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On a Concept of Creation of an Airport Advanced Surface Movement and Ground Control System

Statement of the problem. A concept of creation and stages of development for an airport advanced surface movement and ground control system (A-SMGCS) are offered in the report. The basic purpose of the system is to increase airport capacity and safety of movement of vehicles and aircrafts on its territory. The system structure, structure of its segments are given, simulation results for the main characteristics of the system are presented.

Air traffic intensity growth and as a result traffic density increase on the territory of the airports demand new approaches to the aircraft service organization at the airports and to airport vehicles (AV) information support quality. Existing control airport surface movement and ground control systems (SMGCS), described in ICAO document Doc 9476-AN/927, are not always capable to provide aircrafts with a service necessary for providing required levels of capacity and traffic safety, in particular under the limited visibility conditions because the control of movement is executed visually, and traffic control is generally made by means of a voice radio communication. Advanced SMGCS (A-SMGCS) systems, requirements to which are formulated in Doc9830-AN/452 ICAO, have to provide the appropriate capacity and safety taking into account specific weather conditions and time of day, traffic density and the airfield scheme on the basis of the latest technical means and high level of integration of various functionality. So A-SMGCS suggested in the report differs from SMGCS that it can provide service on an individual basis in much wider range of weather conditions, values of traffic density and versions of airfield schemes.

The onboard navigation complex (ONC) included in the aggregate airport transportation control system becomes an obligatory component of the airport vehicles for implementation of perspective requirements for safety in the airport territory. A satellite navigation receiver, a micromechanical inertial navigation system, an odometer and/or aground speed sensor are the main part of such onboard complex [1, 2, 3]. Such set of subsystems allows solving all kinds of tasks standing the airport vehicles with a required accuracy, continuity and integrity of the navigation solution.

The purpose of the presentation is to acquaint experts with the structure, design, and specific features of the system, including the developed software of the onboard navigation complex of the specified structure, and with the simulation results and semi-natural modeling of its accuracy in difficult operating conditions in the airport territory.

System structure. The use of A-SMGCS will lead to redistribution of the duties connected with various functions of system. Ensuring routing, management and control will depend to a lesser extent on ability of a pilot or governing body to carry out visual supervision, and automated elements will be used to perform some functions. A-SMGCS provides also effective interface to planning function in the air traffic management system (ATM).

Important distinction between functions of existing SMGCS and suggested A-SMGCS is that the new system can provide not only more exact regulation and control of movement of all vehicles and airplanes in the airfield, but also can provide dividing time intervals between all moving objects. Besides, in case of hard movement streams the A-SMGCS can execute functions of airport movement management system, providing planning and the organization of movement of all aircrafts and vehicles in the working area, including interface to ATM system, and represents a part of the global concept of CNS/ATM in respect of ensuring flight from the point to the point.

As the main component of offered system the system which was created by the JSC PRIN with the assistance of experts from Moscow Aviation Institute could be used. It was put into operation at the Domodedovo airport in 1998 [4, 5].

The system consists of ground and onboard segments (Figure 1). The ground segment consists of the dispatching center and the radio center. The onboard segment includes all onboard complexes of the vehicles operating in the territory of the airport. The radio center provides reception and processing of satellite navigation signals and signals of pseudo-satellites, forms differential corrections, provides communication of all participants of movement with dispatchers, and also among themselves.

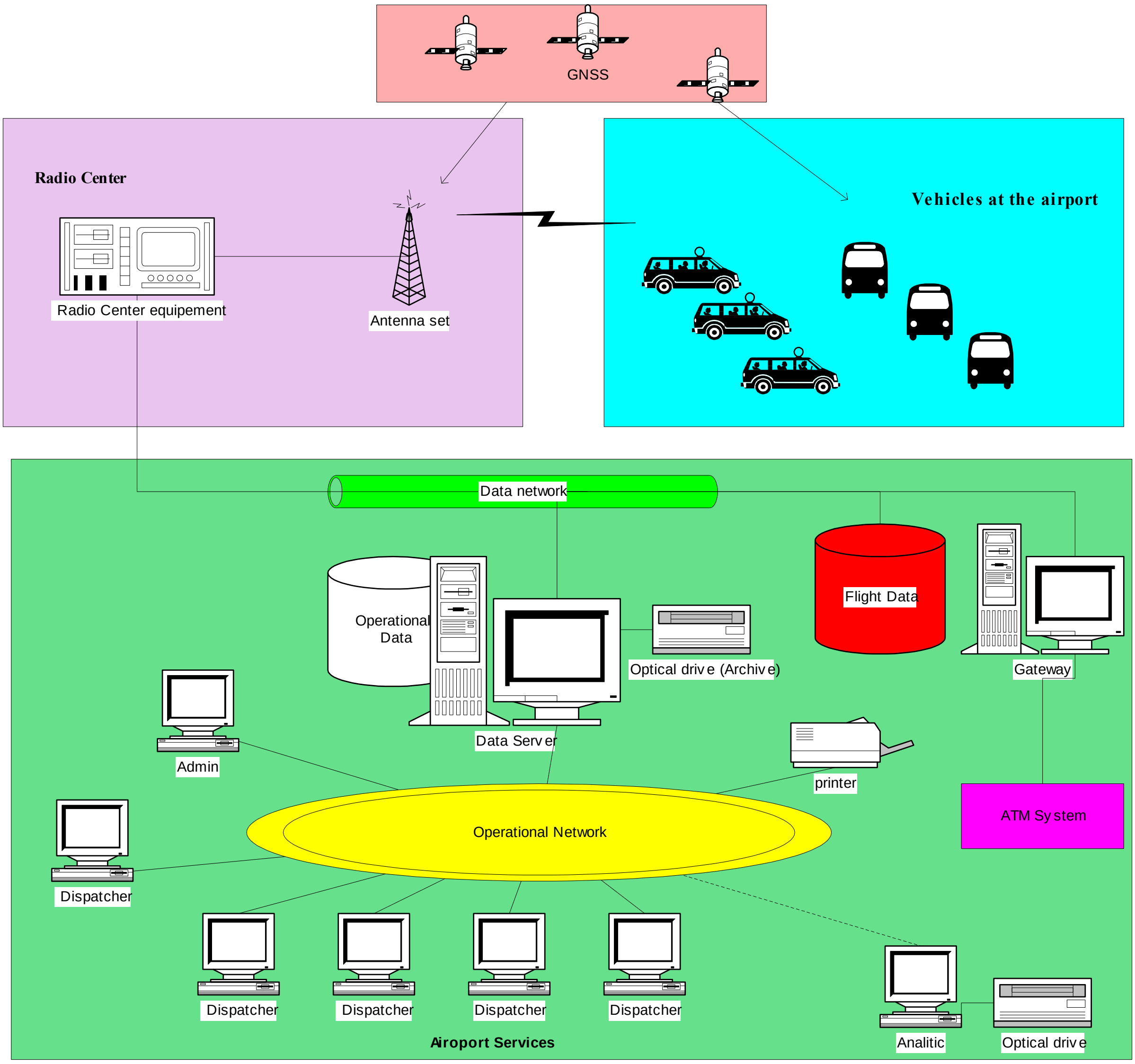
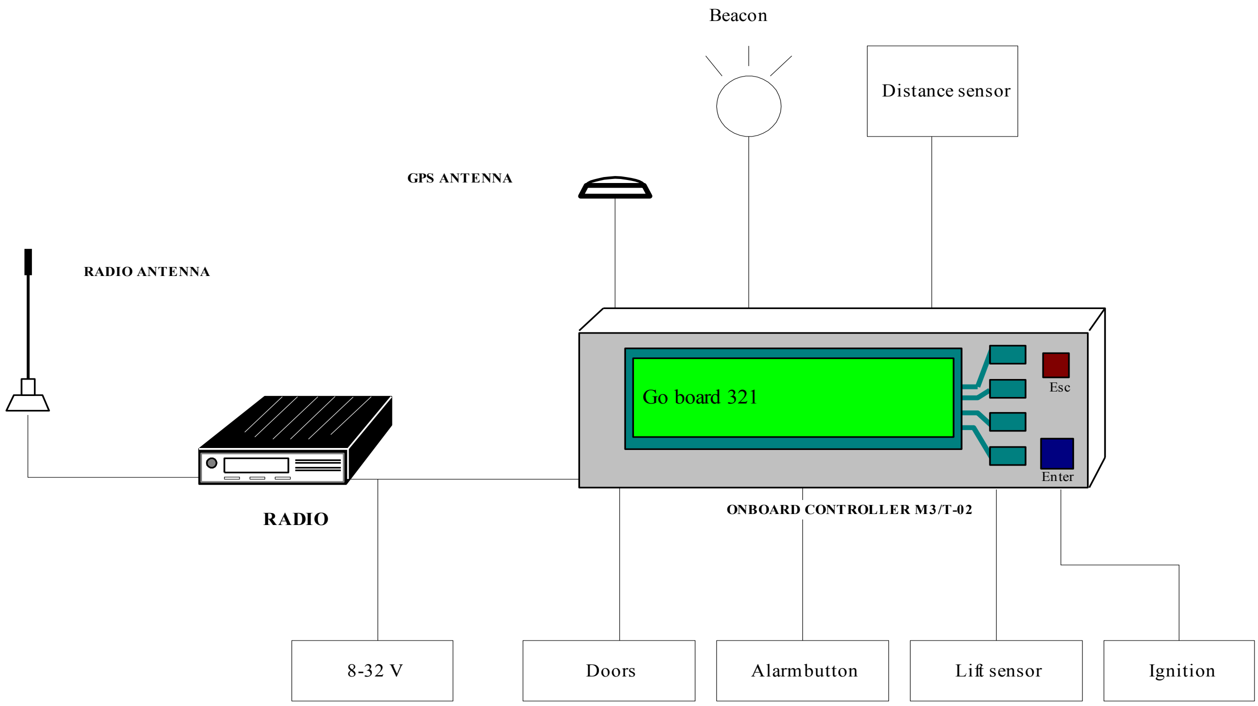
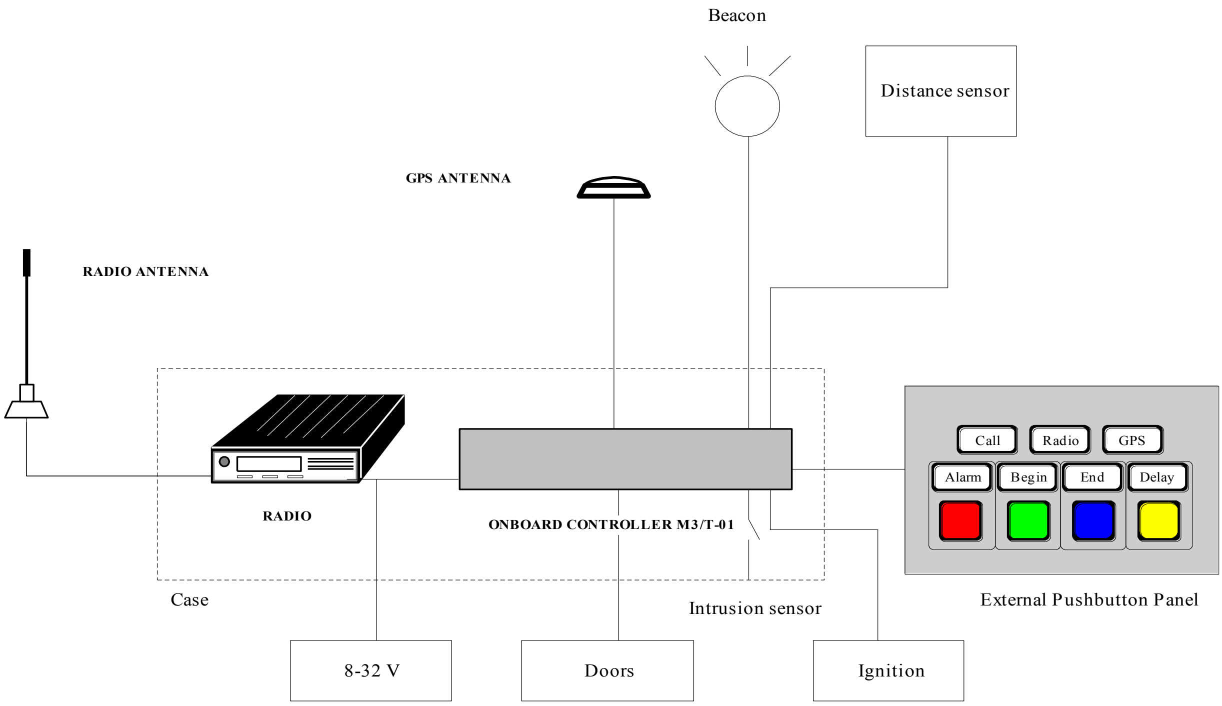


Fig.1. System Structure.

Onboard complexes consist of the small-sized radio systems (Figure 2) and integrated navigation complexes. For the purpose of ensuring reliability of objects tracking in the territory of the airport it is required to have more than one source of navigation information. Radar station of the airfield review can be considered as the main sensor, but it isn't enough. Therefore a satellite navigation GLONASS/GPS/Galileo receiver, a small-sized micromechanical inertial navigation system, an odometer sensor, and in some cases magnetic compass are included into the structure of an onboard navigation complexes. Existence of several navigation means allows to organize the integrated operating mode of a complex that increase its reliability and a noise stability of onboard navigation complexes when working in hard conditions of an airport (Figure 3).



a) The basic complex.



б) Extended complex (with External Pushbutton Panel)

Fig.2. The onboard set.

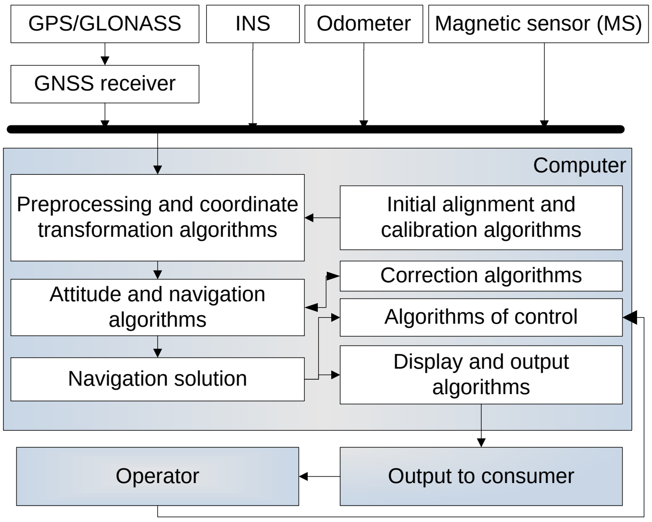


Fig. 3. ONC Structure.

ONC Software. The functional algorithm which is including complex information processing was developed for the specified ONC structure. Strapdown INS is an information base of the ONC, and SNS is the main correction system. In case of outages or bad quality of its signals the onboard odometer gets into operation, and for accuracy improvement of the system in this operating mode the algorithmic type of correction is used. This type of correction is based on calculating measurements taking into account restrictions on lateral component of AV velocity. For observability improvement, and, as a result, an estimation quality in the azimuthal channel the use of magnetic compass is provided. The complex is offered to design as loosely-coupled scheme. In this structure the Kalman optimal filter (KOF) on the basis of position, velocity and angular measurements from SNS and the magnetic sensor forms a state vector estimation which is used for strap-down INS correction. The structure of the software is presented in figure 3.

The complex information processing was realized on Joseph-modification of Kalman filter, providing the better computing algorithm stability. The main measurements in a complex are formed by comparison of strap-down INS and SNS indications. Thus the SNS error model was represented as white noise in OKF algorithm. The state vector is expanded and includes 18 components: 13componentsare $\bar{x}_{INS}$ the errors of two-channel INS including coordinates errors, velocity errors, orientation angular errors, constant errors of accelerometers and gyroscopes, and also latitude and longitude errors calculated from speedometer indications, constant speedometer errors, a speedometer scale coefficient error and a magnetic sensor constant error:

$$\bar{x} = \left\{ \bar{x}_{INS} \quad \delta\varphi_{od} \quad \delta\lambda_{od} \quad \Delta V^{const} \quad k \quad \Delta\psi^{const}_{magn} \right\}^T \qquad (1)$$

The system description in the space of states [1, 2] is presented by the state equations (the equations of INS errors) and the measurements equations. The main matrixes of model are:

- dynamics matrix

$$F = \begin{bmatrix} & & A & & \\ 0_{3x4} & B & & P & 0_{3x5} \\ & & 0_{6x18} & & \\ & 0_{2x13} & & K & \\ & & 0_{3x18} & & \end{bmatrix} \quad (2)$$

in which matrixes A, B, P and K have an appearance:

$$A=\begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \Omega_y^2+\Omega_z^2-\omega_0^2 & \dot{\Omega}_z-\Omega_x\Omega_y & 0 & 2\Omega_z & 0 & -n_z & -n_y & C_{11} & C_{12} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -(\dot{\Omega}_z+\Omega_x\Omega_y) & \Omega_x^2+\Omega_z^2-\omega_0^2 & -2\Omega_z & 0 & n_z & 0 & -n_x & C_{21} & C_{22} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$B=\begin{bmatrix} 0 & \Omega_z & -\Omega_y \\ -\Omega_z & 0 & \Omega_x \\ \Omega_y & -\Omega_x & 0 \end{bmatrix} P=\begin{bmatrix} 0 & 0 & 0 & C_{11} & C_{12} & C_{13} \\ 0 & 0 & 0 & C_{21} & C_{22} & C_{23} \\ 0 & 0 & 0 & C_{31} & C_{32} & C_{33} \end{bmatrix} K=\begin{bmatrix} 0 & 0 & \frac{\cos\psi}{R} & \frac{V\cos\psi}{R} & -\frac{V\sin\psi}{R} \\ \frac{V\sin\psi\sin\varphi}{R^2\cos^2\varphi} & 0 & \frac{\sin\psi}{R\cos\varphi} & \frac{V\sin\psi}{R\cos\varphi} & \frac{V\cos\psi}{R\cos\varphi} \end{bmatrix}$$

- system noise matrix:

$$G=\begin{bmatrix} 0_{2x3} & 0_{2x3} & 0_{2x2} \\ 0_{2x2} & 0_{2x3} & 0_{2x3} \\ 0_{3x3} & 0_{3x3} & 0_{3x2} \\ & 0_{6x8} & \\ 0_{2x6} & & G_1 \\ & 0_{3x8} & \end{bmatrix}$$, in which matrix G_1 is presented as $$G_1=\begin{bmatrix} \frac{\cos\psi}{R} & -\frac{V\sin\psi}{R} \\ \frac{\sin\psi}{R\cos\varphi} & \frac{V\cos\psi}{R\cos\varphi} \end{bmatrix} \quad (3)$$

Noise vector is presented in the form:

$$\overline{W}^T=\begin{bmatrix}\delta n_1 & \delta n_2 & \delta n_3 & \delta\Omega_1 & \delta\Omega_2 & \delta\Omega_3 & \varepsilon_{od} & \xi_{magn}\end{bmatrix} \quad (4)$$

Besides traditional noises of the micromechanical sensors which are a part of the strap-down INS, it includes also speedometer and magnetic sensor noises.

Not only traditional measurements based on differences between coordinates and velocities of INS and other systems are considered in the complex. Measurements received from specific feature of AV movement were taken into account. The matter is that projection of the AV velocity to the cross axis at normal movement has to be equal to zero (there is no sliding), and any difference from zero is accepted as measurement and is expressed through ONC errors.

The error equations of the system base on speedometer data integration are presented as follows:

$$\begin{cases} \delta\dot{\varphi}_{od}=\frac{\cos\psi}{R}\delta V-\frac{V}{R}\sin\psi\,\delta\psi-\frac{V\cos\psi}{R^2}\delta R \\ \delta\dot{\lambda}_{od}=\frac{\sin\psi}{R\cos\varphi}\delta V+\frac{V\cos\psi}{R\cos\psi}\delta\psi+\frac{V\sin\psi\sin\varphi}{R^2\cos^2\varphi}\delta R \end{cases}, \quad (5)$$

Where $\delta\varphi_{od}$, $\delta\lambda_{od}$ – latitude and longitude speedometer system errors, δV – ground speed error, $\delta\psi$ – true heading error, ψ – true heading angle, V – ground speed, φ – latitude.

Ground speed error and true heading error are presented as:

$$\delta V=\Delta V^{const}+kV+\varepsilon;\ \delta\psi=\Delta\psi^{const}+\xi \quad (6)$$

where ΔV^{const} – constant speedometer error, k – speedometer scale factor error, ε – speedometer noise, $\Delta\psi^{const}$– true heading error, ξ – magnetic compass noise.

An algorithm of restructuring on INS autonomous mode of operating is organized in the complex. Such reconfiguration happens by criterion of expected SNS accuracy which is estimated on the basis of filter predicted RMS of navigation errors. When errors exit out of admissible limits ONC passes into autonomous correction mode based on information from speedometer and on calculation of lateral velocity. The algorithm of restructuring of ONC is given in figure 4.

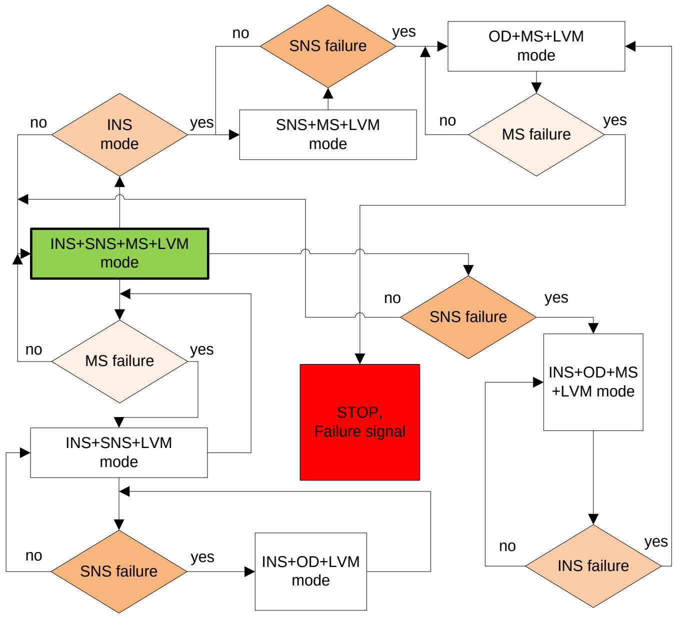


Fig. 4.Logical algorithm of ONC

Stages of system creation. At the first stage of system creation it is offered to develop and to install the system corresponding to level 1 or 2 A-SMGCS, i.e. system in which non visual supervision function over participants of movement is provided. Thus it is necessary to solve the following problems:

- to develop autonomous system of not visual supervision over vehicles on the basis of methods of exact and reliable determination of vehicle location according to information from the satellite GLONASS/GPS/Galileo receiver;
- to develop the integrated system of not visual supervision over vehicles on the basis of information from inertial, odometer systems and radar station;
- to develop complex system of not visual supervision over aircrafts and vehicles;
- to develop information exchange system of the integrated system with an airport information systems for the purpose of receiving and display of planned information on arrival/departure of aircrafts and planned works in the airport territory;
- to develop information exchange system of the integrated system with ATM secondary radars (a survey airfield locator) for the purpose of providing a continuity of radar information;
- to develop the integrated system of not visual supervision over aircrafts on the basis of information from secondary radar and other sensors.

Work on the subsequent stages for A-SMGCS increase to Levels 3, 4 will be possible in process of introduction of necessary technologies, the ground and onboard equipment, and means of communication. Experience of development of such systems of Russia is available, however published information doesn't allow to judge quality of real use of the systems [6]. There is information on experience of use of purchased system in Domodedovo [7, 8], but there is no enough information in this also.

One of the designed navigation module for ground vehicle is presented on figure 5.

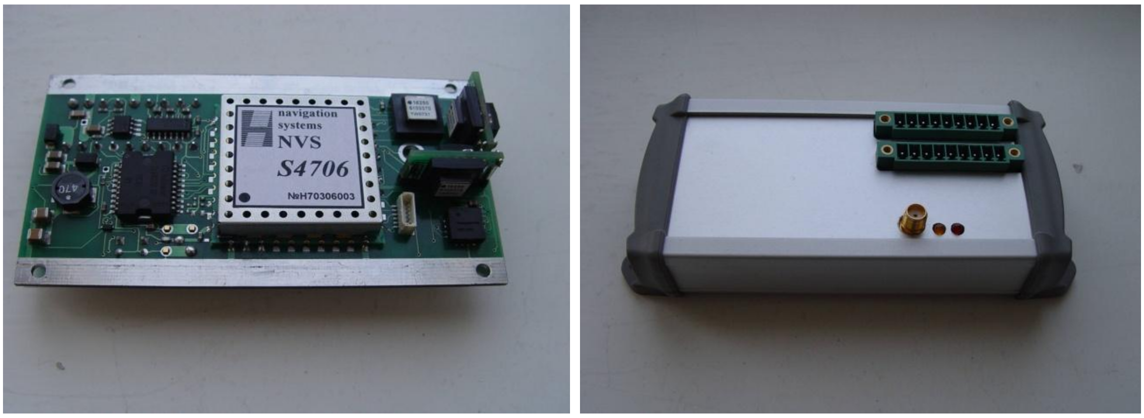


Fig.5. Appearance of the navigation module.

Simulation and test results. The accuracy of ONC of the AV in the conditions of a strong radio noise and at outage of signals of sufficient number of navigation satellites was investigated. For this purpose simulation of several scenarios of ONC operation were carried out with the use of the satellite navigation signals simulator. Losses of satellite signals tracking on various time intervals and under various ONC operating conditions and AV movement were simulated in each scenario. To increase the reliability of the simulation results the satellite navigation signals simulator SN-3803M was used. Some results of semi-natural researches are given in figure 6 [9].

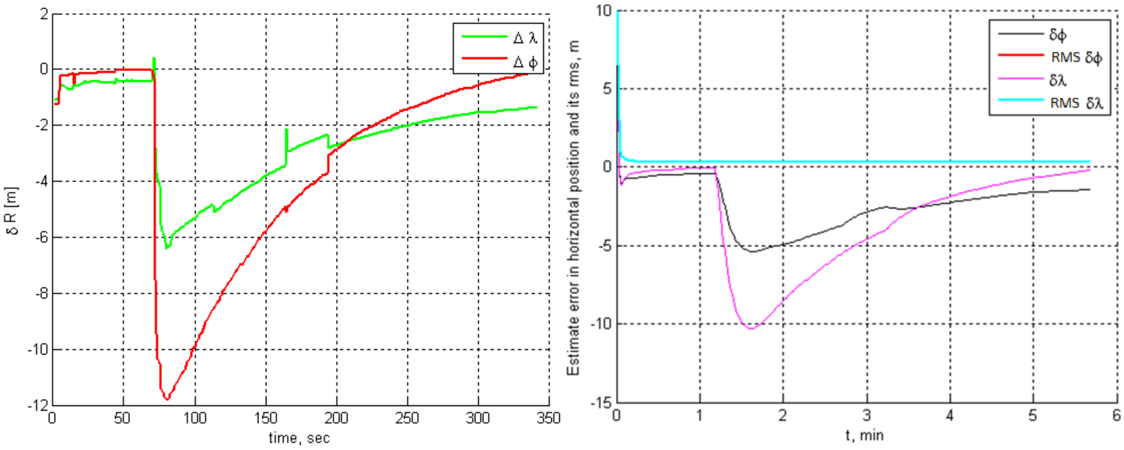


Figure 6. Semi-natural modeling results (at the left – indications of the built-in navigation receiver of the satellite signal simulator, on the right – ONC errors in horizontal coordinates)

It could be seen from the drawings that on the 70th second the action of disturbance begins and the receiver coordinate error makes nearly 12 m on latitude and more than 6 m on longitude whereas at optimal processing the error of estimation has more smoothed appearance and peak values are equal 10 m and 5 m respectively that shows certain advantages of the complex mode. If thus at the moments of spasmodic deterioration of SNS accuracy ONC would switch to an autonomous mode based on odometer/speedometer indications according to algorithms shown in figure 4, it is possible to reduce even more essentially the disturbance influence on complex system output.

Real test results with the designed navigation module are shown in figure 7. A trajectory of a vehicle is marked by colored dots indicating different working modes of the module. It could be seen that in the tunnel under the channel only inertial data is available and during about 12 seconds inertial mode gives good results.

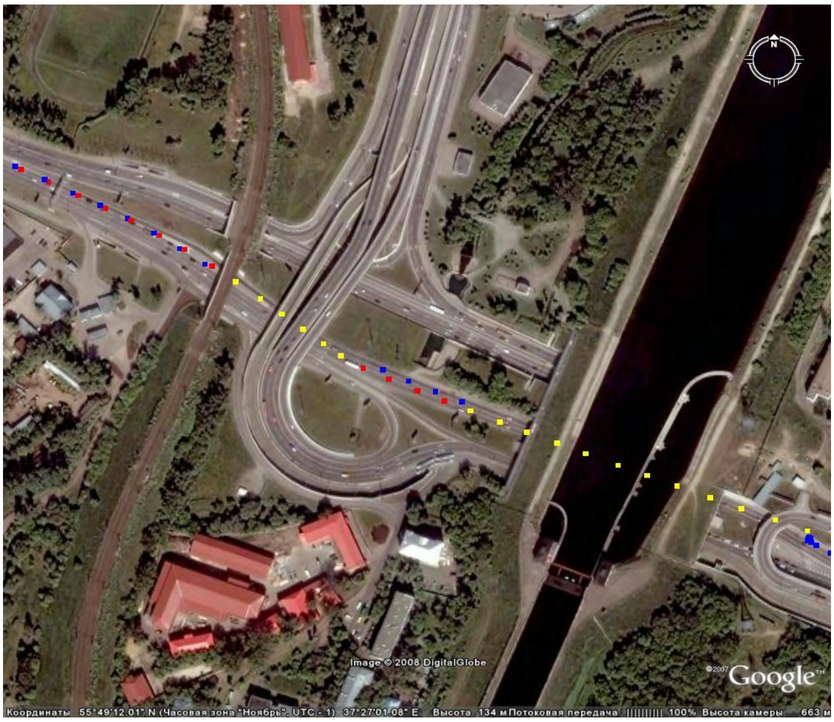


Fig. 7. Test results.

Conclusions. A concept of A-SMGCS is designed and its structure is suggested. The carried-out modeling and tests showed expediency of suggested solutions to A-SMGCS requirements according to Doc 9830 AN/452 ICAO.

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