[EN-I-089]Ground and on-board ATM procedures prototyping tools.

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Abstract: This paper presents the Complex of Prototyping Tools - hardware-in-the-loop and human-in-the-loop simulation tool designed for studying advanced concepts and technologies of Air Traffic Management System. The Complex allows running simulation in different modes. Automatic fast-time simulation is used for performing long-term experiments for study future ATM systems. Real-time human-in-the-loop mode shows functional interaction between aircraft and ATC System. This tool can perform simulation of the entire Air Traffic Control operation cycle and is used to maintain control of aircraft at all stages of its movement from gate to gate, as well as to find and resolve conflicts between airspace users. This paper will also touch upon the problem of using the ATM simulation tool at research tasks of assessment of effectiveness and safety of the airspace use, development and evaluation measures taken to improve the ATM system and airspace. Examples of research results are also reported in this paper.

Keywords: Air Traffic Management, Fast-time Simulation, Airborne ADS-B-based applications, human-in-the-loop simulation, Airport Mapping Database, A-SMGCS.

1. INTRODUCTION

Air Traffic Management (ATM) systems are the key element of the civil aviation. Fast development of this industry has led to strong need for scientific research of assessment of the efficiency of resource use and verification of new concepts in the field of civil aviation. Other important task is creation necessary set of tools that would allow researcher to create mathematical models of any complexity.

The Complex of Prototyping Tools was developed by Russian State Research Institute of Aviation Systems (GosNIIAS) as a tool for hardware-in-the-loop and human-in-the-loop simulation of ATM System. The Complex includes on-board and ground-based models of the ATM system and is designed to simulate and study new airborne procedures, advanced concepts and technologies of the whole air traffic management system.

The Complex of Prototyping Tools was developed as multipurpose instrument and its main tasks are:

- Research of prospective procedures and functions;
- Testing of pilot and air traffic controller interaction [1];
- Demonstration of new airborne and ground functions;
- Evaluation of the airspace structure;

The Complex can perform distributed simulation using numerous host computers. Configuration of models or workstations involved in the simulation may vary depending on the research goals.

Complex allows to work in appropriate mode for each purpose type. For conducting an extensive research of prospective Air Traffic Management (ATM) concepts and technologies Complex is provided with fast-time simulation mode, where the researcher's work includes only input of experiment settings before it starts and processing the results at the end. Approbation of pilot and air traffic controller interrogation can be performed involving human-in-the-loop or automatically mode. Complex also can be used in semi-scale (part hardware and part software) simulation process and allows to work with both Pilot Workstation and air traffic controller simulator[2]. In purposes of demonstration, the Complex has a real-time mode configuration, which allows user to examine and elaborate procedures and functions explored.

2. COMPLEX OF PROTOTYPING TOOLS

2.1 Complex Components.

The Complex of Prototyping Tools currently consist of the following mathematical models and workstations (fig.1):

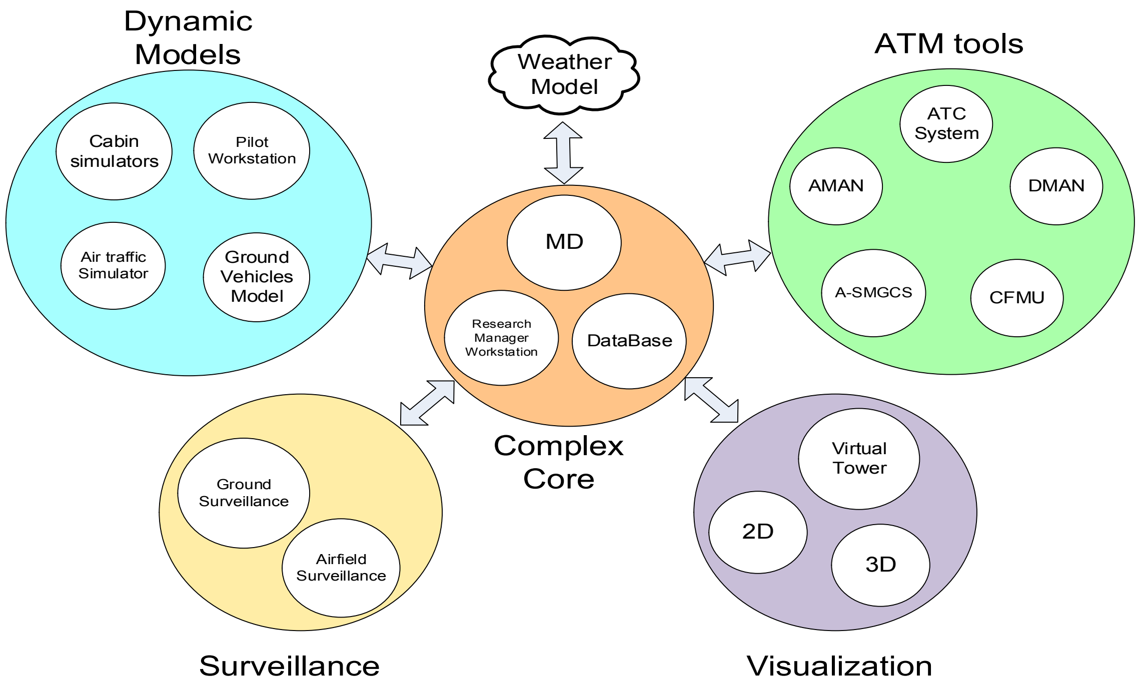

Figure1.Complex Components.

2.2 ATM Tools.

Main goal of ATM Tools as part of Complex of Prototyping Tools is to provide prediction, detection and resolution of violations of separation standards on all phases of flight – from gate to gate. Stand consists of :

- AMAN/DMAN
- ATC System Model
- Central Flow Management Unit

2.2.1 AMAN/DMAN Workstation

Arrival Manager (AMAN) and Departure Manager (DMAN) Workstations provides the possibility of traffic analysis in the "bottlenecks" of the ATM system – on the surface of aerodrome and in the terminal area. These models provide assistance in metering and sequencing of traffic flow, as well as detection of longitudinal separation violations based on actual flight plans and on trajectory prediction. Each model has automatic optimization algorithm and tools for manual regulation of arriving or departing flow. Automatic optimization algorithm allows to obtain conflict-free traffic flow.

2.2.2 ATC System Model

This model simulates functional interaction between aircraft and ATC System and is responsible for control of whole air traffic during all phases of flight from gate to gate. Main functions of ATC System Model are:

- Air traffic control;
- Departure and arrival flow management;
- Conflict prediction, detection and resolution;
- Testing of prospective CNS functions (ITP, FIM, ACM, ASIA, etc.);

2.2.3 Central Flow Management Unit Workstation

Central Flow Management Unit (CFMU) Workstation system is Air Traffic Flow Management (ATFM) system prototype that enables to :

- analyze airspace usage;
- keep updated flight plans based on incoming data from the ATC and surveillance systems;
- distribute actual flight plan data to other components of the Complex;
- perform trajectory prediction;

2.3 Research Manager Workstation.

Research Manager Workstation is a central element of the Complex. It is responsible for controlling of experiment’s progress and providing information flows between all other Complex elements.

Before modelling has started operator needs to choose scenario, that contains all necessary information for all models, or make a new. Workstation has convenient and flexible user interface to solve this problem. Here are some of the scenarios starting data: flight plans, airspace structure, weather data, components involved, experiment settings (starting time, duration, number of iterations, parameters of random factors, etc.).

Flight plans are the most important data for modelling because it serves as a starting point for all dynamic models both for air and ground components. There is two ways to prepare this data: use flight plans from the real archived flight plans received from Main Air Traffic Management Centre of the Unified Air Traffic Management System of the Russian Federation, or build test flight plans (usually also based on the real plans) for special purposes. Second case is used for prospective procedures and applications research. Operator also can select modelled airports and their parameters if it is needed.

During the modelling process operator can pause/stop it, change speed (make real-time or fast-time) and also observe situation with 2D or 3D visualisation. Experiments can be done in fully automatic mode without any human in the loop.

Another important function of Workstation is collecting parameters during modelling process. Operator can define which parameters he wants to save after each session. It is possible to convert them into Excel file for more convenient processing. Using this data wide range of parameters/metrics can be calculated, some of them are: number of controller operations, fuel consumption rate, delays time, number of conflicts. All of them can be used for assessment of new procedures and new airborne applications.

2.4 Ground Subsystem. Stand "Airport".

Ground subsystem of Complex of Prototyping Tools is presented by stand "Airport". It serves for modeling of controlled surface movement of aircrafts and ground vehicles on the airport surface and supports gate-to-gate modeling.

Stand consists of:

- Digital Airport Model (Fig. 2);
- A-SMGCS prototype;
- Dynamic Models of Surface Movement;
- Airfield Surveillance Model;
- 3D Real and Synthetic Vision Systems;

2.4.1 Digital Model

Aerodrome Mapping Data Base (AMDB), based on Guidelines for Electronic Terrain, Obstacle and Aerodrome Mapping Information[3] and User Requirements for Aerodrome Mapping Information[4][11], is the heart of the stand. It serves for displaying aerodrome structure for controllers and pilots as well as for modelling surface movement using surface routing graph from it. Models can get additional data from it, such as wingspan for taxiways, surface type and other. It also can be converted to the ARINC 816 [5] format for airborne functions, e.g. Airport Moving Map (AMM). AMDB can be filled manually (with our self-developed technology using satellite image and Aeronautical Information Publication, AIP) or downloaded from interchange formats such as AIXM, AMXM or ARINC 816. It is enough for starting "Airport" modelling, but the whole Complex modelling needs much more information such as SID, STAR, airspace structure etc.

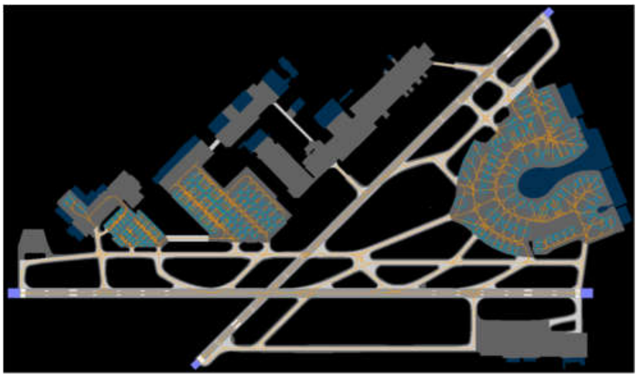

Figure 2. Digital map of Moscow Vnukovo Airport.

2.4.2 A-SMGCS prototype

Advanced Surface Movement Guidance and Control System (A-SMGCS) prototype is responsible for controlling ground movement. It can work in both automatic and manual (with operator) modes and its main functions are:

- Building and appointing taxi routes
- Aircraft service scheduling and appointing tasks for ground vehicles
- Appointing parking places
- Detecting collisions
- Conflicts resolution

Like other controllers in Complex, A-SMGCS prototype using CPDLC for controller-pilot interaction and in addition to the common controller command such as "HOLD POSITION" and "CONTINUE" the taxi message is used. Route from parking to the Runway in this case is: TAXI TO HOLDING POINT RUNWAY 07R VIA 8; Main Twy 1; 1; CROSS RUNWAY 07L.25R; 11. Using this text, on-board functions are able to decode it to a path on AMM. Taxi routes are built by prototype considering various environment parameters like aircraft type, optimal criteria, restrictions etc. , and can be rebuilt online.

In the manual mode operator can control surface movement via virtual strips. It provides all necessary information about each aircraft such as flight number, registration number, aircraft type, speed, altitude and status.

A-SMGCS prototype controls status of runways and taxiways. Operator blocks taxiways for time period (NOTAM messages are built automatically) or change their direction. He also can block Runways or change their working mode (approach, departure, both) but it will impact ATC controllers as well.

A-SMGCS prototype also has data capturing module for collecting different parameters during modelling process: number of collision detected, number of controllers operations, average taxiing time and others can be saved and analysed later. It's also possible to watch/control real-time parameters on heat map displayed over the airport map.

2.4.3 Dynamic models

There are two models designated for ground movement: Ground Traffic Model and Ground Vehicles Model. Apart from ground movement modelling these models provide interaction with ground controllers, collision detection and reaction to them. Ground Traffic Model analyses taxi route given by ground controller and taxi through it, it can stop and contact controller if needed. Ground Vehicle Model models up to 15 vehicle types (tugs, buses, refuelers, etc.). It receives destination (task) and builds route to it by itself. Service work models as a time delay and after it vehicle will return to its parking place. This model needs additional data such as service routing network and service parking stand locations.

Airfield Surveillance Model simulates measurement, processing and distribution of the trajectory data.

Operator of A-SMGCS prototype can use view from tower via Real Vision System. It shows all traffic on airfield irrespective of vehicle or aircraft equipment or state. Quality of view depends on time of the day and weather. On the other hand Synthetic Vision system shows only data received from the ground surveillance model in constantly best weather conditions.

2.5 Air Subsystem.

Air Subsystem of Complex of Prototyping Tools includes Air Traffic Model and Cabin simulators.

2.5.1 Air Traffic Model

Main purpose of Air Traffic Model is to provide controlled flight according to initial flight plan according to air traffic controller commands, thus to perform realistic air traffic. The goal of controlled flight is pursuance to a day flight plan by all aircrafts from air traffic flow determined by researcher. Each aircraft in flow is presented by separate object having its own flight performance and flight plan and individually communicating with air traffic controller using CPDLC (controller-pilot datalink channel) messages.

The Air Traffic Model is implemented in two components of Complex: Air Traffic Simulator and Pseudo-Pilot Workstation.

Air Traffic Simulator is a software, which provides imitation of real air traffic flow. The model interrogates with databases developed by GosNIIAS according to real flight path data, calculates each aircraft state vector during every step of the modeling and in the end of experiment calculates a part of statistics data. The most important part of the model is aircraft dynamics itself, which has two simulation models: interpolation mode based on flight plan data and equations of motion integration using Euler method. Interpolation mode is used in tasks of estimation new air traffic management concepts and methods effectiveness; integration mode describes the flight process more precisely and therefore is applied in tasks of conflict detection and resolution methods and following air traffic controller commands research.

Aircraft flight performance data for each aircraft type are calculated on base of equations and constants provided by Eurocontrol BADA [13] documents. BADA (Base of Aircraft Data) is aircraft performance database containing both constants and user manual, which describes the correspondences and references for calculation of main aircraft motion parameters during all flight phases. This document introduces formulas for maximum and minimum speeds; engine thrust and fuel consumption depending on the atmosphere parameters and aircraft type. Using the same references detailed 4d trajectory prediction can be performed, and this approach allows to minimize the difference between planned and actual aircraft flight path in terms of no uncertainties or random factors. Aircraft dynamics model simulates one random factor, which is lateral deviation from flight path line. It is calculated using determined by researcher required navigation performance (RNP) level for certain airspace areas.

Pseudo-Pilot Workstation is more detailed and precise description of single aircraft movement during all flight phases (gate to gate modeling). Model is equipped with a set of visualization tools and MCDU (Main Cockpit Display Unit) simulator, which allows to communicate with air traffic controller using CPDLC messages. The Pilot Workstation can be used for connection hardware Pilot Workstations to other Complex components and also can be controlled manually via joystick.

2.5.2 Cabin simulators.

Cabin simulator can be connected to the Complex for testing controller-pilot interaction and prospective airborne functions. It also provides testing of prospective airborne functions from position of Integrated Module Avionics (IMA). Developed application prototypes can be uploaded to ARINC 653[16] Platform and work in conditions close to real ones. From the other side, cabin simulator allows Complex to make real-time simulation with the human-in-the-loop. Simulation also can be used as the environment for procedure trainers for both controllers and pilots.

Four cabins can be connected to the Complex:

1. Future Aircraft Cabin designed in cooperation with Russian Flight Research Center (FRC)
2. Russian Central Aerohydrodynamic Intitute (TsAGI) cabin
3. MS-21 prototype cabin developed by GosNIIAS (Fig. 3). It also can be used as procedure trainer as well.
4. MS-21 "Electronic Bird" stand.

Figure3. MS-21 prototype cabin.

3. RESEARCH PROCESS

As already mentioned - main goal of the Complex are the simulation studies in the interest of assessment of potential benefits from use of new prospective ADS-B based procedures, new ATM concepts and technologies.

3.1 Research process stages.

The process of research with the Complex includes several stages :

1. Preparation stage. The first and most important stage of the research is preparation stage. During this stage researcher can create scenario, choose simulation mode and configure the Complex according to research goal. Research Manager Workstation is a flexible tool, that allows researcher to create experiment scenario, set number of repeats of experiment and parameters of random factors, customize each aircraft equipment, flight plan, arrival and departure time, and much more.
2. Simulation stage. During this stage Complex performs a series of a given number of experiments. The simulation stage can be controlled by increasing or decreasing speed of the simulation, suspending, stopping or resuming the experiment. During this stage Complex can calculate big amount of metrics and store them in database for further processing. Operator can monitor simulation process via 2D and 3D visualization.
3. Data processing stage. At this stage researcher analyses calculated metrics, builds charts and graphs and makes conclusions about the impact of the new concepts, methods, procedures and technologies on the performance characteristics.

3.2 Performance characteristics.

In order to estimate the potential benefits of the advanced concepts and technologies introduction Performance characteristics and metrics used in researches on the Complex were selected as a result of the analysis of international documents [14-15] as well as from materials of international air navigation conferences and from published research papers.

Following performance characteristics can be calculated during simulation studies:

- Airspace access;
- The predictability of air traffic;
- Airspace capacity;
- Efficiency;
- Safety;
- Environment;
- The flexibility of air traffic control.

3.3 Conducted researches.

The following researches were successfully conducted on the Prototyping Complex:

1) Testing of the Arrival Management (AMAN) system prototype in Digital Airport Sheremetyevo (SVO) model;
2) Testing of the Departure Management (DMAN) system prototype, testing of DMAN/A-SMGCS systems interaction and collaborative decision making;
3) Assessment of electric taxiing system by simulation of ground movement on Digital Airport Sheremetyevo (SVO) surface;
4) Assessment of the benefits from use of advanced ADS-B-based functions.

- Flight-Deck Interval Management (FIM) procedure, a set of airborne capabilities designed to support a range of interval management operations whose goal is precise inter-aircraft spacing [7][10];
- Airborne Conflict Management (ACM) procedure, which enables aircraft to detect, prevent and resolve air traffic conflicts, thus performing self-separation [9][1];
- Approach Spacing for Instrument Approaches (ASIA) procedure – airborne procedure which provides longitudinal interval between aircraft on the Standard Terminal Arrival Route (STAR) [8][10][12];
- In-Trail Procedure (ITP), which enables aircraft that desire flight level changes in procedural airspace to achieve these changes on a more frequent basis, thus improving flight efficiency while maintaining safe separation from other aircraft [6][1];

5) Approbation of pilot and ATC controller interaction based on controller-pilot datalink channel (CPDLC);
6) Assessment the influence on air traffic characteristics from the use various ATFM procedures.

4. CONCLUSION

In this brief article we described main capabilities of The Complex of Prototyping Tools, human-in-the-loop and hardware-in-the-loop simulation tool for study future Air Traffic Management systems. Complex allows to run distributed simulation from gate-to-gate in real-time and fast-time modes. During simulation studies Complex can calculate and store metrics for future processing by researcher. In the human-in-the-loop mode Complex is useful for approbation of pilot and air traffic controller interaction and demonstration of new airborne and ground functions. Also Complex allows to test new ATM concepts and technologies (ATFM, AMAN, DMAN) and conduct researches for assessment of the potential benefits of advanced ADS-B-based functions (ITP, FIM, ACM, ASIA) in hardware-in-the-loop mode.

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