UDC 629.056.8:629.735.05:621.396.933:629.783(045)

**Volodymyr Kharchenko**[1]
**Yurii Barabanov**[2]
**Andrii Grekhov**[3]
**Fedir Shishkov**[4]

# MODELING OF AIRBORNE COLLISION AVOIDANCE SYSTEM PERFORMANCE USING MATLAB

National Aviation University
Kosmonavta Komarova avenue 1, 03680, Kyiv, Ukraine
E-mails: [1]kharch@nau.edu.ua; [2]grekhovam@ukr.net; [3]brbnv@i.ua; [4]zloon@mail.ua

**Abstract.** *Original software for modeling of real-time TCAS operation was developed using MATLAB. The experimental model with data exchange between onboard systems via Wi-Fi network was created. This model was used for modeling of aircraft approaching. This model can be used as a base for creation a collision avoidance system of Unmanned Air Vehicles.*

**Keywords:** airborne collision avoidance system; modeling of aircraft approaching.

## 1. Introduction

In January 2005 the requirement of ICAO concerning installation of Airborne Collision Avoidance System ACAS-II came into force for all civil fixed-wing aircraft with the maximum certificated take-off mass exceeding 5700 kg or authorized to carry more than 19 passengers [ICAO…2007, PANS-OPS…2006, PANS-ATM…2007].

As a result, the number of aircraft equipped with ACAS-II significantly increased. ACAS II equipment, known as TCAS II (Traffic alert and Collision Avoidance System), is a security tool designed to prevent the collision of aircraft. To achieve the full benefits of TCAS II it is essential for pilots to comply accurately and swiftly with the recommendation of Resolution Advisory (RA). It is emphasized in the materials for the study of ACAS.

It is important for air traffic controllers and engineers to study ACAS-II and the real-time operation of onboard collision warning system.

## 2. Analysis of researches and publications

TCAS II system is an autonomous onboard collision avoidance system [Radio…1983, Radio…1990, Radio…1997].

TCAS II system should be switched on in areas of airspace in which the use of TCAS is required. In activated state TCAS system provides additional resource for collision avoidance with another aircraft, which have switched on transponders with Mode S. This defense is not ensured when transponders do not meet ICAO standards. The system is designed to provide safe separation of aircraft, trajectories of which indicate the probability of a collision, while minimizing the deviation from the proposed air traffic control flight course.

TCAS II system realizes continuous surveillance of airspace around its own aircraft transmitting active interrogations and receiving responses from transponders of the other aircraft in nearest vicinity.

TCAS II system recognizes responses from the aircraft transponders with ICAO Mode A, C, S and determines the range to the other aircraft, their relative bearing and relative altitude if the height indication is functioning. Using this information, the system predicts the trajectory, estimates distance in areas of nearest approaching and determines if there is a potential threat of a collision. In case of such threat the system issues instructions for performance of the optimal maneuver in the vertical plane to avoid the collision.

TCAS system receives also input signals from systems of its own aircraft and has information their state. This information is taken into account during analysis of conflicts.

TCAS system creates around its own aircraft defended airspace, which is called "collision zone".

Because TCAS system is designed in accordance with the principle of a calculation the time before a possible collision, than sizes and a shape of such zone is changing in accordance with approaching velocity of conflicting aircraft and its relative bearing. If a trajectory of conflicting aircraft will cross the collision zone, which surrounds a certain aircraft with TCAS II system, than this system will inform pilots about this event using visual and speech means of a warning.

Two types of an alert can be issued by ACAS II – warning about an air environment – Traffic Advisory (TA) and recommendations for elimination of a conflict situation – RA. These messages are aimed at maintaining or increasing vertical separation required for preventing the collision with conflicting aircraft.

With the objective of collision avoidance TCAS II monitors up to 50 aircraft, which are expected to enter the zone of collision.

TCAS II consists of a set of antennas on the aircraft, computing unit, Mode S transponder, indicators and control panel installed in the cockpit. In Fig. 1 a scheme of the system is shown.

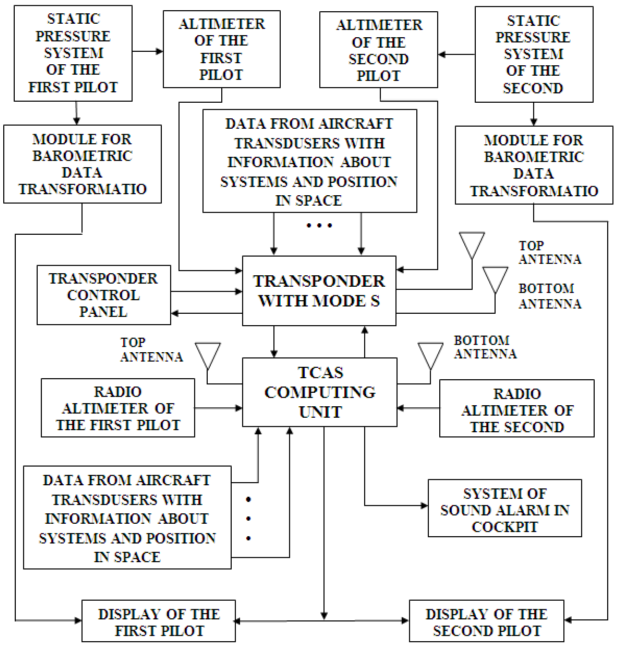


**Fig. 1.** TCAS system

The computing unit of TCAS II receives data from the aircraft instruments (radio altitude, barometric altitude, if the plane stays in the air or on the ground, as well as if landing gears are released). The computing unit interrogates transponders of other aircraft, computes their location, tracks their trajectory, indicates various warnings and recommendations on the display, and transmits voice messages to the pilot through voice warning systems located in the cockpit. The computing unit is the basis of TCAS II.

TCAS II system has Mode S transponder, which responses on interrogations of air traffic control radars with Mode A, C and Mode S, as well as interrogations of other aircraft equipped with TCAS. Each aircraft equipped with the Mode S transponder has its own unique ICAO address, allowing direct exchange of data with compatible systems.

An operation of TCAS II is simulated in a paper [Livadasy et al.] and conditions are determined under which the system guarantees adequate altitude separation for aircraft at risk of collision.

## 3. Aim of the work

The aim of this work is to develop software for modeling real-time operation of on-board collision avoidance system and to create an experimental model with data exchange between on-board systems.

## 4. Structure of ACAS II/TCAS II model

To simulate the real time work of the on-board collision avoidance system programming environment MATLAB was used. Model of TCAS system is shown in Fig. 2.

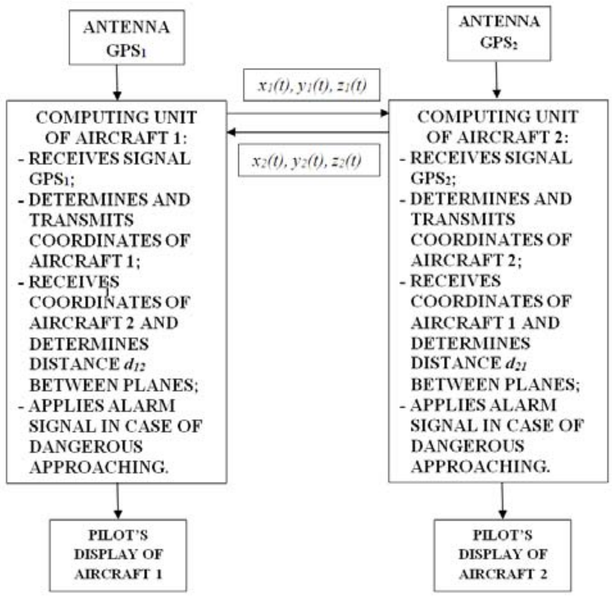


**Fig. 2.** Model of TCAS system

The position of aircraft is determined in the computing unit using data from GPS-receiver signals.

During the relative motion of planes their computing units estimate continuously in real time the relative distance between them and compare it with a given minimum acceptable value.

National Marine Electronics Association (NMEA) data format was used for writing the algorithm of the computing unit, in which the most important information about 3D aircraft position is contained in GGA sentence [NMEA data]. The example of GGA sentence:

$GPGGA,123519,4807.038,N,01131.000,E,1,08,
0.9,545.4,M,46.9,M,,*47
where:

GGA Global Positioning System Fix Data
123519 Fix taken at 12:35:19 UTC
4807.038,N Latitude 48 deg 07.038' N
01131.000,E Longitude 11 deg 31.000' E 1
Fix quality: 0 = invalid
1 = GPS fix (SPS)
2 = DGPS fix
3 = PPS fix
4 = Real Time Kinematic
5 = Float RTK
6 = estimated (dead reckoning) (2.3 feature)
7 = Manual input
8 = Simulation mode
08 Number of satellites being tracked
0.9 Horizontal dilution of position
545.4,M Altitude, Meters, above mean sea level
46.9,M eight of geoid (mean sea level) above WGS84 ellipsoid
(empty field) time in seconds since last DGPS update
(empty field) DGPS station ID number
*47 the checksum data, always begins with *.

The distance between aircraft is calculated using the Pythagorean Theorem, which takes into account the height of each aircraft and the distance between them on the ground. Distance to the Earth's surface was calculated using the 'haversine' formula [Calculate…]:

$$a = \sin^2(\Delta lat/2) + \cos(lat_1)\cdot\cos(lat_2)\cdot\sin^2(\Delta long/2)$$
$$c = 2\cdot atan2(\sqrt{a}, \sqrt{(1-a)}),\ d = R\cdot c,$$

where $R$ is Earth radius (6,371 km) and ellipticity of the Earth is not considered.

In the result of aircraft computing units work the warning is displayed about critical distance achievement (Fig. 3) when the relative distance is less than the given minimal acceptable value.

## 5. Simulation of aircraft approaching

Model of ACAS / TCAS (Fig. 2) has been implemented in a lab class on two computers which perform data exchange in real time according to pre-programmed algorithms in MATLAB environment using the Wi-Fi network [Wi-Fi…].

For simulation in a laboratory the relative motion of aircraft the model was modified (Fig. 4).

For this GPS-navigator eTrex was connected to one of the computers using a COM port [GARMIN…].

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

**COORDINATES OF AIRCRAFT 1**

**GPS RECEIVER TIME**

**DECIMAL LATITUDE**

**DECIMAL LONGTITUDE**

**ALTITUDE**

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

**COORDINATES OF AIRCRAFT 2**

**GPS RECEIVER TIME**

**DECIMAL LATITUDE**

**DECIMAL LONGTITUDE**

**ALTITUDE**

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

**DISTANCCE BETWEEN AIRCRAFT**

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

**WARNING!**
**CRITICAL DISTANCE IS REACHED!**

**Fig. 3.** Interface of the computing unit

From this port data in the NMEA format arrived from the navigator into a computing unit 1, which determined its own coordinates $x_1$, $y_1$, $z_1$.

These coordinates were transmitted in real time to the second computer, where a computing unit of aircraft 2 generated its coordinates in accordance with a given law, imitating the motion of the aircraft 2 relative to aircraft 1.

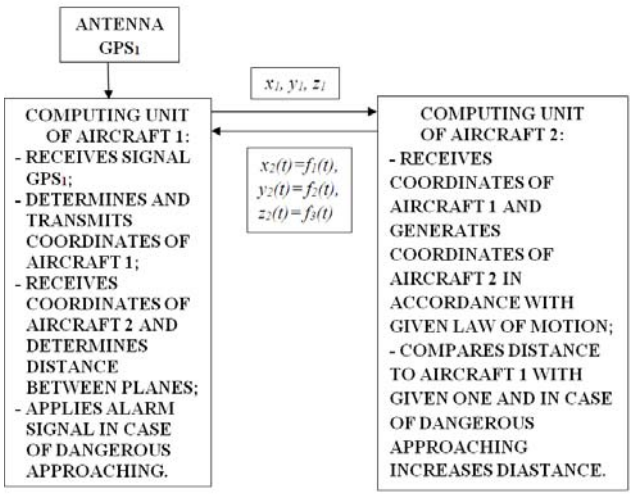


**Fig. 4.** Scheme of simulation of aircraft approaching
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

Variable in time coordinates of aircraft 2 were continuously transmitted via Wi-Fi in the computing unit of the aircraft 1. Both computing units were continuously estimating the relative distance between the aircraft and issued a warning when reaching given minimum acceptable value that can be set arbitrarily.

After an alarm the algorithm of a computing unit of aircraft 2 the law of a motion of the aircraft 2 is changing and planes began to "diverge" in space avoiding collisions.

Results of simulation for aircraft approaching at different speeds are presented in Fig. 5.

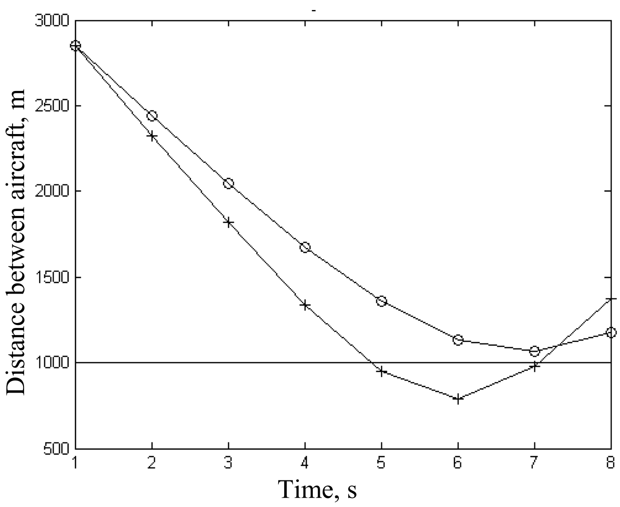


**Fig. 5.** Dependence of the distance between the aircraft on time: curve, marked by circles corresponds to the speed of approaching 412 m/s (1484 km/hour), and marked with crosses – 526 m/s (1893 km/hour)

Two aircraft from a distance of 2900 m begin to approach uniformly along the shortest path. The horizontal line shows the distance at which the computing unit triggers the alarm about the danger.

At lower speed of approaching the system "separates" aircraft without appearance of a warning and at higher speed - issues warning to pilots and aircraft begin to move away from each other.

If we assume that the coordinates are not processed every second, but every ten seconds, the curves in Fig. 5 will correspond to the speeds of approaching ten times lower. This case meet situation with Unmanned Air Vehicles.

## 6. Conclusions

1. Original software for modeling of real-time TCAS operation was developed using MATLAB.

2. The experimental model with data exchange between onboard systems via Wi-Fi network was created.

3. This model was used for modeling of aircraft approaching.

4. This model can be used as a base for creation a collision avoidance system of Unmanned Air Vehicles.

We thank V.V. Konin and O.S. Pohurelskii for consultations while writing the article.

**References**

*Calculate distance, bearing and more between Latitude/Longitude points*. http://www.movable-type.co.uk/scripts/latlong.html.

*GARMIN eTrex*. http://www.hwp.ru/Satellite/ Garmin.etrex/index.html

*ICAO Annex 10*. Vol. IV. Aeronautical Telecommunications - Surveillance and Collision Avoidance Systems, Fourth Edition, July 2007. http://www.eurocontrol.int/msa/public/standard_page/ACAS_ICAO_Provisions.html#manual

Livadasy, C.; Lygerosz, J.; Lynch, N.A. *High-Level Modeling and Analysis of the Traffic Alert and Collision Avoidance System (TCAS).* http://people.csail.mit.edu/clivadas/pubs/IEEE00.pdf.

*NMEA data*. http://www.gpsinformation.org/dale/nmea.htm.

*PANS-ATM*. Procedures for Air Navigation Services - ICAO Doc. 4444 Fifteenth Edition 2007-ATM/501. http://www.eurocontrol.int/msa/public/standard_page/ACAS_ICAO_Provisions.html#manual

*PANS-OPS*. Procedures for Air Navigation Services - Aircraft Operations - Volume I Flight Procedures - ICAO Doc. 8168 OPS/611, Fifth edition – 2006 plus Amendment 3. http://www.eurocontrol.int/ msa/public/standard_page/ACAS_ICAO_Provisions.html#manual

*Radio Technical Commission for Aeronautics (SC-147)*. Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System II (TCAS II) Airborne Equipment, Tech. Rep. RTCA/DO-185A, RTCA, Dec. 1997, Specifications of TCAS II version7.0.

*Radio Technical Commission for Aeronautics (SC-147)*. Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System II (TCAS II) Airborne Equipment, Tech. Rep. RTCA/DO-185, RTCA, Sept. 1990, Consolidated Edition, Specifications of TCAS II-6.04a.

*Radio Technical Commission for Aeronautics (SC-147)*. Traffic Alert and Collision Avoidance System (TCAS) I Functional Guidelines, Tech. Rep. RTCA/DO-184, RTCA, May 1983, Specifications of TCAS I.

*Wi-Fi Research Center*. http://www.networkworld.com/topics/wi-fi.html.

Received 19 September 2013.

**В.П. Харченко[1], Ю.М. Барабанов[2], А.М. Грехов[3], Ф.О. Шишков[4]. Моделювання роботи системи попередження зіткнень літаків у середовищі MATLAB**
Національний авіаційний університет, просп. Космонавта Комарова, 1, Київ, Україна, 03680
E-mails: [1]kharch@nau.edu.ua; [2]grekhovam@ukr.net; [3]brbnv@i.ua; [4]zloon@mail.ua
У середовищі MATLAB розроблено програмне забезпечення для моделювання в режимі реального часу роботи бортової системи попередження зіткнень. Створено макет з обміном даними між бортовими системами за допомогою Wi-Fi мережі. Розроблено модель для моделювання зближення літаків, яку можна використовувати як базову для створення системи попередження зіткнень для беспілотних літальних апаратів.
**Ключові слова:** моделювання зближення літаків; система попередження зіткнень літаків.

**В.П. Харченко[1], Ю.М. Барабанов[2], А.М. Грехов[3], Ф.О. Шишков[4]. Моделирование работы системы предупреждения столкновений самолётов в среде MATLAB**
Национальный авиационный университет, просп. Космонавта Комарова, 1, Киев, Украина, 03680
E-mails: [1]kharch@nau.edu.ua; [2]grekhovam@ukr.net; [3]brbnv@i.ua; [4]zloon@mail.ua
В среде MATLAB разработано программное обеспечение для моделирования в режиме реального времени работы бортовой системы предепреждения столкновений. Создан макет с обменом данными между бортовыми системами с помощью Wi-Fi сети. Разработана модель для моделирования сближения самолётов, которая может быть использована в качестве базовой для создания системы предупреждения столкновений для беспилотных летательных аппаратов.
**Ключевые слова:** моделирование сближения самолётов; система предупреждения столкновений самолётов.

**Kharchenko Volodymyr** (1943). Doctor of Engineering. Professor. Holder of a State Award in Science and Engineering of Ukraine. Winner of a State Prize of Ukraine in Science and Engineering.
Vice-Rector for Scientific-Research Work at the National Aviation University, Kyiv, Ukraine.
Head of the Department of Air Navigation Systems, National Aviation University, Kyiv, Ukraine.
Education: Kyiv Civil Aviation Engineers Institute with a Degree in Radio Engineering, Kyiv, Ukraine (1967).
Research area: management of complex socio-technical systems, air navigation systems and automatic decision-making systems aimed at avoidance conflict situations, space information technology design, air navigation services in Ukraine provided by CNS/ATM systems.
Publications: 400.
E-mail: knarch@nau.edu.ua

**Barabanov Yurii** (1951). Candidate of Engineering (1996). Associate Professor.
Department of Air Navigation Systems, National Aviation University, Kyiv, Ukraine.
Education: Dipl.-Military Radio Engineering Degree from High Military Engineering Aviation Institute, Kyiv, Ukraine (1973).
Research area: computer modeling of antennas, wireless and satellite communication networks, telecommunications, ADS-B systems.
Publications: 50.
E-mail: brbnv@i.ua

**Grekhov Andrii** (1951). Doctor of Physics and Mathematics (1990). Professor (1991). Expert of EUROCONTROL for ADS-B systems.
Department of Air Navigation Systems, National Aviation University, Kyiv, Ukraine.
Education: Physical Department of the Kyiv State Taras Shevchenko University, Ukraine (1973), M.Sc. Degree with Honors confirming qualification of Physicist Theorist.
Research area: air satellite communications and information channels, computer modeling of information flows transmission in airborne collision avoidance systems, ADS-B systems, onboard recorder and communication channels, surveillance processes and modern signal processing, expansion of terrestrial surveillance systems for ADS-B using satellite system IRIDIUM, noise resistant codind and forward error correction, aviation security assessment based on simulation.
Publications: 150.
E-mail: grekhovam@ukr.net

**Shyshkov Fedir** (1993). Student.
National Aviation University, Kyiv, Ukraine.
E-mail: zloon@mail.ua