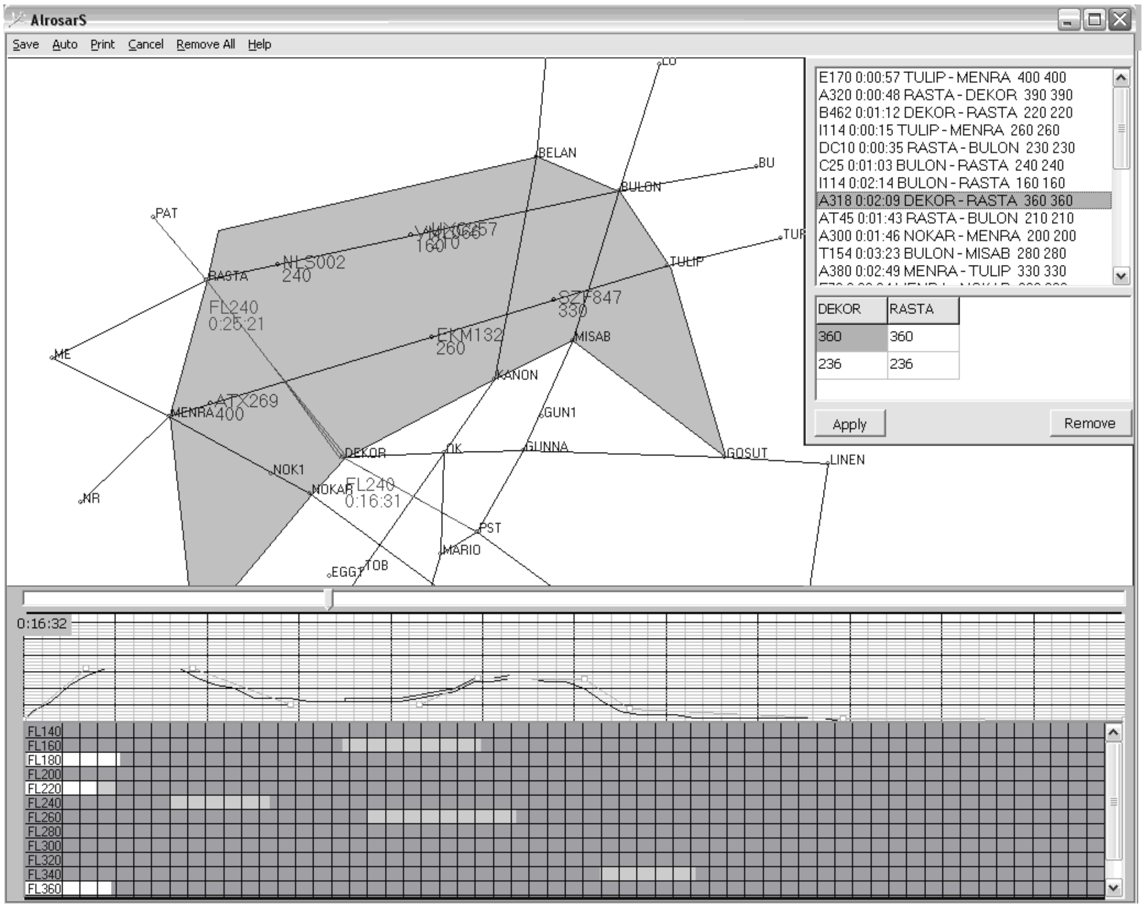

Figure 5 – Visual DATS editor

1) The operator selects one of the possible sector entry points which are highlighted on the airspace map.

2) After the entry point has been selected, the exit points for the possible routes are highlighted and the operator selects one of the routes.

3) Aircraft type select dialogue is opened. The brief information about the aircraft performance is provided for the operator who selects one of the aircraft.

4) After the aircraft selection the visual representation of dependency between the flight parameters of the added flight plan and the presence of the certain type conflict is built. It is a grid with green, red or black cells. The rows represent the flight profile while the columns represent the time of sector entering. The green cell means that no conflict will appear between the added flight plan and the existing ones if the added flight plan has the selected profile and entering time. The red cell means that the separation violation will take place (its place is shown on the sector map and its time is given on the complexity graph). The black colour means that the separation violation will take place right after the aircraft enters the sector. In this case the controller won’t be able to take any appropriate measures; thus for the training exercises adding the flight plans with such parameters should be avoided.

5) While the operator moves the mouse over the flight plan profile and entry time selection grid, the ATC complexity graph is modified to show the impact of the new flight plan to the situation complexity. Also, if the appropriate option is selected in the settings, the DATS on the sector map is rebuilt showing the positions of all the aircraft at the moment the new aircraft is going to enter the sector.

6) As the operator clicks the flight plan profile and entry time selection grid the new flight plan with the selected parameters is created.

7) Right-click on the aircraft opens the emergency situation menu where the UAS parameters can be specified.

Dragging the time trackbar enables quick previewing of the DATS evolution during the modeling time. There are the following means of adjusting the DATS parameters:

- it's possible to adjust the position of the selected flight plan at the specified moment using drag-and-drop technique, thus recalculating its moment of entering the airspace sector;
- the flight profile can be edited manually using the flight plans list and the profile grid. Both the altitudes and speeds at the route navigational points can be edited, the data is automatically verified to ensure its correspondence to the aircraft performance;
- the right-click menu enables changing other flight plan's properties, such as aircraft type and its attributes.

Such tasks of visual DATS editing are automated:

- the operator can draw the curve of the required ATC complexity function and the software will automatically generate the air traffic that will fit the required graph;
- right-click on the air route segment opens the conflict generation menu; two conflicting flight plans are added at once to the flight plan list.

The models and algorithms of automatic DATS generation implemented in the set of software were the subject of the validating experiment [7]. Its result showed that the deviations of the generated DATS parameters from the requirements were within the ranges defined by the guiding documents in the field of ATC training.

The parameters taken into account were the standard and maximum absolute deviations of the number of aircraft and traffic complexity. Also, the conflicts and UES were taken into consideration. Thus such tools can be used for training all the groups of professional abilities and skills.

Conclusions. Measurement of time needed for the phases of DATS generation gave the following results.

For the operator common to the software interface the visual airspace design takes 2-4 hours of work. Automatic loading the sector points and routes data from the air navigational databases and documents reduces this time up to 50%. Processing the airspace data takes another 10-30 minutes. As all these processes take place only once when the new sector is created, these time values are acceptable.

Automatic DATS generation takes 2-5 minutes and visual editing of DATS by the operator takes 10-30 minutes. These values prove that the developed set of software fully enables the individualized approach to the ATC training.

The exercises developed using this software both in the automatic and the manual modes are extensively used in training, self-training and professional competitions of ATC controllers held in the KFA NAU.

References

1. Zhang D.M. Exercise design approach for intelligent simulation based training system / Dong Mei Zhang, Lee Alem // ANZIIS-95 : Proceedings of the Third Australian and New Zealand Conference on Intelligent Systems. – 1995. – P. 13 - 18.

2. Redding R.E. Expertise in air traffic control (ATC): What is it, and how can we train for it? / R.E. Redding, J.R. Cannon, T.L. Seamster // Proceedings of the 36th Annual Meeting of the Human Factors Society. Santa Monica, CA: Human Factors Society. – 1992. – P. 1326–1330
3. Модели процессов управления качеством подготовки авиадиспетчеров / А.В. Извалов, В.Н. Неделько, С.Н. Неделько [та ін.] // Радіоелектронні і комп’ютерні системи 7(41). – Харків: “ХАІ”, 2009. – С. 89–94.
4. Clemente J A proposal for student modeling based on ontologies and diagnosis rules / Julia Clemente, Jaime Ramirez, Angélica de Antonio // Expert Systems with Applications: An International Journal, Volume 38 Issue 7, July, 2011. Pergamon Press, Inc. Tarrytown, NY, USA – P. 8066-8078.
5. Ізвалов О.В. Алгоритм обробки даних повітряної зони що забезпечує можливість автоматичної генерації навчальних вправ / О.В. Ізвалов, Неділько В.М., Неділько С.М., // Радіоелектронні і комп’ютерні системи 5(46). – Харків: “ХАІ”, 2010. – С. 301–304.
6. Ізвалов О.В. Формування навчальних вправ у автоматизованій системі керування тренажерною підготовкою авіадиспетчерів / О.В. Ізвалова, В.М. Неділько, С.М. Неділько // Матеріали ІІ Міжнародної науково-практичної конференції «Управління високошвидкісними рухомими об’єктами та професійна підготовка операторів складних систем», Кіровоград: КЛА НАУ, 2012, - С.7-9.
7. Izvalov A.V. Validation of input data flow generating algorithm for intelligent air traffic control simulator / A.V. Izvalov, V.N. Nedelko, S.N. Nedelko // Радіоелектронні і комп'ютерні системи. Науково-технічний журнал. – Харків: ХАІ, 2013. – Випуск 5 (64). – С. 52 – 56

О. В. Ізвалов, ст.преп., С.Н. Неділько, проф., д-р техн. наук, В.Н. Неділько, доц., канд. техн. наук
Кіровоградська льотна академія національного авіаційного університету

Комплекс програмного забезпечення для автоматизованої системи керування комплексом моделювання повітряного руху

Для забезпечення індивідуального підходу до практичної підготовки авіадиспетчера необхідно досягти суттєвого зниження витрат часу на генерацію динамічної повітряної обстановки.

У статті наводиться склад та функціональна схема роботи комплексу програмного забезпечення, що автоматизує процес керування генерацією динамічної повітряної обстановки для практичної підготовки авіадиспетчера. Комплекс включає редактор повітряних зон, інструмент пошуку у каталозі, генератор і редактор динамічної повітряної обстановки. Формалізовано вхідні та вихідні дані. Виділено основні фази та етапи генерації. Наводяться інтерфейси оператора, засоби візуального редагування та автоматизації. Програмне забезпечення пройшло експериментальну валідацію та було апробовано у навчальному процесі.

Впровадження програмного забезпечення знизило на два порядки витрати часу на генерацію вправ, підвищило їх різноманітність, що уможливлює індивідуальний підхід до практичної підготовки.
авіадиспетчер, програмне забезпечення, автоматизована система керування, динамічна повітряна обстановка, розробка вправ

Одержано 12.05.14