MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL AVIATION UNIVERSITY
FACULTY OF AIR NAVIGATION, ELECTRONICS AND TELECOMMUNICATIONS
DEPARTMENT OF AVIONICS

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GRADUATION WORK

(EXPLANATORY NOTES)

FOR THE DEGREE OF MASTER
SPECIALTY 173 'AVIONICS'

Theme: 'Inertial sensors in remotely piloted aircraft systems'

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Kyiv 2020

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ
ФАКУЛЬТЕТ АЕРОНАВІГАЦІЇ, ЕЛЕКТРОНІКИ ТА ТЕЛЕКОМУНІКАЦІЙІ
КАФЕДРА АВІОНІКИ

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри
________Павлова С.В.
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ДИПЛОМНА РОБОТА

(ПОЯСНЮВАЛЬНА ЗАПИСКА)

ВИПУСКНИКА ОСВІТНЬОГО РІВНЯ МАГІСТР
СПЕЦІАЛЬНІСТЬ 173 'АВІОНІКА'

Тема: 'Інерціальні датчики для дистанційно пілотованих авіаційних систем (ДПАС)'

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Київ 2020

NATIONAL AVIATION UNIVERSITY

Faculty of Air Navigation,

Electronics and Telecommunications

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Speciality 173 «Avionics»

APPROVED

Head of department

S.V. Pavlova

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TASK

for execution graduate work

Student`s name: M. I. Vyhoniuk

1. The theme of bachelor work: «Inertial sensors in remotely piloted aircraft systems», approved by the Rector`s order on «09» September 2020 № 1435/ст.
2. Duration of which: 05.09.2020 – 15.12.2020.
3. Initial data for the thesis: existing problems of remotely piloted aircraft systems, general information about spatial sensors, the value of these in aviation.
4. The content of the explanatory notes (the list of note to be considered): Chapter 1. Research of remotely piloted aircraft systems as a control object; Chapter 2. Inertial navigation system for remotely piloted aircraft systems; Chapter 3. Reliability of INS with position sensors on remotely piloted aircaft systems; Chapter 4. Environmental protection; Chapter 5. Labor protection.

5. The list of mandatory graphic material: unmanned aerial vehicle (1917 y.) «Beetle» Kettering; b) Charles Kettering, 1976–1958 yy.; The first UAV remotely controlled by H.82B QueenBee (1933–1943 yy.); Reconnaissance aircraft Tu-143; Amazon drone Prime Air; Remotely piloted aircraft; RPAS tail unit (numbers 1-3 denote elerons); Benefits of using INS sensors for Remotely Piloted Aircrafts Systems; The principle of operation of the gyroscopic device; Internal construction of uniaxial accelerometer; Functional diagram of automatic flight control; Orientation of accelerometer axes; Kalman filter algorithm; Description of Kalman filter algorithm variables; Kalman filter for discrete form; Mathcad listing with Kalman filter calculation; Microengine failure data fit to a Weibull distribution; Microengine failure data fit to a lognormal distribution; There were two populations leading to bimodal distribution which coincide with the flexure type; Schematic representation of the system safety process step; 5M model of system engineering; SHELL model of a system; Integration of unmanned and manned aviation; Example of EMI; Representative EMI sources.
6. Planned schedule

№	Tasks	Duration	Performance note
1	Selection of literature	05.09 - 20.09	
2	Writing the first chapter	20.09 - 10.10	
3	Writing the second chapter	10.10 - 25.10	
4	Calculations	26.10 - 20.11	
	Writing the third chapter	19.11 - 27.11	

5			
	Writing the fourth chapter	27.11 - 10.12	
	Writing the fifth chapter	24.11 - 10.12	
	Conclusions	11.12 - 15.12	

7. Date of assignment: «05» September 2020

8. Supervisor ______________ O.V. Kozhokhina

The task took to perform ______________ M. I. Vyhoniuk

ABSTRACT

Explanatory note to the thesis «MEMS technology in the supersonic aviation transport»: 139 pages, 24 figures, 1 table, 8 formulas, 33 references, 3 appendix.

Key words: SENSOR, AVIATION SYSTEM, OPERATOR, CONTROL, AVIATION SECURITY, SPATIAL POSITION, INS, RPAS.

The purpose of the diploma thesis – is the development of a spatial position sensor to assess the characteristics of aviation system operators.

The object of the study – the object of this study is directly inertia sensor and how it can be applied on remotely controlled aircraft systems.

The subject of the study – is the RPAS furnished with new technology of inertia sensors.

The methodological principle – comparison, statistical analysis, work with expert groups.

Innovation of the project is the new use of the known technologies. The relevance of scientific work lies in the need for real time obtain the spatial position of aviation systems during the primary and secondary training of operators to manage the above systems.

This will not only get the characteristics of each operator and identify the patterns of its activities, but continue to predict the emergence systematic errors inherent in a particular operator. And further to promote their reduction, which will significantly affect the process of training operators aviation systems and help increase the level of aviation security in general.

CONTENT

LIST OF CONDITIONAL TERMS AND ABBREVIATIONS

RPAS – Remotely Piloted Aircraft Systems

UAV – unmanned aviation vehicle

INTRODUCTION

This report introduces the field of inertial sensors in the remotely piloted aviation systems (RPAS) and is divided into three main chapters.

In the first chapter, the reader is introduced to remotely piloted aircraft systems, its history, current and potential applications; also are described the fundamentals of inertial navigational technology, definitions of it and the development prospects. Human factor challenges and operational risks to manned aviation issues of RPAS are one of the main problems studied in this chapter.

This part describes the birth of RPAS application and its subsequent rise, fall, and revival in commercial transport through the past 50 years.

Drones are unmanned aerial vehicles that are either controlled by an operator remotely, or they move along a predetermined route. Now these devices are at the peak of their popularity. You shouldn't be surprised, because they can be used for entertainment, photography and video filming (including professional ones), military intelligence and surveillance of industrial systems.

Drones are not new to the 21st century. The first prototypes appeared not even in the 20th, but in the 19th century, when the “digital” did not yet exist. Copters of that time were able to participate only in test flights without further practical implementation. As it turned out, the systems have three main disadvantages:
very complex transmission, which must transmit torque from the engine to all rotors at once. She worked, but often broke.

The devices were not stabilized in the air in any way, so the slightest breath of breeze could disable the aircraft.

The advent of cameras and personal drones that are capable of moving away from the operator for many kilometers has raised a number of questions about the ethical side of working with "home" RPAS. After all, anyone could now look into the window of a neighbor, or the window of a neighboring company, directing the audio and video stream directly to their phone or computer. It became known about a large number of abuses when the owners of drones filmed what was happening in private homes, offices of commercial and government organizations. Drones fell on the heads of spectators at sports stadiums, and posed a threat to passenger aircraft and industrial facilities. A drone is almost an ideal tool for a spy, spy (commercial or government), anarchist, etc.

As a result, legislators in many countries have rushed to pass new laws to regulate the sale and operation of drones. Each country has its own laws, but in most cases, drone owners are prohibited from filming people without their explicit consent; RPAS cannot be used near airports, train stations, military and industrial facilities. In most cases, the drone cannot take off to an altitude of more than 150 meters, manufacturers set limits both on the distance covered by the drone and on the maximum speed.

This report deals with the emerging field of MEMS that are miniature devices, which integrate actuators, sensors, and processors to form intelligent systems. Functional sub-systems could be electronic, optical, mechanical, thermal or fluidic. MEMS are characterized by their close relationship to integrated-circuit components both in terms of manufacturing techniques and their potential for integration with electronics.

The second chapter deals with the Inertial Navigation system (INS) and a brief description of the basic sensing and actuation mechanisms of MEMS technology, which can determine and help to solve these electromagnetic interference problem caused by radiation.

Inertial navigation is used in a wide range of applications including the navigation of aircraft, tactical and strategic missiles, spacecraft, submarines and ships. The advances in the construction of microelectromechanical systems (MEMS) have made it possible to manufacture small and light inertial navigation systems. These advances have widened the range of possible applications to include areas such as human and animal motion capture.

An inertial navigation system includes at least a computer and a platform or module containing accelerometers, gyroscopes, or other motion-sensing devices. The INS is initially provided with its position and velocity from another source (a human operator, a GPS satellite receiver, etc.) accompanied with the initial orientation and thereafter computes its own updated position and velocity by integrating information received from the motion sensors. The advantage of an INS is that it requires no external references in order to determine its position, orientation, or velocity once it has been initialized.

An INS can detect a change in its geographic position (a move east or north, for example), a change in its velocity (speed and direction of movement) and a change in its orientation (rotation about an axis). It does this by measuring the linear acceleration and angular velocity applied to the system. Since it requires no external reference (after initialization), it is immune to jamming and deception. The burgeoning new technology of Micro-Electro-Mechanical Systems (MEMS) shows great promise in the weapons arena. It can be now conceived of micro-gyros, micro-surety systems, and micro-navigators that are extremely small and inexpensive.

MEMS has been identified as one of the most promising technologies for the 21st Century and has the potential to revolutionize both industrial and consumer products by combining siliconbased microelectronics with micromachining technology. Its techniques and microsystembased devices have the potential to dramatically affect of all of our lives and the way we live. If semiconductor microfabrication was seen to be the first micromanufacturing revolution, MEMS is the second revolution. That is why they are used in fabrication of different system needing for navigational purposes.

Inertial navigation systems are used in many different moving objects. However, their cost and complexity place constraints on the environments in which they are practical for use.

Gyroscopes measure the angular velocity of the sensor frame with respect to the inertial reference frame. By using the original orientation of the system in the inertial reference frame as the initial condition and integrating the angular velocity, the system's current orientation is known at all times. This can be thought of as the ability of a blindfolded passenger in a car to feel the car turn left and right or tilt up and down as the car ascends or descends hills. Based on this information alone, the passenger knows what direction the car is facing but not how fast or slow it is moving, or whether it is sliding sideways.

Accelerometers measure the linear acceleration of the moving vehicle in the sensor or body frame, but in directions that can only be measured relative to the moving system (since the accelerometers are fixed to the system and rotate with the system, but are not aware of their own orientation).

Onboard electronics equipment such as flight recorders, navigation units, flight-control systems, and radios are perfect examples of components that must comply with EMI shielding specifications. These devices are mission-critical, with the slightest interference potentially causing communication delays or misinformation presented to the crew or ground control staffs. Commercial aircraft observe similar safety requirements while including additional electronics such as in-flight entertainment units that utilize custom shielded display units.

EMI shielding is a crucial consideration in the safe and effective operation of electronic defense systems. Nearly every device developed for military and aerospace applications must utilize gaskets, coatings, adhesives, or a variety of other subcomponents in meeting rigorous military electronics standards.

The third chapter reviews the system safety process steps and most common standards of military and civil aviation. The huge part of the chapter consists in the studying of the reliability tests.

The primary objective of System Safety is accident prevention. Proactively identifying, assessing, and eliminating or controlling safety-related hazards, to acceptable levels, can achieve accident prevention. A danger is a condition, event, or circumstance that could lead to or contribute to an unplanned or unwanted event. Risk is an expression of the impact of an undesired event in terms of event severity and event likelihood. Throughout this process, hazards are identified, risks analyzed, assessed, prioritized, and results documented for decision-making

But reliability refers to the extent to which a scale produces consistent results, if the measurements are repeated a number of times. Reliability in scientific investigation usually means the stability and repeatability of measures, or the ability of a test to produce the same results under the same conditions.

All of the steps of the reliability tests presented in this diploma are data and discussions of the reliability experiments that were performed. The question that is needed to ask is “how do these MEMS devices fail?”, and ended with a focus on environmental effects. The wanted to find the answer for the question is the driving force of tests.

The first reliability test was performed on the Sandia microengine.

Below we describe the first-ever reliability stress test on surface micromachined microengines. It was stressed 41 microengines at 36,000 RPM and inspected the functionality at 60 RPM.

Also it have been observed an infant mortality region, a region of low failure rate (useful life), and no signs in the data of wearout. The majority of the failures were a result of lateral clamping of the comb finger actuation system. This clamping failure occurred before wearout could be observed. A design change preventing lateral motion of the shuttle was recommended.

CHAPTER 1
RESEARCH OF REMOTELY PILOTED AIRCRAFT SYSTEMS AS A CONTROL OBJECT

1.1.The Practical Value of Remotely Piloted Aircraft Systems

Copters (as civilian RPAS are called) are divided into groups by the number of engines: tricopters, quadcopters, hexacopters and octocopters, which have 3, 4, 6 and 8 engines, respectively. The range of models is very diverse, but the basic elements are few: a base frame, an electric motor with propellers and a flight controller. The most common is a quadrocopter - a drone driven by four beams with propellers.

Today, quadcopters are widely used throughout the world. They are viewed as useful equipment that greatly facilitates human activities. For example, there are drones for photographers and video operators, drones for detectives and couriers. In fig. 4 shows a modern drone adapted for filming.

The RPAS itself is only part of a complex multifunctional complex. Unlike manned aircraft, RPAS requires additional support system elements. These include the unmanned aerial vehicle itself, the operator's workplace, software, data transmission lines and elements necessary to fulfill the objectives of the flight. The range of use of unmanned aerial vehicles in the civilian sector is not limited, but with the current state of the legal framework for the use of airspace, it is difficult to fly. RPAS farms can be used in the following areas:

- For conducting prospecting work;
- Performing geological exploration;
- Aerial survey of areas;
- Performance of aerial chemical work;
- Monitoring territories and objects;
- Monitoring of territories and objects;

- Conducting video surveillance.

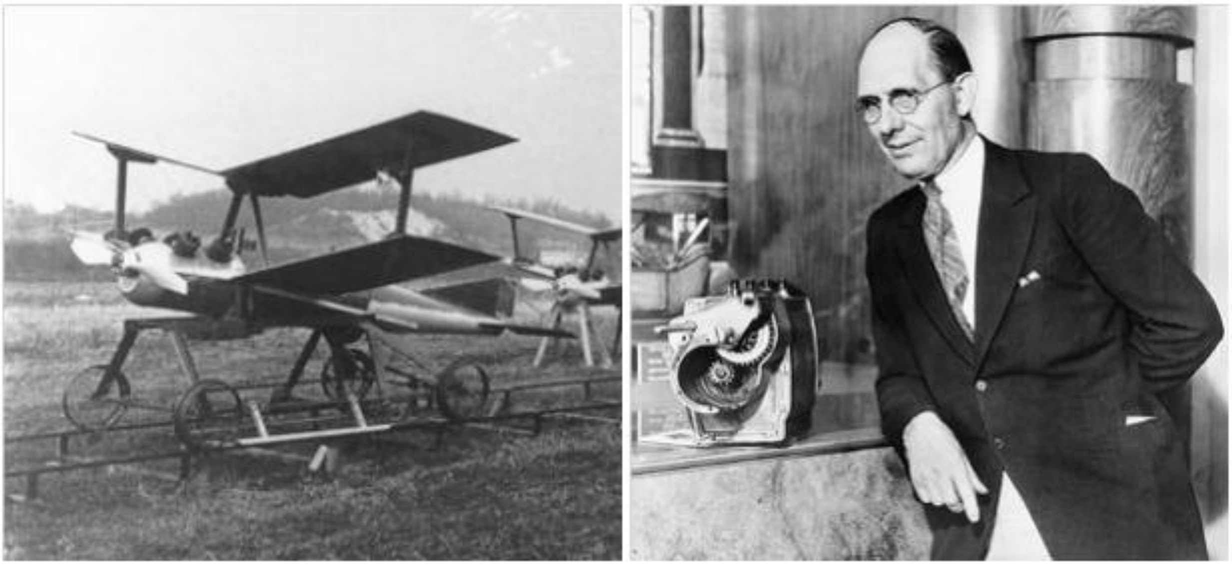
Unmanned aerial vehicles have a number of advantages:

Firstly, to perform the same tasks, light unmanned vehicles cost much less than manned aircraft, which need to be equipped with life support systems, protection, air conditioning, etc. Pilots need to be trained, it costs a lot of money. As a result, it turns out that the absence of a crew on board significantly reduces the cost of completing a particular task, and the useful load of the aircraft also increases. Secondly, lightweight (compared to manned aircraft) drones consume less fuel, and thirdly, unlike manned aircraft, unmanned aircraft need concrete-paved airfields. Most aerodromes are in need of reconstruction, the pace of repairs today do not have time to keep track of the availability of runways. Fourth, an important advantage when using automatic and semi-automatic control systems can be considered the elimination of the human factor in the performance of the task.

Remotely Piloted Aircraft Systems (RPAS) are widely used in the civil sphere. They offer capabilities predisposed them to be employed by state services in ensuring security and public order, as well as in commercial activities. It should be assumed that the number of RPAS users will grow in geometric progression. It also applies to the European Union, where the market of RPAS is considered to be one of the most prospective in the development of small and medium-sized enterprises. This situation generates specific problems that should be solved in order to develop the RPAS' market without limitations as a part of the European aviation system. The final state should be full integration of RPAS into the European aviation system, to conduct flight operations in non-segregated airspace without additional administrative constraints. Some efforts have been made to achieve this ambitious goal in the European Union.

The scope of unmanned aerial vehicles (UAVs), including remotely piloted aircraft (RPVs), is expanding uncontrollably. In military use, RPVs have proven their indispensability in modern armed conflicts and special operations, in particular in Iraq, Afghanistan, Yemen and others [1]. If earlier RPVs were means of artillery reconnaissance and participated in operations to determine the ownership of troops, now RPVs, which have complex sensor systems on board and are capable of using the latest weapons, are used at all levels of combat operations.

For the first time, the idea of radio-controlled objects was implemented by the famous engineer-inventor Nikola Tesla, who in 1889 demonstrated the first radio-controlled boat to the public. But in the future, the next objects were not ships, but unmanned aerial vehicles, proposed in 1910 by the British military engineer C. Kettering (Fig. 1). He designed and stuffed an apparatus with explosives, which was controlled by a clock mechanism, and later an unmanned aircraft-projectile, which remained only an experienced one [2]. 2. Идее ударного беспилотника исполнилось сто лет. URL: http://lenta.ru



a) b)

Fig. 1.1. a) unmanned aerial vehicle (1917 y.) «Beetle» Kettering; b) Charles Kettering, 1976–1958 yy.

The beginning of the development and use of UAVs is considered to be 1933, when British engineers created a reusable radio-controlled UAV. It was created on the basis of the Fairy Queen biplane and served until 1943 for training military pilots as a target aircraft (Fig. 2) [3]. 3. Kettering_Bug.

Fig. 1.2. The first UAV remotely controlled by H.82B QueenBee (1933–1943 yy.)

During World War II, radio-controlled projectiles were created in many countries - in Germany FAU-1 and FAU-2, in the USSR the heavy TB-3 bomber was successfully used as an unmanned vehicle to blow up bridges. After the war, 15,000 Radiophone drones were created in the United States, but widespread use for military and civil purposes began only at the beginning of the new century.

Further, drones were used mainly by the military. Among other models, it is worth mentioning the Ryan Model 147E reconnaissance aircraft, developed in the United States and used in Vietnam, the Soviet drones Tu-123, Tu-141 and Tu-143. These are all large aircraft, which are roughly the same size as aircraft with comparable functionality.
The idea of a military drone gave impetus to the development of civilian UAVs - copters, which today are used not only for entertainment, but also as assistants in many areas of life, such as journalism, sports, courier service, oil industry, agriculture, environmental service, rescue service. medicine, etc. Since 2000, there have been many reports of the use of civilian drones, the use of which is gradually becoming commonplace [4]. In fig. 3 shows Reconnaissance aircraft Tu-143.

Fig. 1.3. Reconnaissance aircraft Tu-143

In 1982, radio-controlled drones developed by the Israelis came into play. They were used during the Lebanese War. The IAI Scout and Tadiran Mastiff were most commonly used. They were developed from scratch; they were no longer airplanes converted for autonomous flight. Their wingspan was no more than five meters, and their weight was about 100 kg. It was possible to reduce the size of drones thanks to the emergence and development of semiconductor electronics, which led to the miniaturization of both household and military equipment.

And then other countries, including the United States, began to produce ultra-modern military drones like the MQ-1B Predator and MQ-9 Reaper, capable of transmitting surveillance data in real time. Some models of such drones are also able to shoot at targets, and with missiles.

From about the second half of the 20th century, such a direction as household radio-controlled drones began to develop actively. Initially, these were completely DIY-models, which were simulated aircraft. But then the business, seeing the demand for radio-

controlled aircraft, took the initiative into their own hands.
However, despite the development of UAVs in the military sphere, one should not forget about the civilian use of these devices. First, more and more such devices appear every year. Secondly, some of the devices developed by private companies are more technologically advanced due to their narrow specialization and small production volumes, which allows engineers to more quickly respond to changes in the consumer market.

The history of the development of civilian drones is much shorter than that of their military ancestors, because the first civilian drones appeared only in 2000 and differed significantly from their predecessors, but the pace of development of this separate branch is much more impressive. Already in the United States, lawmakers are seriously concerned, and at this time, startups appear more and more often, offering to produce not only large unmanned aircraft, but also drones for everyday use.

One of the most striking examples at the moment is the project of the American company Amazon. So, in December last year, the head of Amazon Jeff Bezos promised his users a truly futuristic option for the delivery of goods purchased through their online store. Bezos's plan is that if you are no more than 15 km from the company's warehouses and made a purchase, then in just half an hour a drone will land on your doorstep and leave a package. Sounds entertaining to say the least. Another condition for such an undertaking is the weight of the parcel, which should not be heavier than 2 kg (by the way, more than 80% of Amazon orders weigh less than this figure).

Fig. 1.4. Amazon drone Prime Air

1.2. The Composition Of The RPAS Onboard Equipment

To ensure the tasks of observation of the underlying surface of the Earth in real time during the flight and digital photographing of selected terrain areas, including hard-to-reach areas, as well as determining the coordinates of the investigated areas of the terrain, the payload of the UAV should include:

- Satellite navigation system (GLONASS / GPS);
- Device for command and navigation radio link with antenna-feeder device;
- Device for exchange of command information;
- Board digital computer.

The built-in power supply provides voltage and current matching of the on-board power supply and devices that make up the payload, as well as operational protection against short circuits and overloads in the power grid.

Depending on the UAV class, the payload can be supplemented with various types of radar stations (radar), environmental, radiation and chemical monitoring sensors.

The UAV control complex is a complex, multi-level structure, the main task of which is to ensure the withdrawal of the UAV to a given area and the execution of operations in accordance with the flight task, as well as to ensure the delivery of information received by the onboard UAV means to the control point.

UAV control is carried out on the basis of the controller ArduPilot mega2560 [2] designed for use in autonomous aircraft, cars or ships. The onboard complex "Ardupilot" is a fully functional means of navigation and control of an unmanned aerial vehicle of an airplane scheme. Onboard complex "Ardupilot" is a full-featured navigation and control tool for an unmanned aerial vehicle Support complex: determination of navigation parameters, orientation angles and parameters of UAV movement (angular velocities and accelerations); navigation and control of the UAV along a given trajectory; stabilization of the orientation angle of the UAV in flight; delivery to the transmission channel of telemetric information about navigation parameters, UAV orientation angles. The central element of the Ardupilot airborne complex (BC) is a small-sized inertial navigation system (INS) integrated with a satellite navigation system receiver. The system is built on the basis of microelectromechanical sensors (gyroscopes and accelerometers) according to the ANN principle, it is a unique high-tech product. A built-in static pressure sensor provides dynamic altitude and vertical speed sensing.

BC composition: block of inertial navigation system; satellite navigation system receiver (SNS); autopilot unit; flight data accumulator; airspeed sensor.The complex is compatible with the PCM radio channel (pulse-code modulation) and allows you to control the UAV both in manual mode from a standard remote control, and in automatic mode, according to the autopilot commands. Autopilot control commands are generated in the form of standard pulse width modulated (PWM) signals suitable for most types of actuators. Physical characteristics:

Dimensions and weight:

- autopilot unit, mm-40 x 72 x 20;
- weight, kg -0.135. Electrical characteristics:
- supply voltage, V-10 ... 27;
- power consumption (max.), W -5.

Environment:

- temperature, degrees C -from minus 40 to plus 70;

- vibration / shock, g -20.

This is a fully programmable autopilot board, by connecting a GPS module and sensors, you can get a fully functional electronic control unit for unmanned aerial vehicles (UAVs). The autopilot is able to simultaneously stabilize flight and control navigation, eliminating the need for a separate stabilization system. The autopilot supports "fly-by-wire" mode. The board is designed on the basis of a 16MHz microcontroller Atmega. Communication with the controller is carried out using an analog receiver "HiTEC RCD 9500".

ArduPilot was chosen because of the ability to freely correct the code and make changes to the algorithm. Also one of the reasons is the availability on the market. Automatic takeoff and landing facilitates control. There is also full support for Xplane [3] and Flight Gear [4] simulators. Atmega specifications:

- Digital Inputs / Outputs 54;
- Analog inputs 16;
- Clock frequency 16 MHz.

Equipment includes the following:

- three-axis gyroscope;
- three-axis accelerometer;
- Barometric pressure sensor for altitude determination;
- 10Hz GPS module; -Battery voltage monitoring;
- 16Mb memory kit for storing flight logs. Tasks will be automatically recorded and can be exported to KML.
- Ability to automatically return to the starting point when the signal is lost;
- Relay for turning devices on and off according to a script;
- 3-axis compass (magnetometer) HMC5883L.

1.3. Description of the Research Object

The UAV belongs to the "mini" class, since it has a mass of about 4 kilograms (Fig. 1.5). According to the calculated characteristics, the aircraft will be able to stay in the air for at least two and a half hours, in the "hover" mode - up to 30 minutes. The nominal altitude is 1 kilometer.

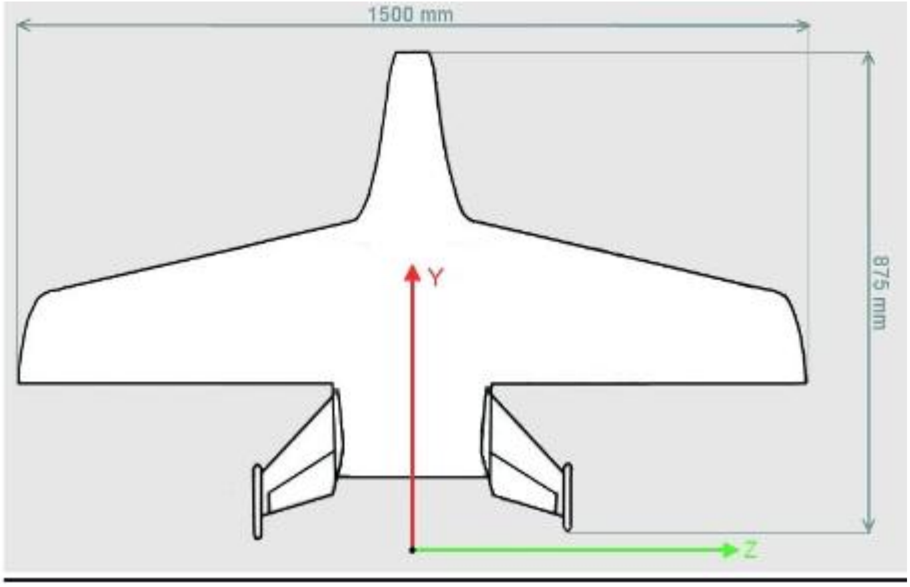


Fig. 1.5. Remotely piloted aircraft

The initial geometric parameters of the investigated RPAS are presented in table 1.1.

Table 1.1.

Wingspan, m	1.2
Aircraft length, m	0.875
Aircraft height, m	0.24
Wing area, m2	2.02
Average aerodynamic chord length, m	0°
Cross V wing	13°
Wing angle	0.286
Elerons square	NACA-W-5 68009[8]
Wing profile	0.12
middle section area, m2	
Weight, kg	3.06
- Empty airplane	8
- maximum takeoff	Electrical
Engine type	2.2

power, kWt	200
Maximum speed, km / h	150
Cruising speed, km / h	400
Practical range, km	2500
Practical ceiling, m	5 kg

By design, the UAV can be classified as a vertical takeoff and landing aircraft (VTOL) or English VTOL — Vertical Take-Off and Landing — an aircraft capable of taking off and landing at zero horizontal speed using engine thrust. The fundamental difference between VTOL aircraft and various rotary-wing aircraft is that in the horizontal flight mode at cruising speed, as in the traditional aircraft, the lift is created by a fixed wing.

Piloting this type of vehicle is very difficult for the pilot and requires him to be highly skilled in piloting technique. This is especially true in flight in the "hover" and transient modes — at the moments of transition from "hover" to horizontal flight and back. In fact, the VTOL pilot must transfer the lift, and, accordingly, the weight of the machine - with the wing-vertical streams of the engine thrust jet or vice versa.

This feature of the piloting technique poses difficult tasks for the VTOL pilot. In addition, in hovering and transient modes, VTOL aircraft are generally unstable, prone to side slip, a great danger at these moments is a possible failure of lifting motors. Such a refusal was often the cause of accidents in serial and experimental VTOL aircraft. Also, the disadvantages include the significantly lower carrying capacity and flight range of the VTOL aircraft in comparison with the conventional aircraft, the high fuel consumption in vertical flight modes, the overall complexity and high cost of the VTOL aircraft design. What makes the aircraft of this design more difficult to design and operate.

Aircraft operation requires automatic control algorithms for two modes: "hover" and "flight along a trajectory". The hover mode allows the aircraft to take off vertically using the forward engine thrust backward altitude and stay there for a specified period of time, or immediately transfer the aircraft to a horizontal position. And the mode of "flight along the trajectory" allows you to control the aircraft at normal cruising speed as a conventional aircraft, lifting force is provided by the fixed wings of the aircraft. To carry out these maneuvers, a complex automatic control system (ACS) with the ability to switch to manual mode during takeoff and landing is required.

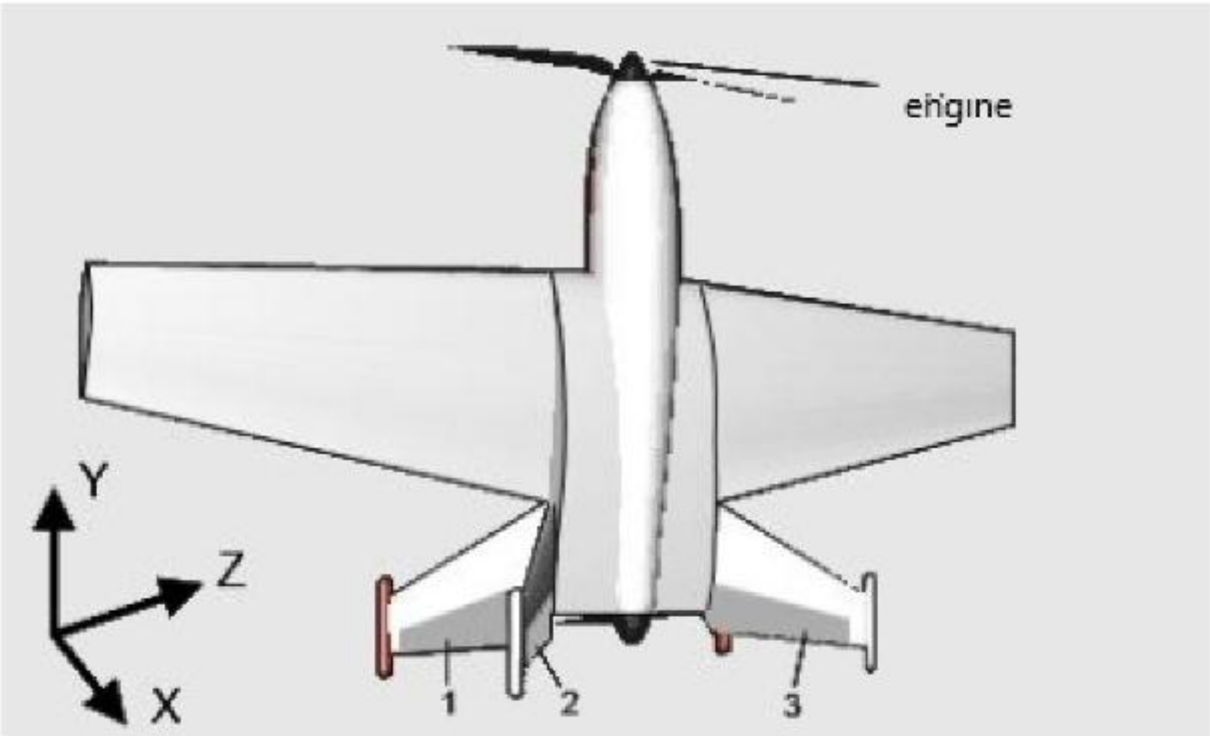


Fig. 1.6. RPAS tail unit (numbers 1-3 denote elerons)

The UAV, like most aircraft of the classical design, has two wings connected to the aircraft fuselage, which provide lift. However, these fenders do not have smaller wing arms.

In classical control schemes, the rudder, the elevator (aerodynamic control of the aircraft that rotates around the transverse axis) and ailerons (aerodynamic controls, symmetrically located on the trailing edge of the wing consoles of the classic airplanes [9]) are used, which are designed to create control moments around the three orthogonal axes of the aircraft.

The tail unit of the UAV consists of four wing-elerons (aerodynamic aircraft controls, symmetrically located on the trailing edge of the wing consoles) (Fig. 1.6), located perpendicular to each other at an equal distance from each other, in the form of a cross. Elevons play the role of ailerons when controlling the roll angle (rotation of the object around its longitudinal axis) of the aircraft, and the elevator when controlling normal overload in pitch (angular movement of the aircraft relative to the main transverse axis) and yaw (the angle of rotation of the aircraft body in the horizontal plane). To control the roll angle of the aircraft, the elevons deviate differentially, that is, for the aircraft roll to the right, the right elevons rotate up, and the left — down; and vice versa. The in-phase deflection of elevons allows you to control the normal overload of the aircraft, that is, to increase the pitch of the aircraft in horizontal flight, all the elevons rise up. Such control of the aircraft creates great difficulties for manual piloting, so it was proposed to develop an algorithm for controlling the UAV.

1.4. Conclusions

The past 60 years have seen the rise and fall of supersonic commercial aircraft. Challenges of supersonic flight seemingly reduced supersonic travel to wishful thinking. However, while SST was on the backburner, NASA's High-Speed Research, among others, continued the advancement of supersonic technology and today we are equipped with tools well beyond the infancy of Concorde's time. Now a revival of supersonic transport aircraft is starting to be seen in companies like Boom Technologies, and Aerion with its supersonic business jet collaboration with Airbus. Along with these independent companies, NASA continues to push on that sound barrier with projects like QueSST working towards diminishing the sonic boom. As technology continues to advance, and man's thirst to break the boundaries of what is possible gets stronger, maybe it will be possible to fly from Seattle to Tokyo, conduct your business, and fly home, perhaps not. The biggest challenge for supersonic transport may not be muffling the sonic boom or creating a magically efficient engine. No, breaking the sound barrier was the easy part. Making it profitable is the real challenge.

Another problem is the heat generated by friction as the air flows over the aircraft. Most supersonic designs use aluminum alloys such as Duralumin, which are cheap and easy to work but lose their strength quickly at high temperatures. This limits the maximum speed to around Mach 2.2.

The problems associated with the thermal barrier should be addressed in a comprehensive manner. Any progress in this area pushes the barrier for this type of aircraft towards greater flight speed, not excluding it as such. However, the pursuit of even higher speeds leads to the creation of even more complex structures and equipment that require the use of higher-quality materials. This is noticeably reflected in the mass, the purchase price and the costs of operating and maintaining the aircraft.

CHAPTER 2
INERTIAL NAVIGATION SYSTEM FOR REMOTELY PILOTED AIRCRAFT SYSTEMS

2.1. Inertial Navigation System (INS)

An Inertial Navigation System (INS) is a device, which computes the real-time state of a moving vehicle using motion sensors. By state, we mean the position, velocity, and orientation of the vehicle. An INS can be used either as an isolated unit to provide continuous state information to a pilot or in conjunction with a control system for autonomous movement. INSs are widely used in military and commercial projects and have been under constant development and revision for several decades, but it is only recently that the technology has been accessible to hobbyists. An INS can be logically decomposed into an Inertial Measurement Unit (IMU), which measures instantaneous accelerations or velocities in the body frame, and a state update system, which uses the IMU values to update the position, velocity, and orientation of the vehicle in the navigation frame. [16]

There are several different ways to design an IMU, and the particular design chosen is often the driving factor in the cost of the entire INS. The recent proliferation of MEMS sensors has enabled the construction of low-cost IMUs with a tradeoff of reduced accuracy. MEMS IMUs generally require three orthogonal measurements of acceleration and three measurements of rotational velocity around the same orthogonal axes. Accelerometers and gyroscopes respectively can produce these measurements. Both use micromachined surface capacitors to measure forces, whether due to acceleration or the Coriolis effect.

One of our primary goals for the INS was to use position sensors components. There are many choices for particular MEMS sensors. We considered the following parameters before deciding on the specific sensors:

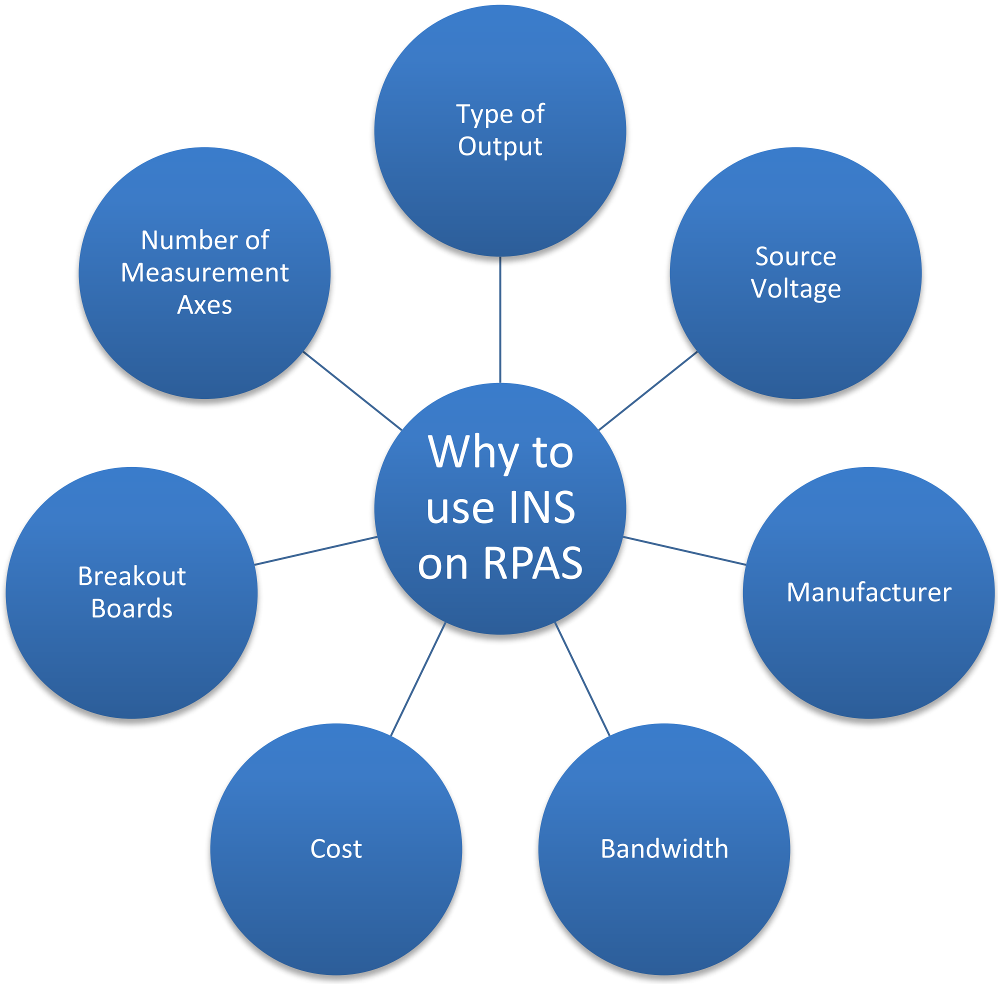


Fig. 2.1. Benefits of using INS sensors for Remotely Piloted Aircrafts Systems

Fig. 2.1 shows us the main characteristics of benefits using MEMS technology for INS. Let us check below each of these advantages:

– A number of Measurement Axes. Many manufacturers have created two or three-axis accelerometers and gyroscopes. These are tremendously useful as they reduce the required number of chips and supporting passive components, and eliminate misalignment errors.

– Breakout Boards. To eliminate the difficulty of soldering various packages and to speed up prototyping time, it is convenient for the sensors to come mounted on a breakout board. These boards also usually provide the necessary filtering capacitors.

- Source Voltage. The input voltage to the sensors must be within the range of our source, and it is most convenient if it is exactly equal to the source voltage. Our primary source voltage was 5V from a regulator. Many sensors require a nominal 3.3V or 3V input.
- Type of Output. MEMS sensors generally provide either digital or voltage proportional analog output.
- Cost. We wanted to keep costs as low as possible. One can pay hundreds of dollars for more accurate sensors, but these are out of our budget range.
- Bandwidth. Different sensors have different bandwidths. For moderate to very accurate systems, the bandwidth is an important factor to consider. However, for our project, this constraint was less important than the others.
- Manufacturer. Not all manufacturers provide the same quality products and datasheets. [17]

2.2. Spatial Sensors Application

Piloting the aircraft in blind flight, ie in the absence of visibility of the ground, is possible only in the presence of devices that indicate the pilot position of the vessel in space. The position of the aircraft in space is determined by three main angles: roll, pitch and true course.

A massive flywheel (rotor) driven in rapid rotation around its axis of symmetry has properties different from the properties of a stationary flywheel. The new properties are manifested only if the axis of rotation of the flywheel has the ability to rotate in space, ie if the flywheel has more than one degree of freedom.

A device in which a rotor that has more than one degree of freedom rotates rapidly around its axis of symmetry is called a gyroscope. The gyroscope can have two or three degrees of freedom, depending on how the rotor suspension is arranged.

Gyroscope - a device capable of responding to changes in the orientation of the base on which it is mounted relative to the inertial space.

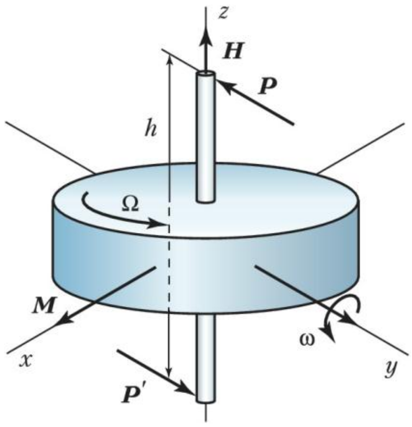


Fig. 2.2. The principle of operation of the gyroscopic device

The angular velocity of the precession can be calculated by the formula:

$$\omega_p = \frac{L}{H} \quad (1)$$

, where L is the moment of external force; H is the kinetic moment of the gyroscope.

An accelerometer is a device that measures the projection of an apparent acceleration onto one or more axes, called the axes of sensitivity. The term seeming acceleration should be understood as acceleration due to the sum of all forces applied to the object, except gravity. The term is mainly used in navigation systems. If only the force of gravity acts on the accelerometer, it will measure the acceleration of free fall, because under the action of this force, the sensing element will deviate from equilibrium.

There are several types of accelerometers, which differ in the sensitive elements and the principles of conversion of a physical quantity into an electrical signal. In order to better understand the principle of operation of the accelerometer, it should be presented as a load mounted on springs. The principle will be the same - there is a displacement of the sensitive element under the action of any force. In Fig. 2.3. presents a block diagram of a uniaxial accelerometer [3].

It should be noted that the accelerometer can be found in the design of unmanned devices. Due to the operation of the sensor, the control of the plane of movement of the device is carried out. This greatly facilitates remote control, especially if the device is out of sight. The presence of the accelerometer avoids the wrong direction of movement of the device, and also allows it to automatically return to the starting point if the control was lost or the corresponding button was pressed.

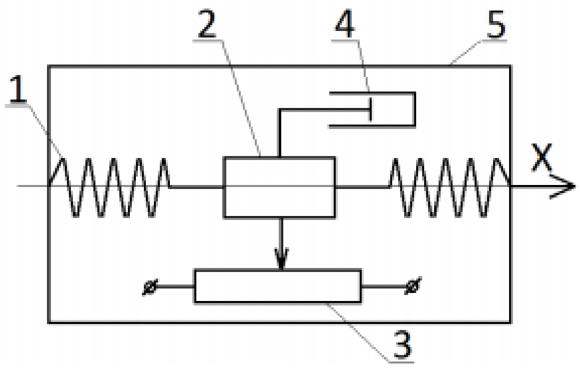


Fig. 2.3. Internal construction of uniaxial accelerometer. Where 1 - spring, 2 - sensing element, 3 - potentiometer, 4 - damper, 5 - housing

2.3. Classification of aerodynamic schemes of RPAS

Today in Ukraine there is no generally accepted classification of RPAS. The Missiles.UA website [5] together with Uav.UA [6] offers a modern classification of aircraft-type RPAS, developed on the basis of the approaches of the RPAS International [7] organization, taking into account the specifics and situation of the Russian market. The proposed classification includes the following categories:

- micro and mini RPAS of short range (takeoff weight up to 5 kg, range 25 ... 40 km);
- light RPAS of short range (takeoff weight 5 ... 50 kg, range 10 ... 70 km); -
- light RPAS of medium range (takeoff weight 50 ... 100 kg, range 70 ... 150 km);
- medium RPAS (takeoff weight 100 ... 300 kg, range 150 ... 1000 km);
- medium-heavy RPAS (takeoff weight 300. ..500 kg, range 70 ... 300 km);
- heavy RPAS of medium range (takeoff weight over 500 kg, range 70 ... 300 km);
- heavy RPAS of long duration of flight (takeoff weight over 1500 kg, range of about 1500 km);
- unmanned combat aircraft (takeoff weight more than 500 kg, range of about 1500 km).

2.4. Determination of Requirements for ACS

During the control of the aircraft movement, aerodynamic forces and moments arise. The pitch, yaw, and thrust roll angles of the engine are used as regulating factors that allow influencing the aircraft to control its movement.

UAV as a control object is a complex dynamic system due to the presence of a large number of interconnected parameters and complex cross interactions between them. Complex movements are often divided into the simplest types: angular movements and movements of the center of mass, longitudinal and lateral movement. The governing bodies creating control actions can be divided into two groups:

- longitudinal controls, providing movement in the longitudinal plane;
- lateral movement controls, providing the necessary character of the change in the angles of roll, slip and yaw.

Such a division of controls is conditional, since it is possible to bring flight modes in which the controls have cross effects on other movements. At the same time, this approach makes it possible to single out the main functions of specific bodies and control channels and independently solve many relatively simple and practical tasks.

To ensure complete automation of flight control, four control channels are required:

- engine control (thrust) channel;
- a pitch control channel;
- a roll control channel;
- a yaw control channel.

The engine control channel controls the thrust in accordance with the specified flight program. The next three control channels provide the required angular position of the apparatus in space.

Information about the movement of the UAV enters the appropriate channels, where commands are generated for the rudders, ailerons and the engine control lever, which provide the specified flight control. Stable flight control is impossible without creating an automatic control system of an acceptable quality.

The aircraft control system is used to ensure flight along a given trajectory by creating the required aerodynamic forces and moments on the wing and tail [10]. There are three types of control systems - manual, semi-automatic and automatic.

In the manual control system, the pilot-operator, evaluating the situation, generates control impulses and, using the command levers through the control panels, deflects the steering surfaces, keeping them in the desired position. In a semi-automatic system, the pilot-operator control signals are converted and amplified by various types of automatic machines and amplifiers, providing optimal stability and controllability characteristics of the aircraft.

Automatic systems provide complete automation of individual flight phases, freeing the operator-pilot from direct participation in aircraft control. In the process of adjusting control by the angles or altitude of the aircraft flight in the automatic system, the desired values of the angles or altitudes are fed to the controller input, and the controller output variables will deflect the aileron angles along the pitch, roll and yaw channels.

Requirements for the control system:

- minimal time of the transient process,
- absence of overshoot (aperiodic process).

It is necessary that the control system provides the given parameters of the transient process.

Actuators are an integral part of LBLA automatic motion control systems. The inclusion of mathematical models of these devices in the control object makes it possible to take into account their dynamic and static properties.

The actuating drives of the steering bodies are selected from the condition that their load characteristics provide the necessary dynamics of control processes, in other words, they are required to ensure movement at a given speed of the steering body loaded by external forces or external moments.

Figure 2.4 shows a simplified scheme for regulating control channels and engine thrust. Ul and U2 denote respectively the motion state vectors of the actuators, which are the input signals of the individual control channels. The diagram also shows the cross effects of the control channels. On the basis of the data obtained, the control regulatory actions to the aircraft are sent from the ACS through the vectors δ1 and δ2.

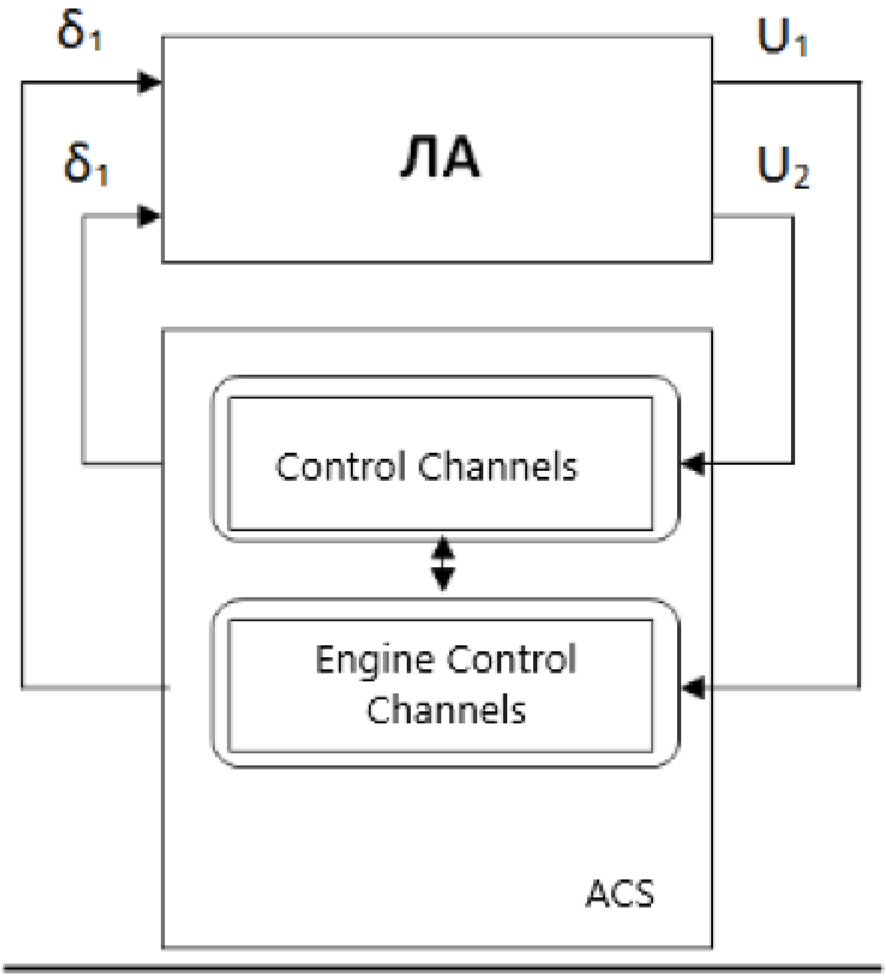


Fig. 2.4. Functional diagram of automatic flight control

For the UAV under consideration, the classical regulation of control channels is not suitable, due to the non-standard flight control design. There is a need to broadcast the standard control system through the channels to control the four ailerons. Based on this, the problem arises of compiling algorithms for controlling four elerons on the roll, pitch and yaw channels. The main task is to create a fully automatic ACS that will regulate the deviations of the control surfaces for the aircraft flight along the desired trajectory.

Already, manned aircraft are far more expensive than drones, both in terms of maintenance and production. While conventional aircraft require protection and life support systems for pilots, an unmanned aerial vehicle costs little. Last but not least, there are the costs of training and pilot training, which takes much more time than UAV operator training.

Unmanned aerial vehicles consume much less fuel due to their weight, while the possibility of using alternative fuels is not excluded. So, for example, in the opinion of the overwhelming majority of aircraft designers, it is possible to switch to cryogenic fuel, which is used by spacecraft.

While a manned aircraft must be landed on a huge landing pad, the drone freely lands on a small runway no more than 600 meters, not to mention micro drones that can even land on the doorstep or windowsill.

Supersonic flight's high speeds inherently cause problems in aircraft design, for both the airframe and engine. First and foremost, aerodynamics requires a long, slender airframe in order to reduce drag and make flight efficient. As mentioned before, flying at high Mach numbers increase the temperature on the airframe due to friction, and shock formation occurs. Because supersonic vehicles travel at high speeds and altitudes, engines must provide more thrust than a commercial aircraft while minimizing NOx emissions in order to be viable. Engine inlets must be aerodynamically efficient and must be designed to handle the required mass flow at supersonic cruise and subsonic speeds. Often times a variable geometry inlet is required, especially when cruising above Mach 1.6.

The complexity in design leads to high costs of manufacturability, which compounded with fuel costs, drives ticket prices for supersonic travel somewhere near the 5-10 thousand dollar price. The following describes what is being done to overcome the design challenges faced when designing a supersonic aircraft.

2.4. Conclusion

Various methods are currently being investigated, including the application of an insulating layer of refractory materials by plasma spraying. Others considered promising approaches did not find the application. Among other things, it was proposed to use a "protective layer" created by blowing gas on the casing, cooling by "sweating" by supplying a surface with a high evaporation temperature liquid through a porous casing, as well as cooling created by melting and entraining part of the casing (ablative materials).

CHAPTER 3

RELIABILITY OF INS WITH POSITION SENSORS ON REMOTELY PILOTED AIRCAFT SYSTEMS

3.1. Calibration of the Sensors

The error of the gyroscope is the deviation of its main axis "X" from a given direction relative to the ground. Technical gyroscope has errors due to:

- friction in bearings of axes of a cardan suspension;
- imbalance of the rotor relative to the axes of rotation;
- diurnal rotation of the Earth around its axis.

To eliminate or reduce the errors of gyroscopes in gyroscopic devices, tracking devices are used, which rotate the main axis in a given direction, from which it deviated due to precession. Such devices are called corrective.

When the accelerometer is running, its measurement readings may be exceeded. This can primarily be affected by humidity and ambient temperature. This changes the properties of the materials used in the manufacture of devices. Interference also creates an external magnetic field. To minimize its impact, the sensor design can have various technical additions. Also, the measurement error results from the vibration of the measurement object.

Accelerometer calibration

Expensive equipment can be avoided to calibrate the accelerometer. It is enough to take a few readings of the accelerometer, if it is affected only by gravity.

Taking into account the initial offset and the sensitivity of the sensor, all the values obtained from the accelerometer can be represented as follows:

$$A_1 = A_0 + K \cdot A_{дійсне} \cdot \sin(\alpha) \quad (2)$$

where - A0 initial offset; K is the sensitivity factor; The actual-actual value of the acceleration acting on the sensor is also 1g; - the angle between the current acceleration and the sensitive axis of the sensor.

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Concultant	O.V.Kozhokhin				173 Avionics		
S.Controller	V.V.Levkivskyi						
Head of dept.	S.V.Pavlova						

The task of the initial calibration is to find the values of and K. To find these values, we obtain the reading from the accelerometer, in positions where the axis of sensitivity is sequentially rotated by an angle of 0º, 90º, 180º and 270º relative to the original. Mathematically obtained values can be written in the following form:

$$A_2 = A_0 + K \cdot A_{дійсне} \cdot \sin\left(\alpha + \frac{\pi}{2}\right) \quad (3)$$

$$A_3 = A_0 + K \cdot A_{дійсне} \cdot \sin(\alpha + \pi) \quad (4)$$

$$A_4 = A_0 + K \cdot A_{дійсне} \cdot \sin\left(\alpha - \frac{\pi}{2}\right) \quad (5)$$

Given that, and after adding expressions (2), (3), (4) and (5) we obtain:

$$A_0 = \frac{1}{4} \cdot (A_1 + A_2 + A_3 + A_4) \quad (6)$$

To find the sensitivity factor, we use the following trigonometric identities: $\sin\left(\alpha + \frac{\pi}{2}\right) = \cos(\alpha)$ and $\sin^2(\alpha) + \cos^2(\alpha) = 1$.

Writing the sum of the squares of the differences A1-A3 and A2-A4 we get that:

$$(A_1 - A_3)^2 + (A_2 - A_4)^2 = 4 \cdot K^2 \cdot A^2_{дійсне} \cdot \left(\sin^2(\alpha) + \cos^2(\alpha)\right) \quad (7)$$

Where

$$K \cdot A_{дійсне} = \frac{1}{2} \cdot \sqrt{(A_1 - A_3)^2 + (A_2 - A_4)^2} \quad (8)$$

The considered method of calibration of the accelerometer is not demanding to the initial orientation of the axis of sensitivity, which greatly simplifies its implementation. The described sequence of actions must be performed for each of the axes of sensitivity of the accelerometer.

Combined gyroscope and accelerometer module

Using a combined gyroscope and accelerometer module, you can measure the orientation of work in space in the angles of rotation around three axes: the longitudinal axis "X" (roll angle), the transverse axis "Y" (pitch angle), the vertical axis "Z" (angle).

The orientation of the X and Y axes relative to the housing is indicated on the sensor board. The "arrow" of the turn points in the direction of increasing the angle. Here, the "Z" is directed vertically upward relative to the "front" side of the board, on which all components are located. The angle of rotation around the axis increases when rotated clockwise.

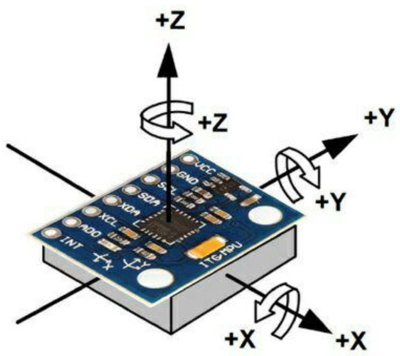

Fig. 3.1. Orientation of accelerometer axes

Due to the fact that the sensor combines two devices (gyroscope and accelerometer), it can issue evidence based on each of them (modes "accelerometer only" and "gyroscope only"), or combining these indications for averaging and stabilization (mode "Averaged")

Accelerometer only mode: Angles are measured only with the accelerometer based on the measurement of gravity vector.

Pros: no accumulated time errors.

Cons: readings are extremely unstable, sensitive to vibration and lateral acceleration.

Because it is not possible to determine the rotation around the vertical Z axis based on information about the position of the gravitational vector, you will always receive a "0" when you try to read the Z axis in the "accelerometer only" mode. Determination of rotation around Z is possible only in the modes "gyroscope only" and "averaged".

Gyroscope Only mode: Angles are measured with a gyroscope by measuring angular velocities and integrating them over time.

Pros: readings are stable and less susceptible to random accelerations and vibrations.

Cons: The error accumulates over time. The readings depend on the time intervals between measurements. The more frequent the measurements, the more accurate the result.

"Average" mode (recommended in most cases): the readings of both sensors are software combined, mutually eliminating each other's shortcomings. Accelerometer readings, in which the error does not accumulate over time, are "filtered" by gyroscope readings, so jumping in readings at random accelerations and vibrations are ignored.

Pros: readings are stable and less susceptible to random accelerations and vibrations.

Cons: the Z axis still accumulates an error, because it uses only a gyroscope.

Kalman filter

The Kalman filter is probably the most popular filtering algorithm used in many fields of science and technology. Due to its simplicity and efficiency, it can be found in GPS receivers, sensor readers, control systems, etc.

Any measuring device has some error, it can be affected by a large number of external and internal influences, which leads to the fact that the information from it is noisy. The louder the noise, the more difficult it is to process such information.

The filter is a data processing algorithm that removes noise and unnecessary information. In the Kalman filter it is possible to set a priori information about the nature of the system, the relationship of variables and on this basis to build a more accurate estimate, but even in the simplest case (without entering a priori information) it gives excellent results.

The Kalman filter uses a dynamic model of the system (for example, the physical law of motion), known control actions and many sequential measurements to form an optimal assessment of the state. The algorithm consists of two repeating phases: prediction and adjustment. The first calculates the forecast of the state at the next time (taking into account the inaccuracy of their measurement). In the second, the new information from the sensor adjusts the predicted value (also taking into account the inaccuracy and noise of this information) (Fig. 3.2).

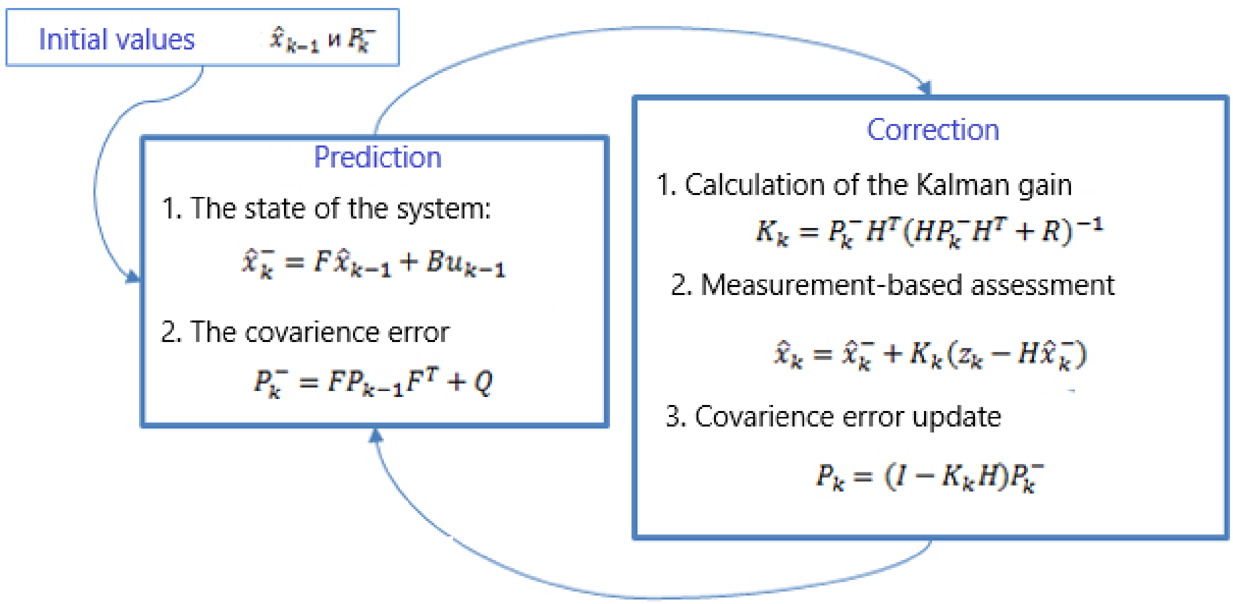

Fig. 3.2. Kalman filter algorithm

The equations are presented in matrix form, if you do not know linear algebra - no problem, then there will be a simplified version without matrices for the case with one variable. In the case of one variable matrix degenerate into scalar values.

Let's understand first in the notation: the subscript indicates the time: k - current, (k-1) - previous, the sign "minus" in the superscript indicates that this is the predicted intermediate value.

The description of variables is presented in Fig. 3.3.

Fig. 3.3. Description of Kalman filter algorithm variables

Consider the scheme of the Kalman filter for its discrete form (Fig. 3.4).

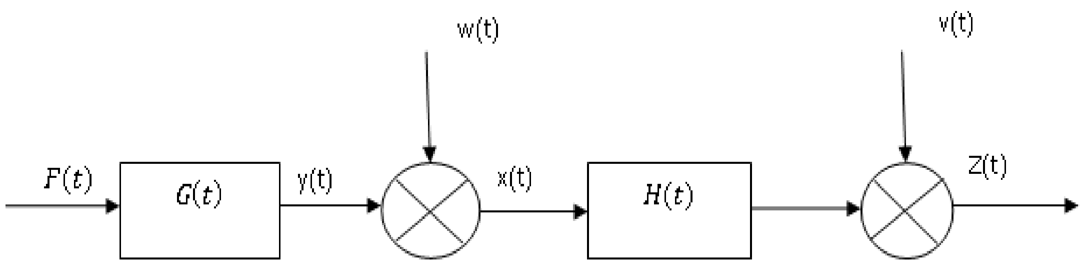

Fig. 3.4. Kalman filter for discrete form

```
Z := | y ← 0
     | x1 ← 0
     | Q ← 0.1
     | R ← 0.1
     | z ← dnorm(rnd(2·√Q), y, √Q) + dnorm(rnd(2·√R), 0, √R)
     | P ← Q·R / (Q + R)
     | x1 ← (Q·z + R·x1) / (Q + R)
     | T ← 5
     | for k ∈ 1..100
     |   | x1 ← 1 − exp(−1/T) + x1·exp(−1/T)
     |   | P ← P − P^2 / (P + Q + R)
     |   | y ← 1 − exp(−1/T) + y·exp(−1/T)
     |   | z ← dnorm(rnd(2·√Q), y, √Q) + dnorm(rnd(2·√R), 0, √R)
     |   | x1 ← (P·z + R·x1) / (P + R)
     |   | P ← P·R / (P + R)
     |   | Z_k ← z
     |   | Y_k ← y
     |   | X1_k ← x1
     |   | k
     | Z
```

Fig. 3.5. Mathcad listing with Kalman filter calculation

G (t) block whose operation is described by linear relations. A non-random signal y (t) is generated at the output of the unit. This signal is summed with the noise w (t) that occurs inside the controlled object. As a result of this addition, we obtain a new signal x (t). This signal is the sum of a non-random signal and noise and is a random signal. Next, the signal x (t) is converted by a linear block H (t), summing with the noise v (t), distributed differently than w (t) of the law. At the output of the linear block H (t) we obtain a random signal z (t), which determines the non-random signal y (t). It should be noted that the linear functions of blocks G (t) and H (t) may also depend on time.

We will assume that random noises w (t) and v (t) are random processes with variances Q, R and zero mathematical expectations. The signal x (t) after the linear transformation in the block G (t) is distributed in time according to the normal law. Given the above, the ratio for the measured signal will look like:

$$z(t) = H(x(t)) + v(t)$$

Modeling and filtering according to the Kalman filter algorithm can be performed in the Mathcad software environment. An example of a listing is shown in Fig. 3.5.

Weibull Distribution

Fig. 3.6 depicts the fit of microengine failure data to the Weibull distribution model. The resulting straight-line fit indicates that the Weibull distribution is a reasonable model for cycles-to-failure of these devices. The Weibull fit results in an estimate for the "characteristic life" of α= 66 million cycles (the characteristic life is defined as the point in time when (1-e-1) 100% = 63.2% of the parts are expected to fail), and an estimate for the shape parameter of β= 0.22. The shape parameter is essentially a measure of dispersion, and lower values correspond to greater spread in a logarithmic lifetime. Typical values of β for production-ready electronic and mechanical products fall in the range of 0.5 to 5 [28].

The considerably wide dispersion in lifetimes for the microengines is to be expected because there is still considerable process learning to occur in this infant technology.

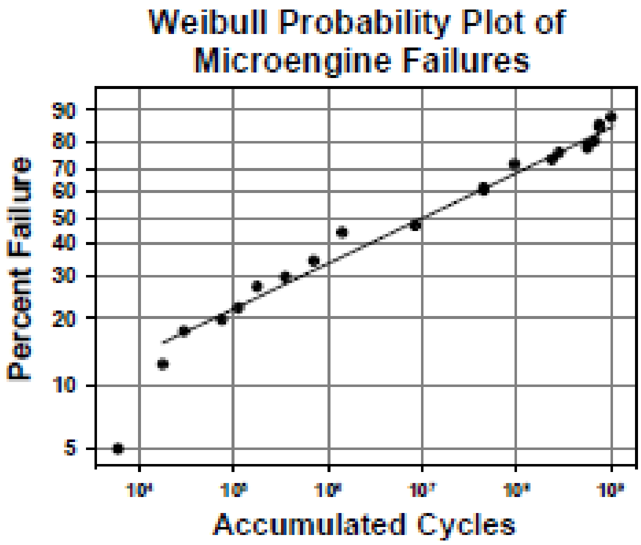

Fig. 3.6. Microengine failure data fit to a Weibull distribution

Lognormal Distribution

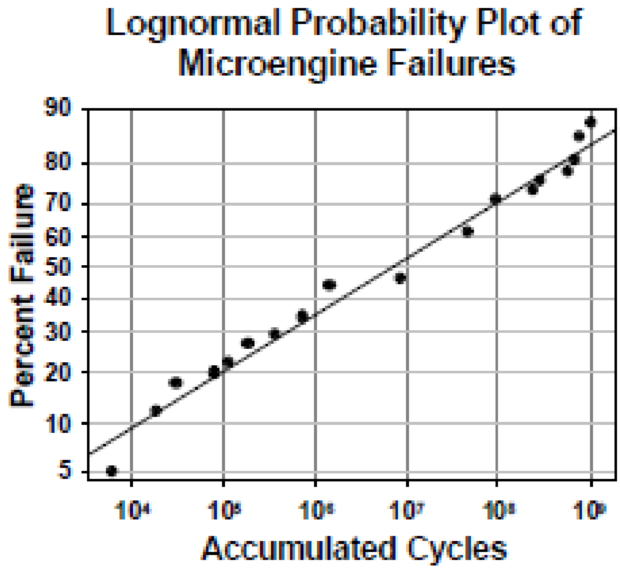

Fig. 3.7. Microengine failure data fit to a lognormal distribution

Fig. 3.7 depicts the fit of the microengine failure data to the lognormal distribution model. The resulting straight-line fit indicates that the lognormal distribution is also a reasonable model. The lognormal fit results in an estimate of a median lifetime of t50% = 7,800,000 cycles, which means that 50% of the parts would be expected to fail by 7,800,000 cycles. The estimate for the lognormal shape parameter is s = 5.2. In this case, the relatively high value of the lognormal standard deviation again indicates a large spread in the log lifetimes. Typical semiconductor products show lognormal standard deviations in the range of 0.1 to 1.0[28].

In the case of the lognormal distribution fit, it is not simple to determine if the failure rate is decreasing, constant or increasing, since the lognormal distribution can manifest all of these in a single unimodal case. By physical argument, it is reasonable to expect that a transition from infant mortality (decreasing failure rate) to wear out (increasing failure rate) would be due to a change in physical failure mechanism and bimodality would be observed in the distribution fit. Still, increasing and decreasing failure rates cannot be easily discriminated on a lognormal probability plot.

Examine the lognormal plot more closely it can be observed a bimodal distribution as seen in Fig. 3.8. This is a typical 'shaped' curve, which implies the presence of two populations. The slopes are implying one dominant failure mode equivalently. The upper population had a median time to failure of t 50% of 2.5 x 108 with a sigma of 0.8. The lower population had a median time to failure of 1.4 x 105 with a sigma of 1.0. Further examination of the data showed that most of the thick flexures were the earlier failures. The thin flexures were the population that lasted longer. This will be explained later.

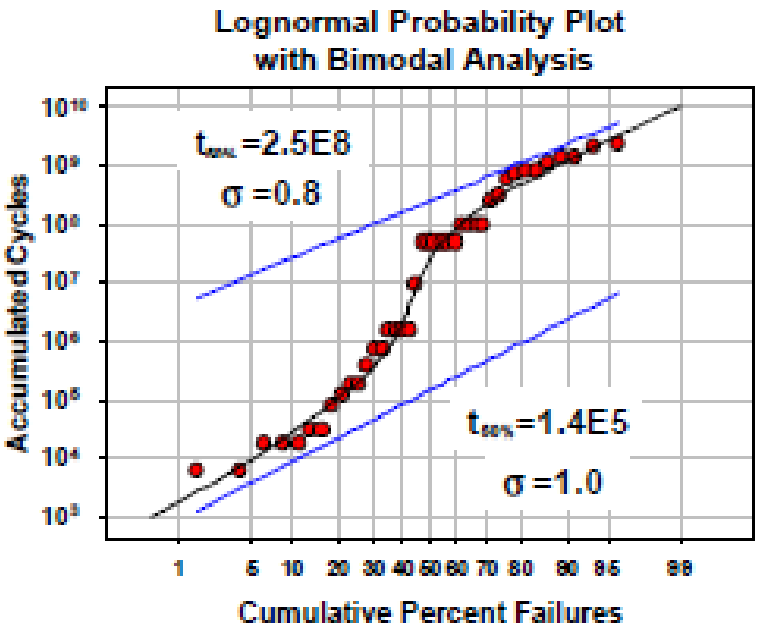

Fig. 3.8. There were two populations leading to bimodal distribution which coincide with the flexure type

3.2.System Safety Process Steps

The primary objective of System Safety is accident prevention. Proactively identifying, assessing, and eliminating or controlling safety-related hazards, to acceptable levels, can achieve accident prevention. A danger is a condition, event, or circumstance that could lead to or contribute to an unplanned or unwanted event. Risk is an expression of the impact of an undesired event in terms of event severity and event likelihood. Throughout this process, hazards are identified, risks analyzed, assessed, prioritized, and results documented for decision-making (it is represented on the Fig. 3.9).

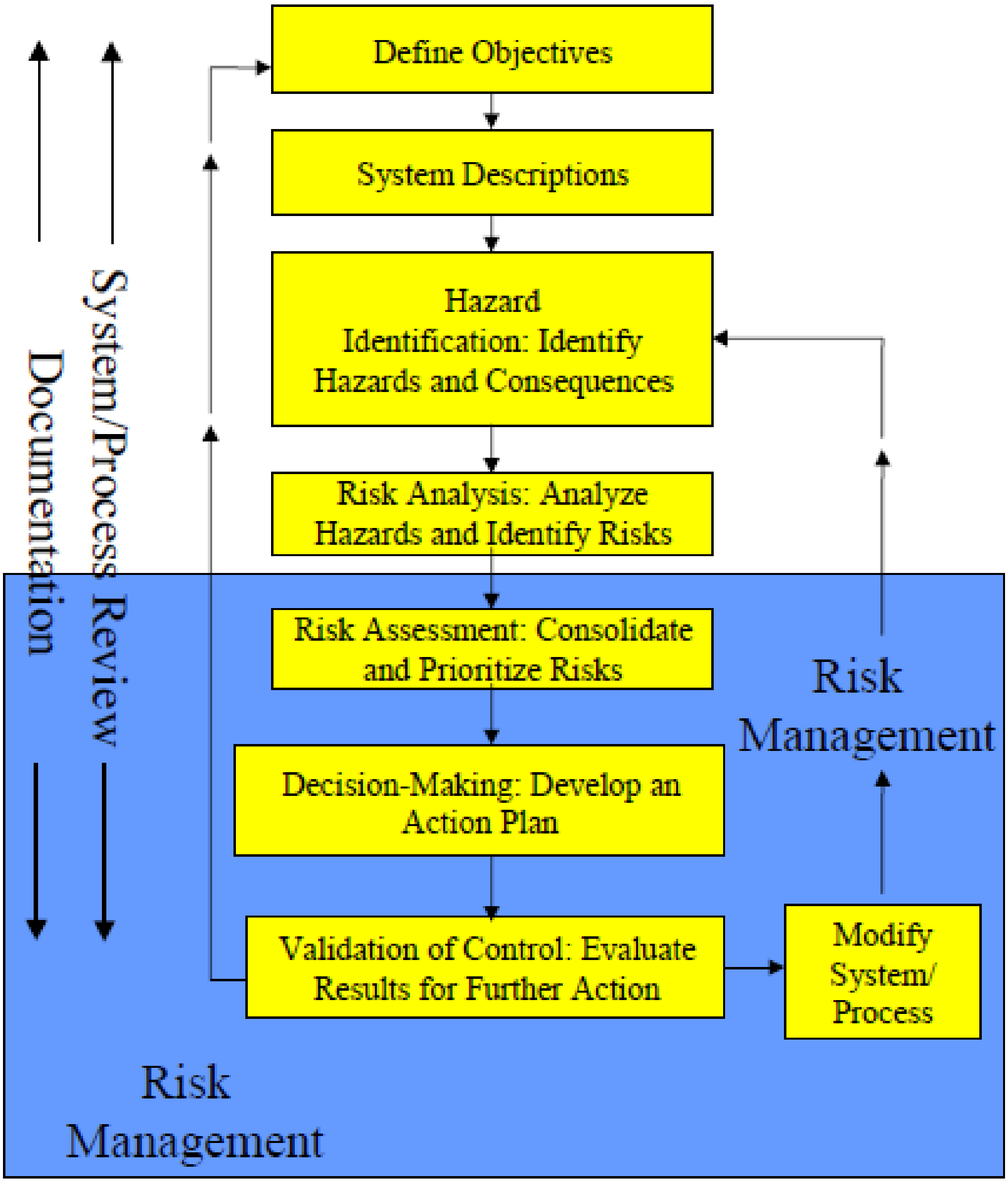

Fig. 3.9. Schematic representation of the system safety process step

For any system safety effort to succeed there must be a commitment on the part of management. There must be mutual confidence between program managers and system safety management. Program managers need to have confidence that safety decisions are made with professional competence. System safety management and engineering must know that their actions will receive full program management attention and support. Safety personnel needs to have a clear understanding of the system safety task along with the authority and resources to accomplish the task. Decision-makers need to be fully aware of the risk they are taking when they make their decisions. They have to manage program safety risk. For effective safety risk management, program managers should:

- Ensure that competent, responsible, and qualified engineers are assigned in program offices and contractor organizations to manage the system safety program.
- Ensure that system safety managers are placed within the organizational structure so that they have the authority and organizational flexibility to perform effectively.
- Ensure that all known hazards and their associated risks are defined, documented, and tracked as a program policy so that the decision-makers are made aware of the risks being assumed when the system becomes operational.
- Require that an assessment of safety risk be presented as a part of program reviews and at decision milestones. Make decisions on risk acceptability for the program and accept responsibility for that decision.

Modern safety management, i.e.--“system safety management”-- adopts techniques of system theory, statistical analysis, behavioral sciences, and the continuous improvement concept. Two elements critical to this modern approach are a good organizational safety culture and people involvement. [29]

The establishment of system safety working groups, analysis teams, and product teams accomplishes a positive cultural involvement when there are consensus efforts to conduct a hazard analysis and manage system safety programs.

The system safety program uses models to describe a system under study. These models are known as the 5M model and the SHEL model. While there are many other models available, these two recognize the interrelationships and integration of the hardware, software, human, environment, and procedures inherent in FAA systems.

The first step in performing safety risk management is describing the system under consideration. This description should include at a minimum, the functions, general physical characteristics, and operations of the system. Normally, detailed physical descriptions are not required unless the safety analysis is focused on this area.

Keep in mind that the reason for performing safety analyses is to identify hazards and risks and to communicate that information to the audience. At a minimum, the safety assessment should describe the system in sufficient detail that the projected audience can understand the safety risks.

A system description has both breadth and depth. The breadth of a system description refers to the system boundaries. Depth refers to the level of detail in the description. In general, the level of detail in the description varies inversely with the breadth of the system. For a system as broad as the National Airspace System (NAS) our description would be very general in nature with little detail on individual components. On the other hand, a simple system, such as a valve in a landing gear design, could include a lot of detail to support the assessment.

Graphically, this is represented by the 5M (fig. 3.10) and SHEL models (fig. 3.11), which depict, in general, the types of elements that should be considered within most systems.

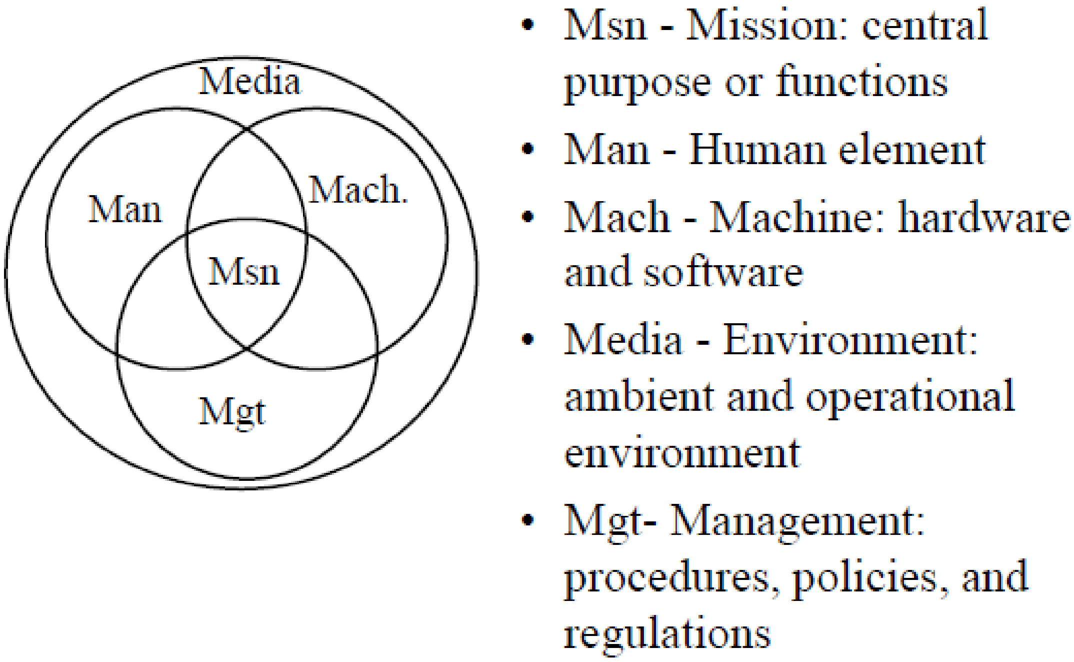

Fig. 3.10. 5M model of system engineering

- Mission. The mission is the purpose or central function of the system. This is the reason that all the other elements are brought together.
- Man. This is the human element of a system. If a system requires humans for operation, maintenance, or installation this element must be considered in the system description.
- Machine. This is the hardware and software (including firmware) element of a system.
- Management. Management includes the procedures, policy, and regulations involved in operating, maintaining, installing, and decommissioning a system. [30]

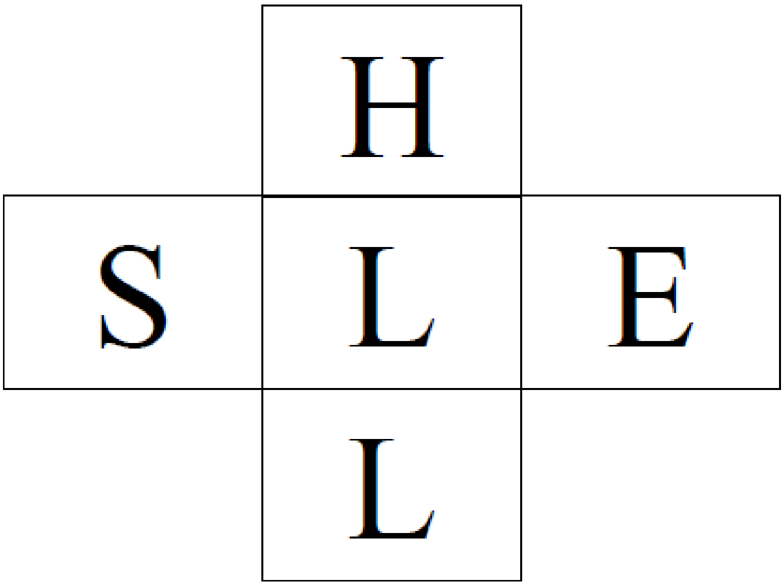

Fig. 3.11. SHELL model of a system

S= Software (procedures, symbology, etc.

H= Hardware (machine)

E= Environment (operational and ambient)

L= Liveware (human element)

In the SHELL model, the match or mismatch of the blocks (interface) is just as important as the characteristics described by the blocks themselves. These blocks may be re-arranged as required to describe the system. A connection between blocks indicates an interface between the two elements.

Each element of the system should be described both functionally and physically if possible. A function is defined as an action or purpose for which a system, subsystem, or element is designed to perform. Both models describe interfaces. These interfaces come in many forms. [30]

System safety requirements must be consistent with other program requirements. A balanced program attempts to optimize safety, performance, and cost. System safety program balance is the product of the interplay between system safety and the other three familiar program elements of cost, schedule, and performance as shown in Figure 3-1. Programs cannot afford accidents that will prevent the achievement of the primary mission goals. However, neither can we afford systems that cannot perform due to unreasonable and unnecessary safety requirements. Safety must be placed in its proper perspective. A correct safety balance cannot be achieved unless acceptable and unacceptable conditions are established early enough in the program to allow for the selection of the optimum design solution and/or operational alternatives. Defining acceptable and unacceptable risk is as important for cost-effective accident prevention as is defining cost and performance parameters.

3.3. Military and aviation standards

Three crucial areas have been identified as challenges for the integration of RPAS into the European civil aviation system.

Firstly, general concepts of integration of Remotely Piloted Aircraft into the European airspace including the development of the U-space concept. Secondly, the field of legal regulations, without which the functioning of RPAS as a part of the European aviation system is impossible. In this context, it is justified to continue the implementation of the Roadmap for the integration of civil Remotely-Piloted Aircraft Systems into the European Aviation System proposed by the EC in 2013. Also relevant are the EASA proposals for categorising RPAS and conducting flight operations based on the risk approach which is a new solution. The discussion may be triggered due to by-pass of all regulatory competencies to EASA, without taking into account the specificity of the national systems. Thirdly, the societal field. Full integration of RPAS into the European civil aviation system requires social acceptance for air operations involving RPAS. Despite the undeniable social benefits of RPAS utilisation, in particular in ensuring security and public order, it will be necessary to address issues related to the perception of RPAS by the public, including privacy and data protection, law enforcement associated with the application of RPAS, third-party liability and insurance requirements of RPAS.

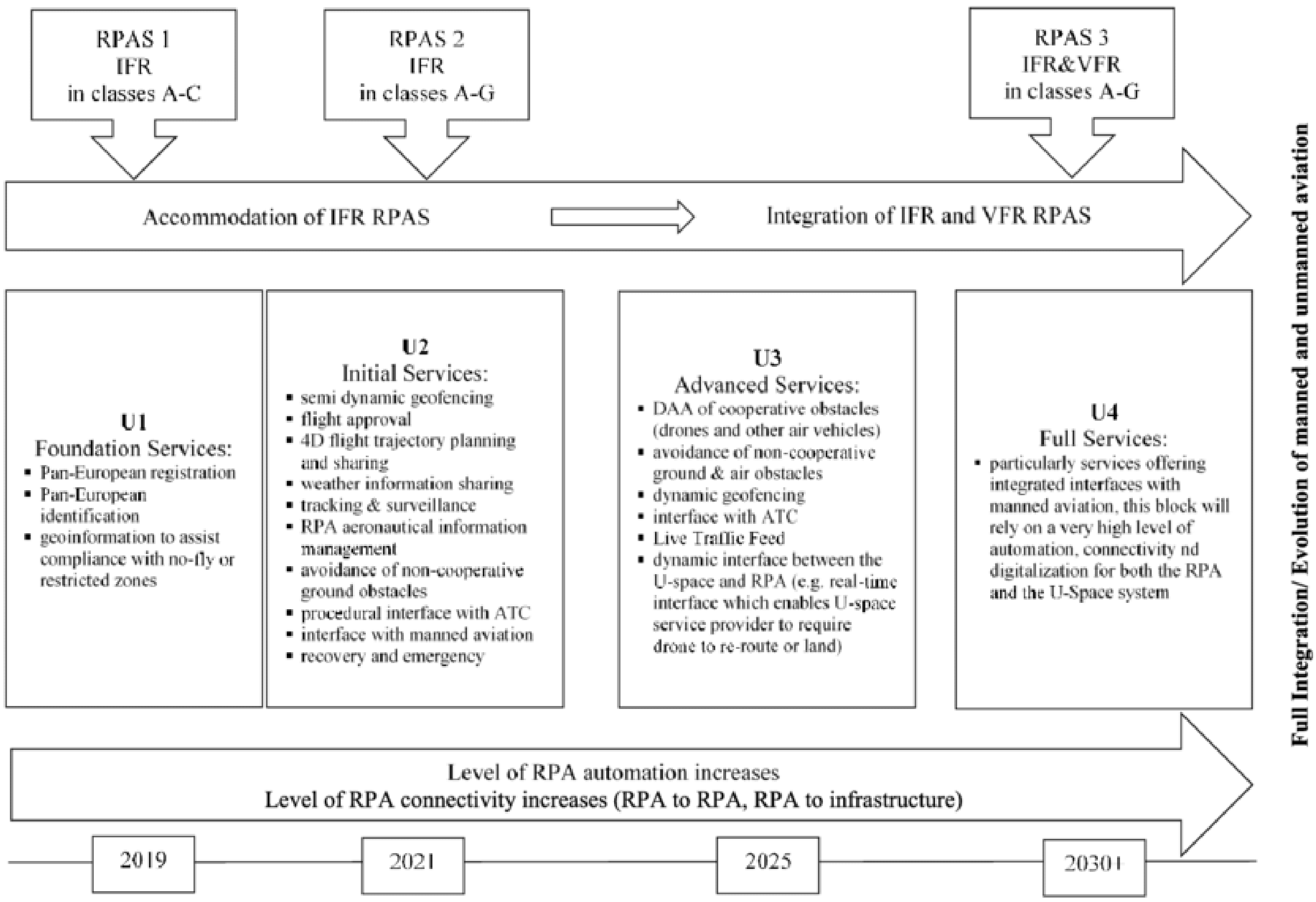

Fig 3.12. Integration of unmanned and manned aviation

The range of tasks for the use of RPVs for civilian purposes is very wide and tends to further rapid expansion: environmental monitoring, remote diagnostics, search and rescue operations, object security, and others [2].

The rapid progress in the creation of unmanned aircraft systems for various purposes is largely due to two factors (economic and scientific and technical) [2]:

- a significant increase in the cost of operating manned aircraft in peacetime and wartime;
- general scientific and technological progress and the development of computer technology.

The performance, observability, and affordability of most military vehicles are influenced by fluid physics either directly by their interaction with the surrounding air/water or indirectly through the many fluidic based systems they incorporate. The ability to manipulate a fluid flow to improve efficiency or performance is of immense technological importance and is currently one of the most high profile topics in fluid dynamics. The potential benefits of flow control include improved performance and maneuverability, affordability, increased range and payload, and environmental compliance. The intent of flow control may be to delay/advance transition, to suppress/enhance turbulence, or to prevent/promote separation. The resulting benefits include drag reduction, lift enhancement, mixing augmentation, heat transfer enhancement, and the suppression of flow-induced noise. The desire to minimize drag (both skin friction and pressure) and to control flow separation in order to improve the high lift and propulsive performance of a wide range of vehicles is providing a driver for increased research activity in this field. In most cases, drag and flow separation are dominated by the thin layer of fluid (often just a few millimeters thick), known as the boundary layer, that forms at the interface between the vehicle's components and the surrounding fluid. [31]

Despite over a century of intensive research, turbulence remains mostly an enigma that is analytically unapproachable yet practically very important. The mysteries of turbulence are only now being solved by the use of physical and numerical experiments, which is a far-from-trivial task at the high Reynolds numbers of practical interest to the aerospace engineer. Controlling a practical turbulent flow to achieve the desired effect such as drag reduction, lift enhancement or noise reduction is a very difficult task. Passive control methods, while always preferable, are generally limited in their utility. Brute force suppression, or taming, of turbulence via active, energy consuming control devices is always possible, but the penalty for doing so often exceeds any potential savings. The challenge is to achieve the desired effect with a minimum of energy expenditure by utilizing the inherent instabilities within the fluid structures to amplify control inputs. [32]

3.4. Conclusion

Most supersonic aircraft, including many military fighter aircraft, are designed to spend most of their flight at subsonic speeds, and only to exceed the speed of sound for short periods such as when intercepting an enemy aircraft. A smaller number, such as the Lockheed SR-71 Blackbird reconnaissance aircraft and the Concorde supersonic airliner, have been designed for cruising continuously at speeds above the speed of sound, and with these designs, the problems of supersonic flight are more severe.

MEMS will help enable the development of these new military capabilities. Such capabilities will allow the introduction of low-cost, “high-end” functionality to military systems, thereby extending their performance and lifetimes. Examples of such novel capabilities include the development of complete inertial navigation units on a single chip. They have distributed sensing systems for monitoring, surveillance, and control. These capabilities will be realized through developments in civil applications which will be advanced, if necessary, to address the military requirements. In the context of military systems, the performance of MEMS devices must satisfy the stringent specifications and environmental conditions expected to be posted by such applications. Packaging for military MST/MEMS is, therefore, more critical than that for commercial applications of the technology, and even there it is regarded as a prime discriminator between commercial success and commercial failure. For commercial microsystems, the packaging is said to account for 80% of the cost and 80% of the failures. The proportions of both in a military environment are not likely to be lower, and will in all probability be even higher. The packaging is inextricably linked to the environmental specifications and is often all that stands between the delicate and complex microstructure and the hostile world around it. Properly designed and implemented, it can protect the microsystem from the worst excesses of a military application. It is significant that for existing MEMS products (e.g. those developed specifically for automotive use), the only feature that distinguishes the commercial product from variants marketed as saying “aerospace quality” is the packaging and final testing.

Safety management must be based on the behavior of people and the organizational culture. Everyone has a responsibility for safety and should participate in safety management efforts. Modern organization safety strategy has progressed from “safety by compliance” to more of an appropriate concept of “prevention by planning”. Reliance on compliance could translate to after-the-fact hazard detection, which does not identify organizational errors, that are often times, the contributors to accidents.

CHAPTER 4
ENVIRONMENTAL PROTECTION
ANALYSIS OF ELECTROMAGNETIC ENVIRONMENT PROBLEM

Environmental protection is becoming a complex problem, determined by the complexity of a system that combines nature, society and production. Along with environmental tasks, it also solves socio-economic problems - improving the living conditions of a person, preserving his health. Obviously, a written, science-based approach is needed to protect the environment. Any technical process in one way or another affects the environment by polluting it.

This thesis deals with the influence of human factors on the operation and maintenance of remotely controlled aircraft systems. In addition, it should be noted that the problem of EMI is closely related to one of the most popular models of the human factor, which is the SHEL model. In the production rooms, the sources of electromagnetic radiation are the unshielded working elements of high-frequency installations (inductors, capacitors, high-frequency transformers, feeder lines, capacitor batteries, oscillator coils, etc.). In the operation of HF, UHF, UHF transmitters on radio and telecentres, the sources of electromagnetic radiation are high-frequency generators, antenna switches, devices for assembling electromagnetic field capacities, communication (from the generator to the antenna device), antennas.

The complexity of this problem can be analyzed on the example of integrated circuits, which reveals a number of factors that have an impact on the environment. The circuit elements are mounted on printed circuit boards made of foil fiberglass. When processing it inevitable waste: pieces of boards, powder dust, which, getting into the soil, is stored for quite a long time. And the vapors produced by etching have a detrimental effect on the workers employed in the production and are released into the environment.

During the operation of the computer, the elements of its design produce heat (heat the circuits, transistors, resistors), resulting in heated protective varnishes, paints, creating toxic substances in the atmosphere, in the form of volatile fractions. This is only a surface analysis of one of the components of a computer.

4.1 Description of Electromagnetic Interference

Over the last two decades, there have been tremendous changes in the impact of electromagnetic interference (EMI) on human health, especially during the maintenance of any aviation system. It is so important that the study of the EMI effect is necessary for all aeronautical engineers, complying with the requirements of EASA PART 66, and described in Module 5, topic 5.1 Electromagnetic environment [2].

In Ukraine, companies engaged in the maintenance of aircraft equipment, such as "UIA equipment", the minimum safety and health requirements for personnel when using personal protective equipment in the workplace with the subsequent [7]. Moreover, regulated by Order No. 1804 of November 29, 2018, it is effective from January 15, 2019, published by the Ministry of Social Policy of Ukraine. On approval of the Minimum Safety and Health Requirements for workers using personal protective equipment in the workplace. [8].

Electromagnetic Interference (EMI) is a disturbance generated by an external source that affects the electrical circuit by electromagnetic induction, electrostatic coupling or conductivity (Fig. 4.1).

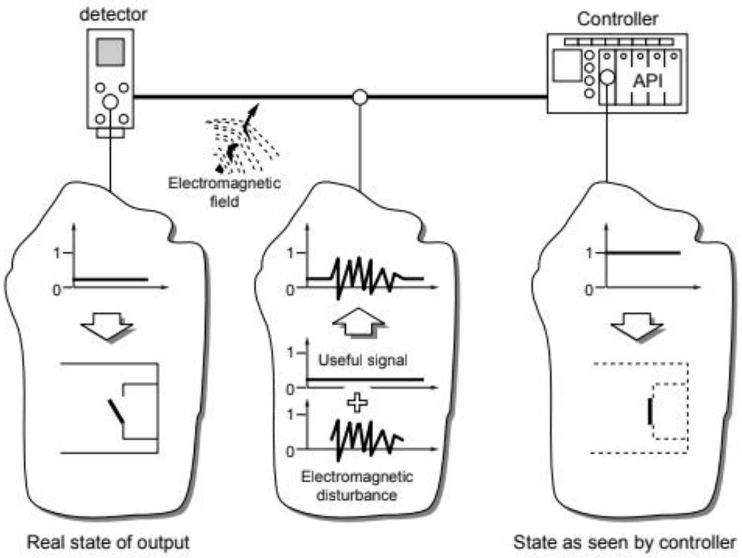

Fig.4.1. Example of EMI

Electromagnetic fields are harmful to the health of service personnel. Low frequency, radio frequency and microwave frequencies can cause current to flow through the human body. This current flow generates heat and causes thermal injury. Natural low-frequency fields are static electric fields between the ionosphere and the Earth and static electromagnetic pulses arising from lightning. These fields kept living beings in an invisible cell of EM waves and pulses. The health effects that can result from EM radiation are almost certainly the most complex and difficult to understand of all the effects of EM radiation.

The degree of exposure of workers depends on the number of transmitter housed in the room (up to 20 in separate zones, radio and telecentres), their capacity, the degree of shielding, the placement of individual blocks inside and outside the room.

Electromagnetic radiation is a powerful physical stimulus. Different organisms have different sensitivity to natural and anthropogenic (artificial) EMRs: the nature and severity of the biological effect depend on the EMR parameters and the level of organization of the biosystem. Millimeter EMR waves affect mainly the receptor apparatus, longer wavelengths affect the central nervous system.

Radio frequency radiation absorbs different organs and systems of the body in different ways: their shape and linear dimensions, orientation with respect to the EMF source are essential. Primary changes in the functions of the central nervous system and related disorders cause biological effects at the level of organs and systems. Long-term action of high levels of electromagnetic radiation leads to overstressing of adaptation-compensatory mechanisms, significant deviations of functions of organs and systems, impaired metabolism and enzymatic activity, hypoxia, organic changes. Since electromagnetic radiation in the production environment usually works in combination with other factors, its effect on the human body is amplified.

The protective-adaptive reactions that occur in humans under the influence of electromagnetic radiation are nonspecific. Often the adaptive reactions are excitation of the central nervous system and increase the level of metabolism.

The effects of the influence on the biological tissues of the human electromagnetic radiation of low-frequency radio frequency range are divided into thermal and non-thermal. The thermal effect can be manifested in humans either by increasing the body temperature, or by selective (selective) heating of individual organs, whose thermoregulation is difficult (gall and bladder, stomach, intestines, testes, crystals, vitreous body, etc.). The effect of electromagnetic radiation on a biological object is manifested when the radiation intensity is lower than its thermal threshold values, that is, non-thermal effects or specific action of radio waves, which is determined by the informational aspect of electromagnetic radiation, which is perceived by the source. ulcer. It is obvious that information processes also play a role in the thermal action of an electromagnetic field on the body. In addition, the action of low-intensity electromagnetic radiation leads to local heating - micro-heating.

The following mechanisms of biological action of EMF are conditionally distinguished:

- direct effect on tissues and organs, when the function of the central nervous system changes and the neurohumoral regulation associated with it;

- reflex changes in neurohumoral regulation;

- combination of the main mechanisms of pathogenesis, the action of EMR with a predominant metabolic disorder, enzyme activity.

The specific gravity of each of these mechanisms is determined by physical and biological changes in the human body.

Therefore, the effect of electromagnetic radiation is systemic in nature and requires appropriate systemic protection against it.

The biological effect of an electrostatic field on a person depends on its duration, the shape of the conductive parts of the equipment, the location of the workplace relative to the radiation source, climatic conditions, etc. Experimental on animals found that ESP affects the nervous, cardiovascular, endocrine and other systems of the body. In particular, changes in the electrical activity of the cerebral cortex and conditioned reflex activity were reported. The electrostatic field causes changes in blood pressure that are unstable and phase in nature, the rate of blood clotting, the content of sulfhydryl groups in the blood.

The effect of ESF on workers leads to manifestations of irritability, headache, sleep disturbance, decreased appetite, impaired general function of the central nervous system, changes in heart rate (most often in the form of bradycardia) and carbohydrate, lipid, protein and mineral metabolism, as well as decreased enzyme activity.

4.2. Electromagnetic Interference during Maintenance

In production conditions, electromagnetic radiation is characterized by a variety of modes of generation and variants of actions of employees (radiation in the near zone, induction zone, general and local, which often acts together with other adverse environmental factors). The radiation can be isolated (from one EMR source), combined (from multiple EMR sources of the same frequency range), mixed (from multiple EMR sources of different frequency bands), and combined (when another adverse factor simultaneously operates). The effect of the EMR can be continuous or intermittent. The latter, in turn, can be periodic and aperiodic.

The electromagnetic field adversely affects the human body. There are two forms of electromagnetic radiation in the radio frequency range - acute and chronic, which in turn is divided into three stages: light, medium and heavy. The chronic form is characterized by functional disorders of the nervous, cardiovascular and other systems of the body, manifested by asthenic syndrome, and vegetative disorders, mainly the cardiovascular system.

Persons under the influence of chronic EMR are more likely (1.9 times men and 1.5 times women) than those who are not exposed to ill health, including headache (1.5 times males and 1.3 times females), heartache (1.8 times males and 1.5 times females), palpitations, general weakness, drowsiness, tinnitus, paraesthesia, etc.

It should be noted that the increased concern of EMR (Fig. 4.3.) During maintenance in recent years, as it happens through the following and regulated 3.3.6.096-2002 "On approval of state sanitary rules and regulations when working with the electromagnetic field Sources" [15]:

1. Greater dependence on electrical and electronic systems for further safe flight.

2. Reduction of electromagnetic shielding due to greater use of composite materials.

3. Increased susceptibility of electrical and electronic systems to HIRF by increasing the speed of the data bus and processor, integrated circuits and cards of higher density and greater sensitivity of electronic equipment;

4. Extended use of frequency, especially above 1 GHz (GHz);

5. Increased weight of the HIRF environment due to the increase in the number and radiation power of radio frequency (RF) transmitters; and

6. Side effects experienced by some aircraft under the influence of HIRF.

EMI SOURCES (electromagnetic interference)

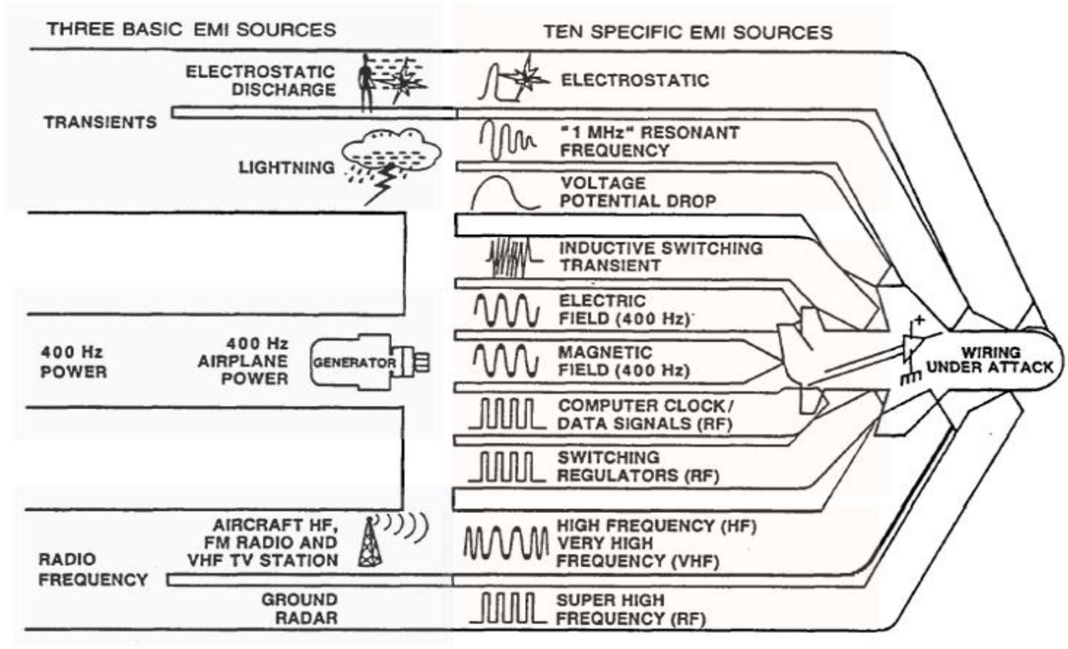

Fig. 4.2. Representative EMI sources

EMI on the aircraft can be controlled as follows:

• Well-placed antennas - obstacles to communication / navigation systems such as ADF and VHF

• Grounding of electronic equipment and protection and grounding of relevant wires.

• Light current flows through the outer skin and is fully discharged.

• Fastening - all equipment connected together, not less than R = 0,05 Ohm.

• Static arrester - provide a path of resistance to the atmosphere.

There are also concerns about the suspicion of electromagnetic interference in aircraft systems. Reports of many related aviation incidents, such as:

● June 7, 1997 B737-300: * Position check * was indicated on the CDU. The position of the IRS and the radio was correct. FMC's position was not that. The difference quickly increased to 8 nautical miles. After processing GSM in the cabin from STBY to OFF, FMC is normally updated. The FMC was produced by the correct test of the rest of the flight and on the call flight.

● April 30, 1997 B737-400: During a cruise, the AR level rises and passes with an ROC / ROD of 400 fpm. The other AP has no changes. What checks were performed using a PC and other electronic devices: nothing was found. Asked passengers to check that their mobile phone (GSM) is turned off. Shortly after this request, all high pitches stopped.

Then it is easy to know that EMI affects not only personnel services, but also all aviation systems and can lead to aviation incidents and accidents.

4.3. Methods of protection against electromagnetic radiation

If the characteristics of the EMR exceed the requirements of normative acts, different means and methods of flight crewmembers protection are used.

The following methods of protection against EMR were the most widespread:

1. Reducing radiation power in the source. Reducing the radiation parameters directly in the source itself is achieved by the rational choice of the generator, the use of coordinated loads and special devices – absorbents of power (equivalent to the antenna and load). The latter is used as generator loads instead of open emitters. Power absorbents are coaxial and wave guidelines, partly filled with absorbent materials.

2. Distance protection system unit and monitor should be as far away as possible from the user. If it is impossible to reduce the intensity of irradiation by these methods, use protection distance and its increase. Distance protection is provided by the mechanization and automation of production processes, the use of remote control and special manipulators, and the rational placement of equipment in the workplace.

3. Screening of radiation sources and workplaces. Screening is one of the most effective and most frequently used protective devices from the EMR.

4. Use of a liquid crystal monitor, since its optical radiation, is much smaller than other types of monitors. This option is also widely used on-board of modern aircraft.

5. To protect against radiation and health, it takes much time to spend in the fresh air and to protect from a sedentary seat behind the computer you need to interrupt the work for physical exercises and rest for the eyes.

6. It is also necessary to take care of the eyes, for example, to use glasses with appropriate light filters [3].

4.4. Conclusion

Electromagnetic pollution of the environment is one of the most pressing problems of humanity in our time.

Widespread use of a variety of electrical appliances, including personal computers, aircraft systems, leads to an unceasing increase in electromagnetic background. It has already been proved that the action of electromagnetic waves on a human body has a disastrous nature.

Electromagnetic interference (EMI) can cause avionic equipment performance to degrade or even malfunction. EMI can affect cockpit radios and radar signals, interfering with communication between pilot and control tower. Airborne devices that can cause interference include laptop computers, electronic games, cell phones, and electronic toys, and all have been suspected of causing events such as autopilot disconnection, erratic flight deck indications, and airplanes turning off course.

EMI effects from lightning, solar flares, electrostatic discharge, and high-intensity radiated fields (HIRF) from radar and various kinds of transmitters or communications equipment – have all resulted in numerous aviation incidents throughout the years. As a result, EMI effects are now considered in all aspects of avionics design and certification.

Generators of electromagnetic interference to an aircraft can come from several sources, for example:

- Transmitters of radio frequencies that may be installed on the aircraft itself, such as high-frequency (HF) or very high frequency (VHF) communication links, or high-energy sources located on the ground such as our everyday frequency modulated (FM) radio or HF-VHF-UHF broadcast stations high intensity radiated fields (HIRF);

- The aircraft power line 400-Hz electric and magnetic fields;
- The computer and avionics microprocessor timing and control clock signal circuits that generate radio frequencies of one MHz or higher;
- The aircraft power switching regulators which are used to convert from one level of power to another;
- Electrical switching transients sparked by the turn on and off of aircraft lights, fans, and engines or by the operation of control surfaces, ailerons slats, and flaps ;
- Electrostatic discharges including lightning.

The conductive paths of electrical wiring provide an avenue to usher electromagnetic interference directly to airplane avionics and signal inputs. Eliminate wiring, and electromagnetic interference almost vanishes. Wiring is the most important factor in electromagnetic interference and electromagnetic compatibility.

In order to prevent or reduce the negative impact of EMI, workers must comply with the norms of electromagnetic radiation and the peculiarities of working with it. It is also worth to make sure of compliance with sanitary standards for electronics and high-tech optical technology.

Since electromagnetic radiation on the aircraft at least meets international norms and standards, but has a negative impact on human health, it therefore needs to take recommended measures to protect against EMF in the radio frequency range and optical range.

CHAPTER 5
LABOR PROTECTION

This section addresses issues related to the creation of safe and healthy working conditions at all stages of design, creation, repair and operation of inertial sensors on remotely controlled aircrafts.

The organization of labor protection measures at civil aviation enterprises can be carried out at a high level only with the use of inertial methods of occupational safety. At the same time, legal and organizational methods of improving working conditions play an important role.

Strict compliance with labor laws, guidelines, industry standards, rules and regulations aimed at protecting the health of workers is required. The most important of them are the correspondive actions of the administration to organize the implementation of labor protection requirements, as well as labor and production discipline of employees themselves.

So, the main task of occupational safety is to create safe and healthy working conditions for employees, makes a great contribution to improving flight safety. This is one of the current problems of civil aviation.

The process of human activity is carried out in close interaction and is formed by the production environment. In other words, the working environment affects a person's work process and, consequently, his health and ability to work, which is the working conditions.

Factors can be destructive, dangerous and harmful. Factors that lead to a sharp deterioration in health are called harmful. Harmful production factors include: danger of electric shock or static electricity.

Factors that can cause injury can be called dangerous. Dangerous factors are associated with the use of toxic substances, emissions of dust, vapors, various radio radiation.

5.1 Analysis of harmful and dangerous production factors

Main dangerous and harmful factors during work with sensors of remotely piloted aircraft systems according ГОСТ 12.0.003-74 includes:

- increased or decreased temperature of surfaces of equipment, materials;
- increased voltage in the electrical circuit, the short circuit of which can occur through the human body;
- increased level of electromagnetic radiation;
- increased electric field strength;
- increased magnetic field strength;
- sharp edges, burrs and roughness on the surfaces of workpieces, tools and equipment.

Electrical appliances, installations, equipment in sensors of remotely piloted aircraft systems that an engineer deals with can provoce great danger to him. Because of the human skin can not detect the electrical voltage at a distance, such as thermal, light or mechanical energy. Therefore, the body has protective reaction which is manifested only after direct exposure to electric current.

The second principle of the electric current on the human body is that the current passing through the body acts not only at the points of contact and on the way through the body, but also causes reflex disturbances in the normal functioning of individual organs (cardiovascular system, respiratory system).

The third principle is the possibility of getting electric injuries without direct contact with live parts - when moving on the ground near the damaged electrical installation (in case of earth fault), electric arc damage.

There are three degrees of influence of current when passing through the human body (alternating current):

- palpable current - the beginning of pain (up to 0-1.5 mA);
- unsettled current - cramps and pain, shortness of breath (10-15 mA);
- fibrillation current - fibrillation of the heart during the duration of action current 2-3 s, respiratory paralysis (90-100 mA).

Electromagnetic waves are partly reflected, and partly absorbed and propagated in them interacting with organisms,. The degree of impact depends on the amount of energy absorption by body tissues, the frequency of waves and the size of the biological object.

At constant action of electromagnetic waves of low intensity there are frustration of a nervous and cardiovascular system, endocrine bodies and other. The person experiences irritation, headaches, memory loss, etc. Adaptation to electromagnetic effects does not occur. Electromagnetic fields vary in frequency and intensity. Their characteristics fluctuate over time.

Increased level of electromagnetic radiation is one of the most important physical factor for engineers during aviation maintenance. Different organisms have different sensitivity to natural and anthropogenic (artificial).

The nature and severity of the biological effect depend on the parameters of Electromagnetic Fields (EMFs) and the level of organization of the biosystem.

Millimeter EMF waves affect mainly the receptor apparatus, long waves - on the central nervous system. Electromagnetic energy is emitted into the surrounding space, primarily by the antenna device. In addition, the sources of electromagnetic fields (EMF) are located in different places where digital computer can be created or maintained, such as laboratories and aircraft design centers, onboard etc.

The effect of electromagnetic radiation on a biological organism is detected when the intensity of radiation is lower than its thermal threshold values, ie non-thermal effects or specific action of radio waves, which is determined by the information aspect of electromagnetic radiation perceived by the body and depends on the EMF source and channel. The action of low-intensity electromagnetic radiation leads to local heating - micro-heating.

Therefore, the effect of electromagnetic radiation requires appropriate systemic measures to protect it.

5.2. Measures to reduce the impact of harmful and dangerous production factors

While working at the workplace is important to follow the recommendations for thermal comfort.

To have “thermal comfort” means that a person wearing a normal amount of clothing feels neither too cold nor too warm. Thermal comfort is important both for one's well-being and for productivity.

Temperature preferences vary greatly among individuals and there is no one temperature that can satisfy everyone. Nevertheless, an office which is too warm makes its occupants feel tired; on the other hand, one that is too cold causes the occupants' attention to drift, making them restless and easily distracted.

Maintaining constant thermal conditions in the offices is important. Even minor deviation from comfort may be stressful and affect performance and safety. Workers already under stress are less tolerant of uncomfortable conditions.

The airworthiness of RPAS is laid down during the design, taking into account previous operating experience and flight safety requirements. Following the commissioning of the RPAS, the airworthiness of the RPAS must be maintained by compliance with the rules of flight, maintenance and repair.

Alternating current with a frequency of 50 Hz, passing through the human body from hand to hand or from hand to foot, at a value of about 100 mA can paralyze the heart, if the effect of current on a person lasts at least 3 seconds. Ventricular fibrillation may occur, meaning that the individual fibers of the heart muscle twitch erratically instead of contracting and relaxing at the same time. At higher currents, heart failure can occur faster, even in a split second.

The duration of the current is important because the risk of heart failure depends not only on the magnitude of the current, but also on whether the moment of the current coincides with this phase in the heart in each cycle of compression and expansion, when it is particularly sensitive to current. If the current lasts longer than one cycle of compression and expansion of the heart, it will inevitably coincide with the dangerous phase.

With a current of 20-25 mA passing between the hands or between the arm and the legs, the fingers convulsively squeeze the hand-held object, which is under tension, paralysis of the forearm muscles occurs, and the person can not free himself from the action of the current. Many victims have laryngeal spasms: they cannot call for help. The longer the current lasts, the lower the electrical resistance of the body, and the current increases. If it is not stopped immediately, death can occur.

The maximum releasing is called the largest current of such magnitude at which a person can still tear his hands away from a live object. A slightly larger current can be considered a threshold (minimum) non-releasing.

In the way not to be influenced by the current is important to calculate the contour grounding of the production room. According to the state standard 12.1.030-81 the initial data for the calculation are according to PUE at U <1000V R = 4 Ohms; specific soil resistance 0.5 Ohm • m • 10^2; seasonally dependent coefficient of climate zone - 2,1; grounding conductors - steel pipes L = 3,0 m; laying depth H = 0.85 m; grounding line - strip steel, width B = 0.04 m; Single earthing factor ηtr = 0.85 and strips ηfloor = 0.75;

a) Calculate the specific soil resistance

$$\rho = \rho_{вим} \cdot Кс$$

$$\rho = 0,5 \cdot 10^2 \cdot 2,1 = 105\ Ом$$

b) Determine the resistance of a single earth conductor - steel pipe:

$$R_{тр} = 0,366\rho/L\ (\ lg2L/d + 1/2lg((4H+L)/(4H-L)))$$

$$R_{тр} = 0,366 \cdot 105/3,0\ (lg(2 \cdot 3,0/0.025) + 1/2lg((4 \cdot 0,85+3,0)/(4 \cdot 0,85-3,0)))= 32,81\ Ом.$$

c) Calculate the required number of pipes:

$$n = R_{тр}/R \cdot \eta_{тр}$$

$$n = 32,81/4 \cdot 0,85 = 9\ шт.$$

d) Let's determine the length of the strip connecting the grounding conductors:

$$l = 1,05 \cdot L \cdot n = 1,05 \cdot 3,0 \cdot 9 = 28\ м.$$

e) Determine the resistance of the leakage current from the strip, taking into account the depth of its laying:

$$R_{пов} = 0,366 \cdot \rho/l \cdot lg\ (2 \cdot l^2/B \cdot H)$$

$R_{пов} = 0,366 \cdot 105/28\ lg(2 \cdot 28^2/0,04 \cdot 0,85) = 2,32 Ом$

f) Resistance of grounding device:

$r_{кз} = (R_{тр} \cdot R_{пов})/(R_{тр} \cdot \eta_{пов} + nR_{пов} \cdot \eta_{тр})$

$r_{кз} = (32.81 \cdot 2.32)/(32.81 \cdot 0,75 + 9 \cdot 2.32 \cdot 0,85) = 1.78\ Ом.$

5.3. Occupational Safety Instruction

Instructions on labor protection when working with sensors of remotely piloted aircraft systems are presented below:

1. General labor protection requirements

1.1 Persons who have reached the age of 18 years, who have passed a mandatory medical examination, induction instruction, initial instruction at the workplace, trained in safe working methods passed the examination test RPAS operator certificate (ROC) allow to work independently.

1.2 When working on with RPAS, the employee must:

- Comply with all requirements established by the State of the Operator regarding its operation. These requirements should be consistent with the size, structure and complexity of the RPAS operator's organization.
- Follow the internal labor regulations.
- Correctly use protective equipment (if required).
- Observe labor protection requirements.
- Undergo mandatory periodic (during employment) medical examinations (examinations), as well as undergo extraordinary medical examinations (examinations) directed by the employer in cases provided for by the Labor Code and other federal laws.
- Be able to use primary fire extinguishing means.

1.3 If the floor is slippery (doused with oil, emulsion), the worker must demand that he be sprinkled with sawdust, or do it himself.

1.4 When working with RPAS, an employee is prohibited from:

- remove or replace the buses, microprocessors and the other equipment RPAS consists with;

- wash your hands in emulsion, oil, kerosene and wipe them with wiping ends contaminated with shavings.

1.5 In cases of injury or discomfort, it is necessary to stop work, notify the supervisor of the work and contact a medical institution.

2. Labor protection requirements before starting work.

2.1 Put on overalls, avoiding hanging ends and constraint when moving, put on special safety shoes and personal protective equipment.

2.2 Check and make sure that the fixed equipment, tools, fixtures and protective equipment are in good working order. Position the tool for maximum ease of use, avoiding unnecessary items in the work area.

2.3 Check the serviceability of the machine at idle speed.

2.4 Prepare a chip hook, wrenches and other tools before installation.

Do not use a hook with a loop handle.

2.5 The employee is prohibited from:

-use improper and incorrectly sharpened tools and devices;

-touch moving parts of the object.

3. Labor protection requirements during work

3.1 Install and remove parts only when there are no moving parts and the power is off.

3.2 While working with sensors of RPAS, the employee must:

- carefully open the latches;

-Installation and removal of parts and devices should only be carried out according mandatory rules described in instructions;

4. Labor protection requirements in emergency situations

4.1 In case of a break in the grounding check-in of the object and other malfunctions that can lead to an emergency and accidents, it is necessary:

4.1.1 Immediately stop the operation of the systems, switch off the device.

4.1.2 Under the guidance of the person responsible for the performance of work,
promptly take measures to eliminate the causes of accidents or situations that may lead to accidents or accidents.

4.2 In the event of a fire, rags, equipment or fire:

4.2.1 Immediately report the fire to the guard post.

4.2.2 Open emergency exits at the workplace.

4.2.3 Start extinguishing the fire with primary fire extinguishing equipment, if it is not associated with a risk to life.

4.2.4 Arrange a meeting for the fire brigade.

4.2.5 Leave the workplace and stay in the evacuation zone.

5. Labor protection requirements upon completion of work

5.1 Check the serviceability of the object.

5.2 Tidy up the workplace:

- remove shavings and metal dust from the workplace;
- clean the working surfaces from dirt;

5.4 Conclusion

Careful handling of labour protection in the maintenance environment should serve to minimize risks. However, should health and safety problems occur, all personnel should know as far as reasonably practical how to deal with emergencies, which may include:

- An injury to oneself or to a colleague;
- A situation that is inherently dangerous, which has the potential to cause injury (such as the escape of a noxious substance, or a fire).

The organization should also provide procedures and facilities for dealing with emergencies and these must be adequately communicated to all personnel. Maintenance organizations should appoint and train one or more first aiders.

Compliance with the requirements of regulatory documents is necessary to ensure a safe and high-performance working process in the production and operation of technical systems. While working with sensors of UAVs, it is recommended to pay particular attention to fragility of the sensor and fire safety issues related to it. After all, in the first place, the violation of these requirements leads to the most serious consequences for both technical personnel and the property of the enterprise.

CONCLUSIONS

The past 60 years has seen the rise and fall of supersonic commercial aircraft. Challenges of supersonic flight seemingly reduced supersonic travel to wishful thinking. But, while SST was on the backburner, NASA's High Speed Research, among others, continued the advancement of supersonic technology and today we are equipped with tools well beyond the infancy of Concorde's time. Now a revival of supersonic transport aircraft is starting to be seen in companies like Boom Technologies, and Aerion with its supersonic business jet collaboration with Airbus. Along with these independent companies, NASA continues to push on that sound barrier with projects like QueSST working towards diminishing the sonic boom. As technology continues to advance, and man's thirst to break the boundaries of what is possible gets stronger, maybe it will be possible to fly from Seattle to Tokyo, conduct your business, and fly home, perhaps not.

The biggest challenge for supersonic transport may not be muffling the sonic boom or creating a magically efficient engine. No, breaking the sound barrier was the easy part, making it profitable is the real challenge.

In this graduate work the using of MEMS technology as sensors and actuators for measuring heating and radiation parameters was proposed. According to the results it is possible to make next conclusions:

1. Some manufacturers already taking their steps towards creation of a specific safety management system for using of the proposed technology on SST.

2. At this very moment the leading aviation authorities and organizations of the world are working on renovation of supersonic transport for increasing the quality of passenger ait transportation.

3. The MEMS technology has been revealed reliable, i. e. the Weibull and lognormal distributions both fit the observed data equally well. In fact, visual comparisons of the probability density function, cumulative distribution functions, and failure rate plots of the lognormal distribution and the Weibull distribution show that they can have very similar shapes.

4. MEMS has been identified as one of the most promising technologies for the 21st Century and has the potential to revolutionize both industrial and consumer products by

combining siliconbased microelectronics with micromachining technology. Its techniques and microsystembased devices have the potential to dramatically affect of all of our lives and the way we live.

5. It was noticed that with consistent characteristic lifetimes and the respective shape parameters that were derived from the lognormal and Weibull distribution fit, the two distributions are nearly indistinguishable across the observed range of failure data. The fact that the failure rate is consistently decreasing indicates that the parts contain defects that result in the observed failures.

6. To be able to propose personal solution to a problem it is always necessary to study and analyze existing solutions and systems, make a research and find new technologies, that are able to help with problem solving, make an algorithm of work and based on the steps listed above create a personal solution. In the future, it is important to make some edits and updates to the system, in order to have the best operation of the system.

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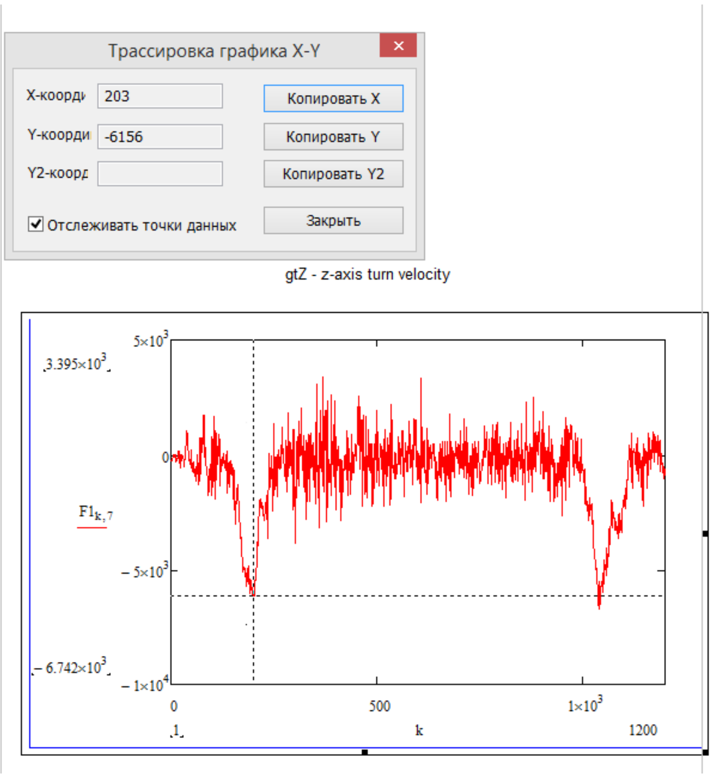
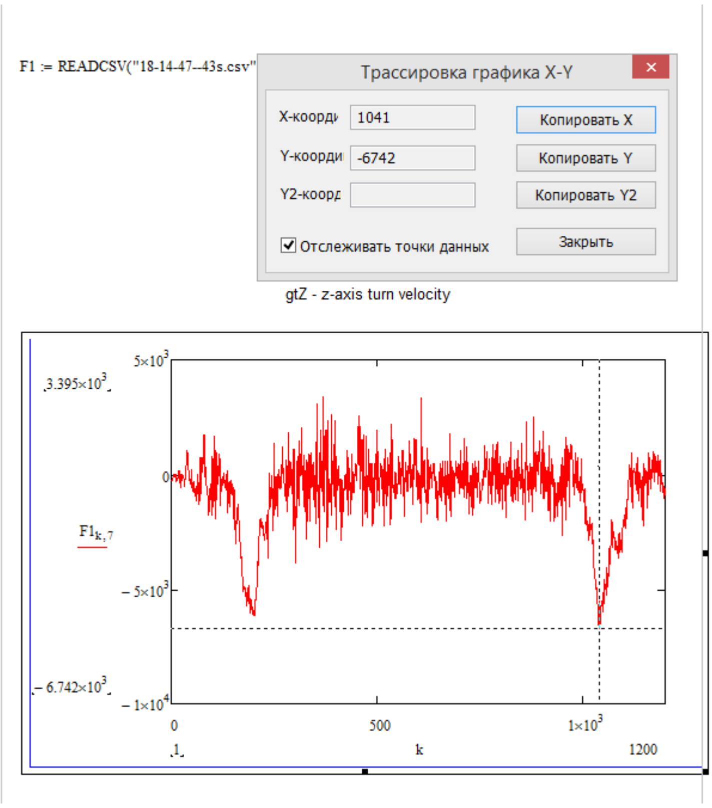
Appendix 1. Risks

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X-коорди
1041
Y-коорди
-6742
Y2-коорд
Копировать X
Копировать Y
Копировать Y2
Отслеживать точки данных
Закрыть
gtZ - z-axis turn velocity
3.395×10^3
F1k,7
− 6.742×10^3
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− 5×10^3
− 1×10^4
0
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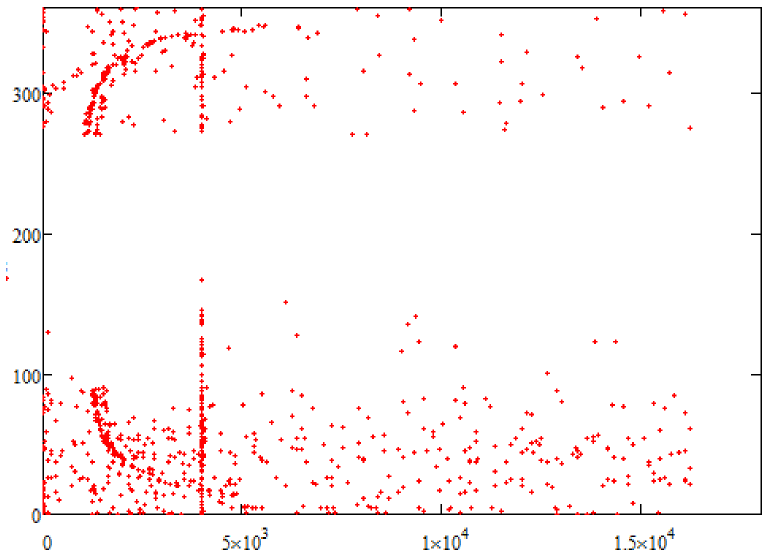
1
k
1200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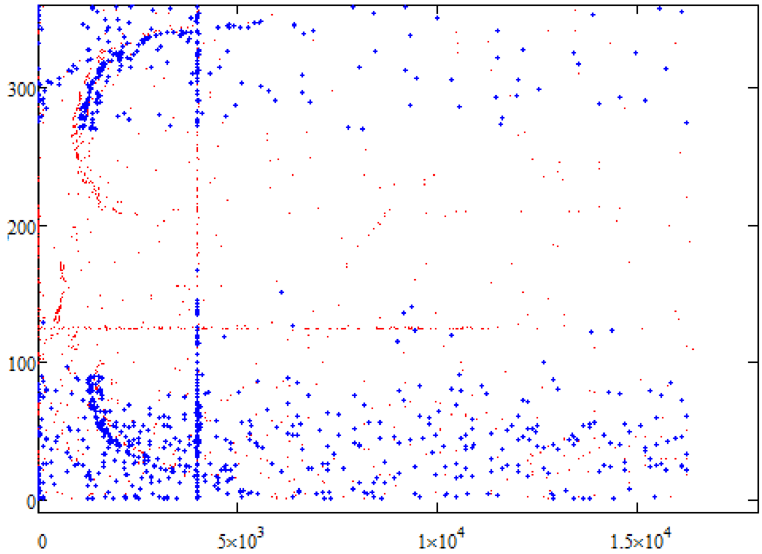
1.5×10^4



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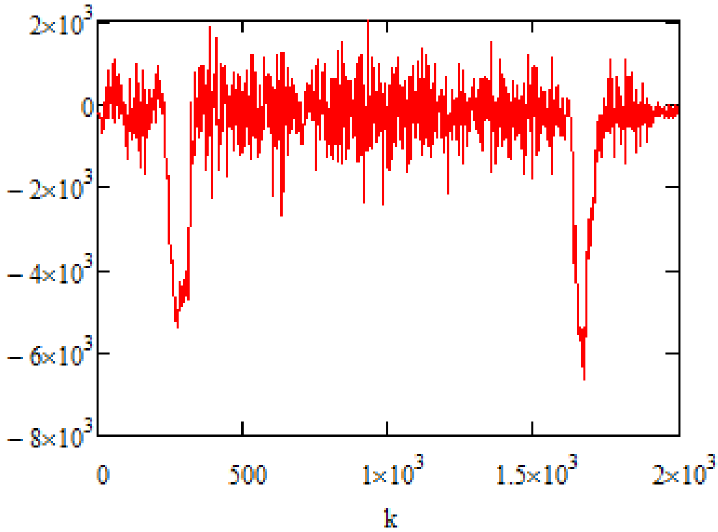

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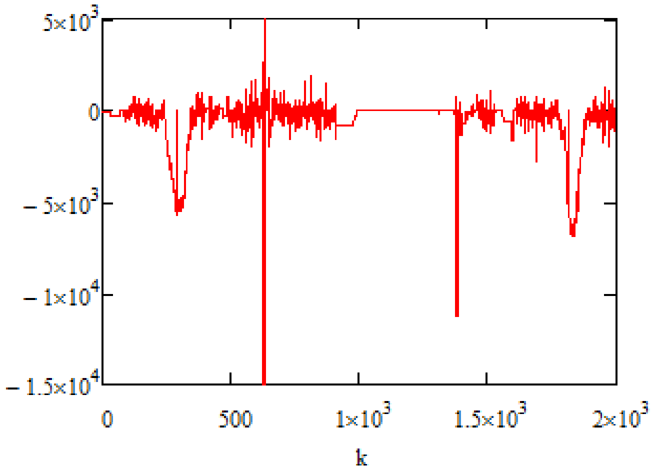
2×10^3
k



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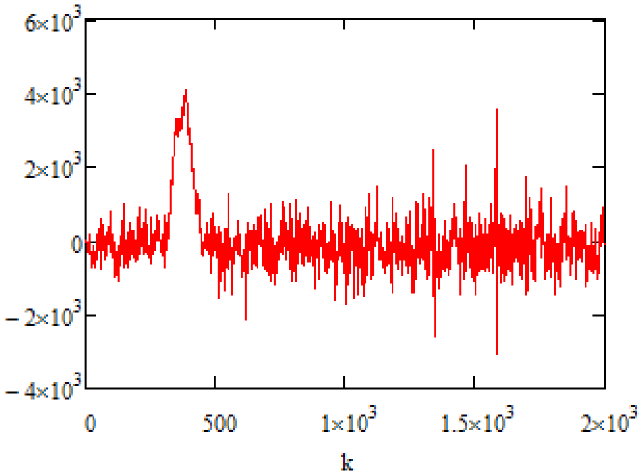
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− 2×10^3
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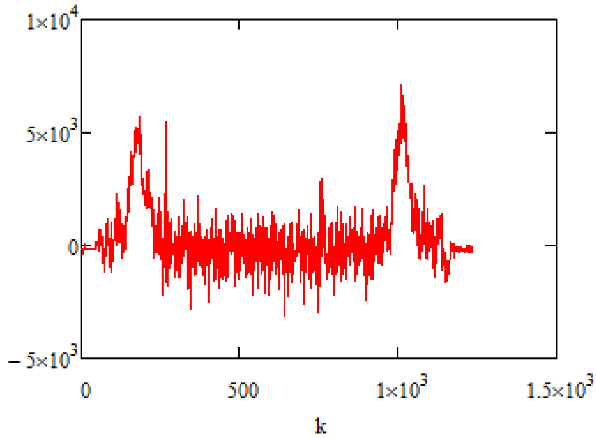
k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500
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1.5×10^3
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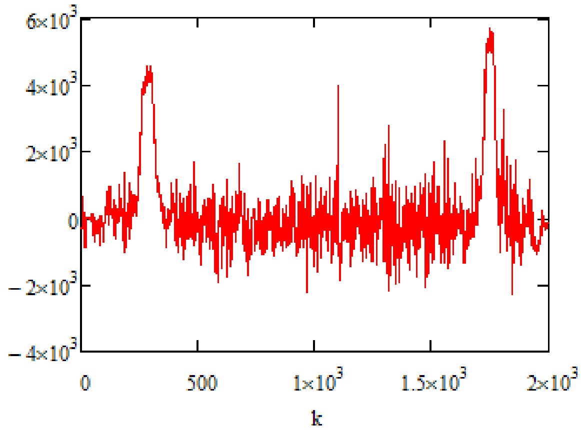
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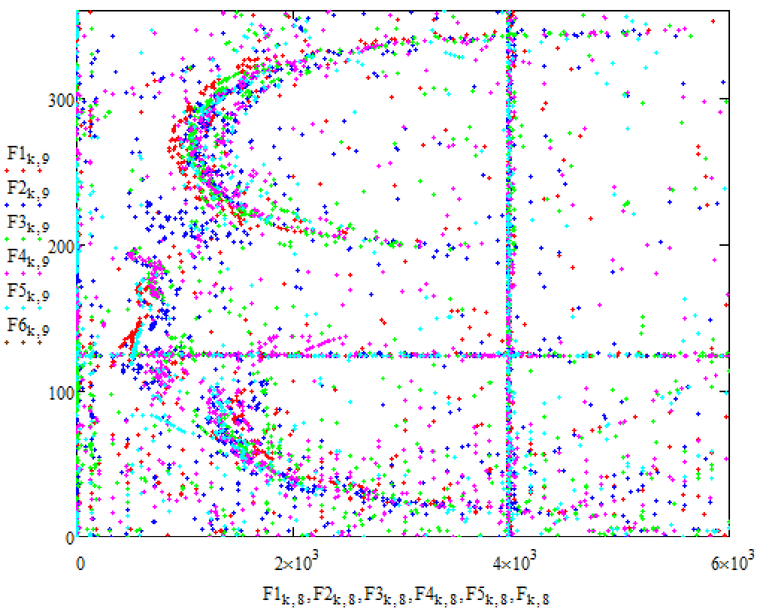
k



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200
100
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F2k, 9
F3k, 9
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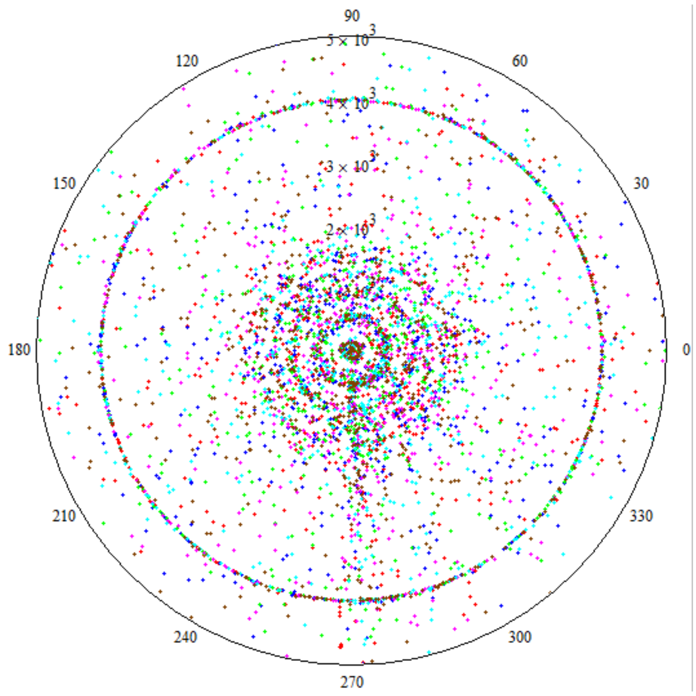

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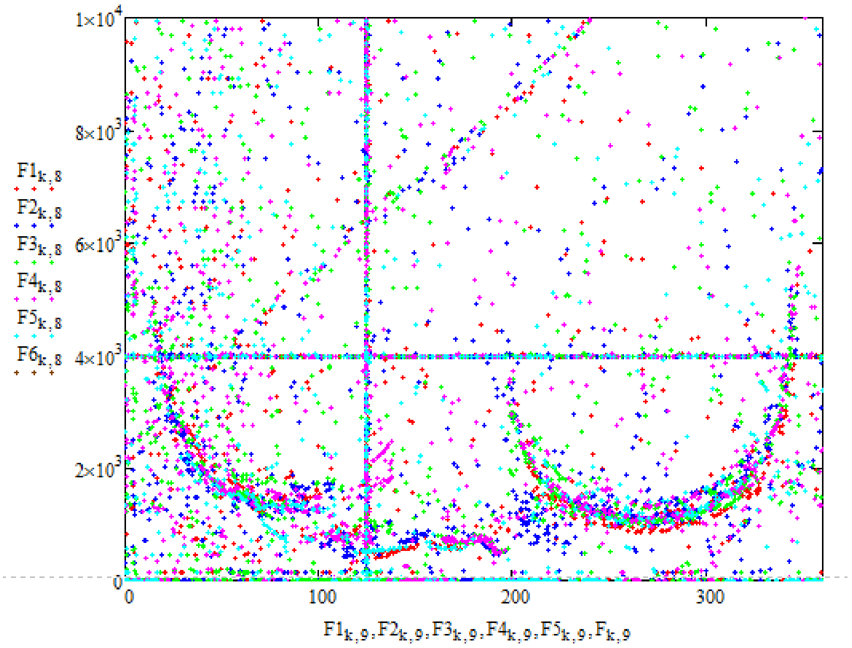
4 × 10³
3 × 10³
2 × 10³



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F2k,8
F3k,8
F4k,8
F5k,8
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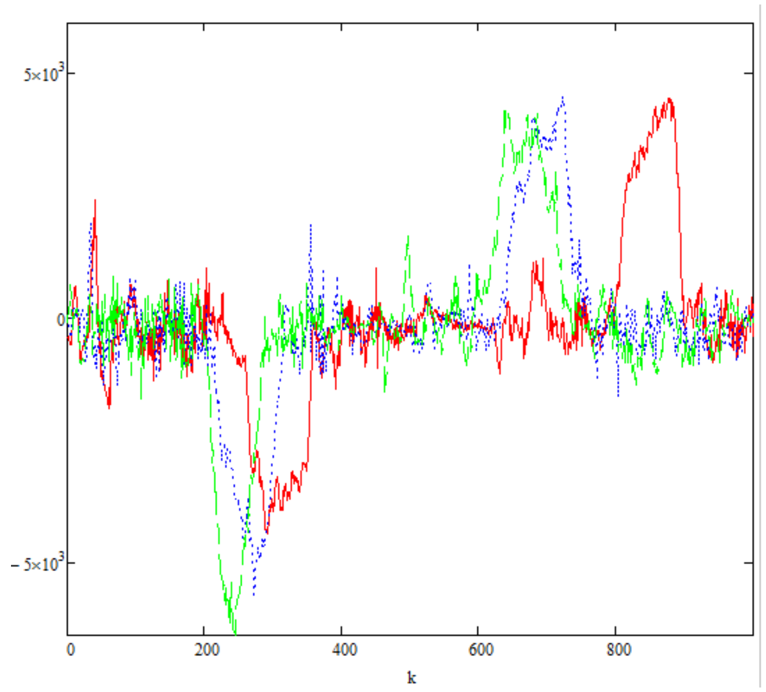

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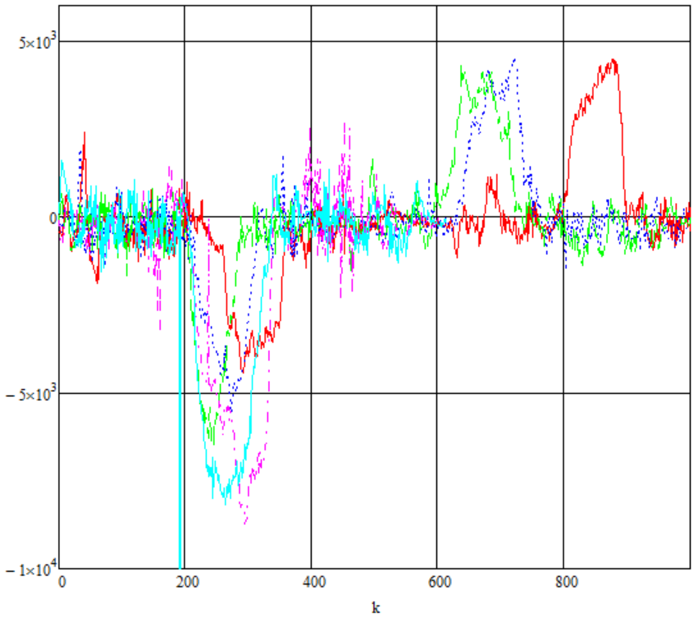
− 5×10^3
0
200
400
600
800
k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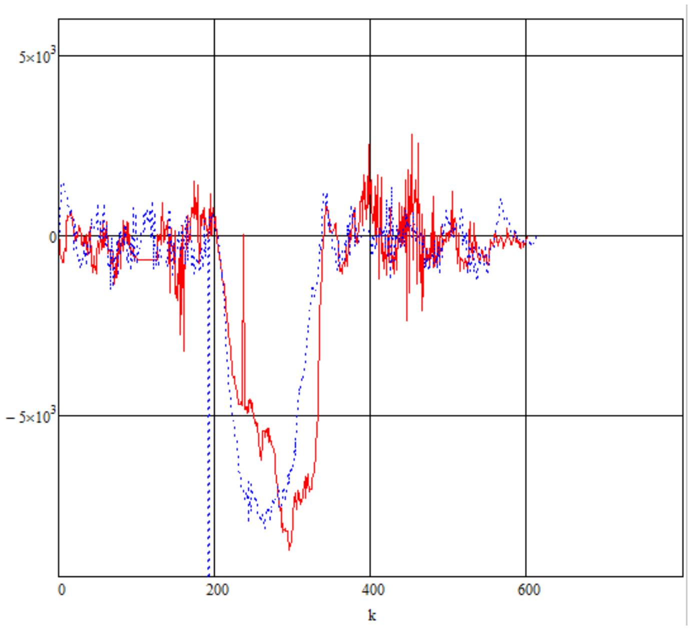
− 1×10⁴
0
200
400
600
800
k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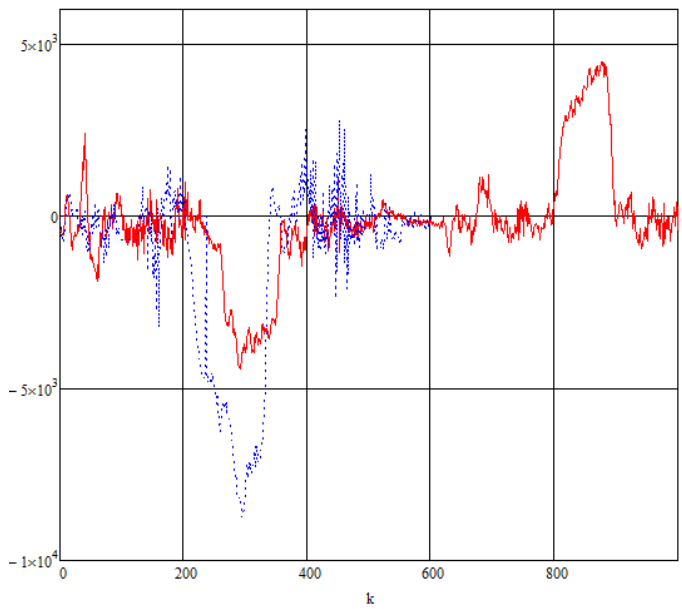
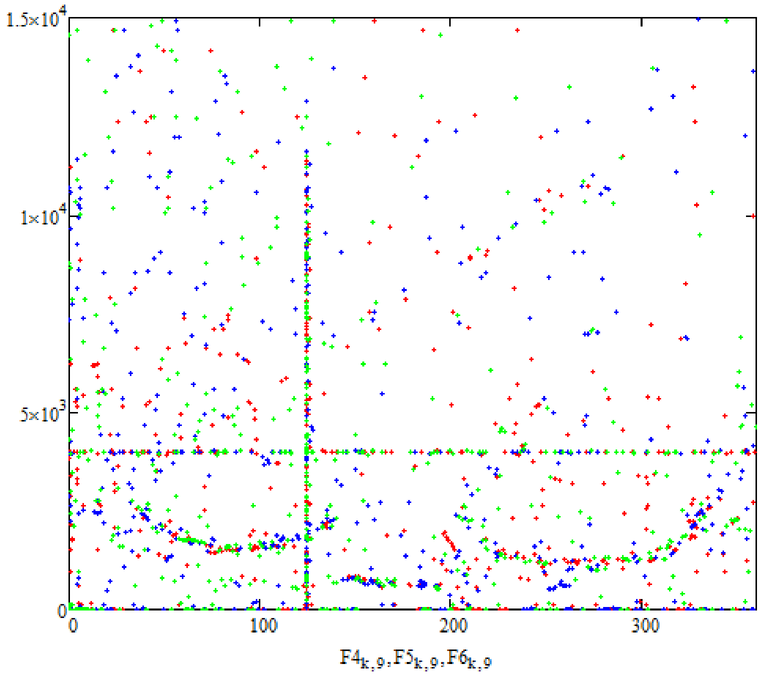
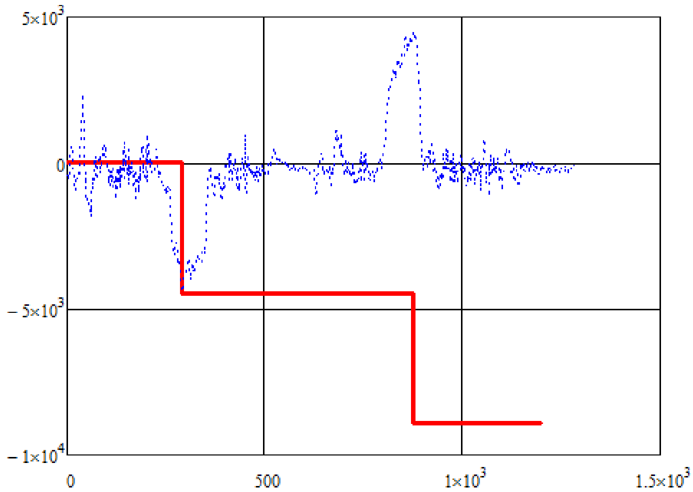
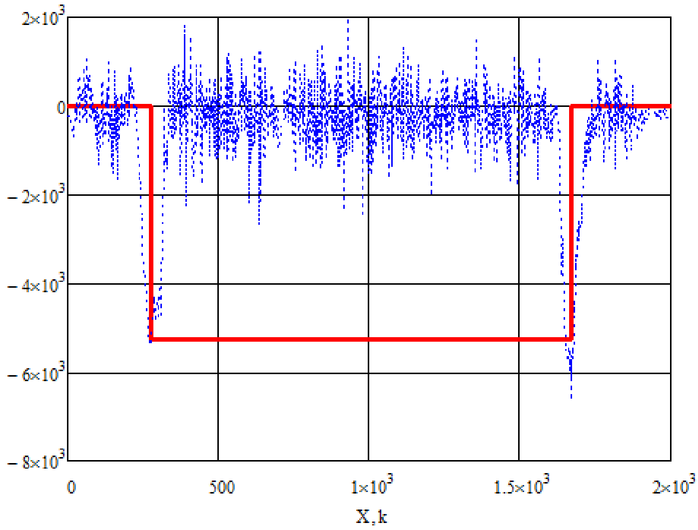
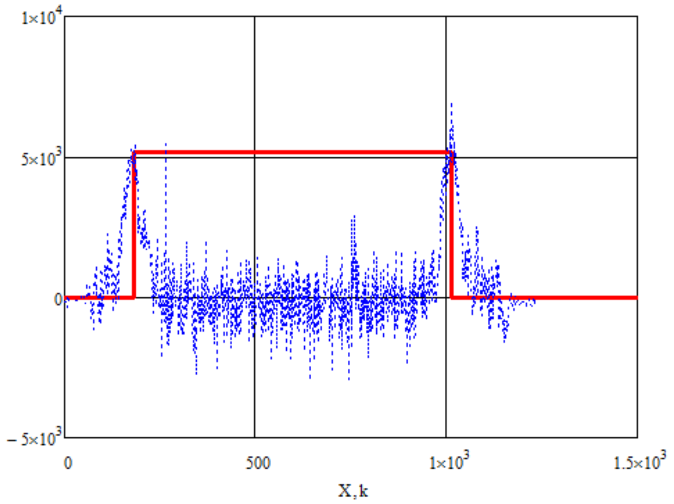
0
200
400
600
k


5×10³
0
− 5×10³
− 1×10⁴
0
200
400
600
800
k

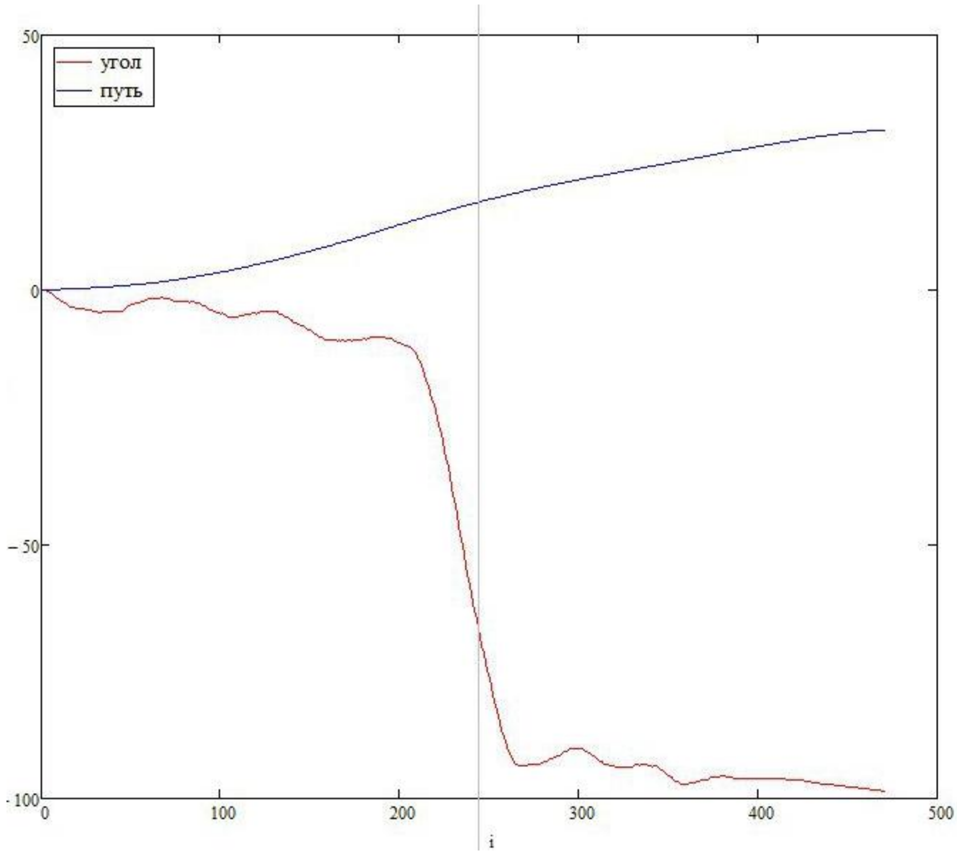

1.5×10^4
1×10^4
5×10^3
0
0
100
200
300
F4k,9,F5k,9,F6k,9


5×10^3
0
−5×10^3
−1×10^4
0
500
1×10^3
1.5×10^3


2×10^3
0
−2×10^3
−4×10^3
−6×10^3
−8×10^3
0
500
1×10^3
1.5×10^3
2×10^3
X,k

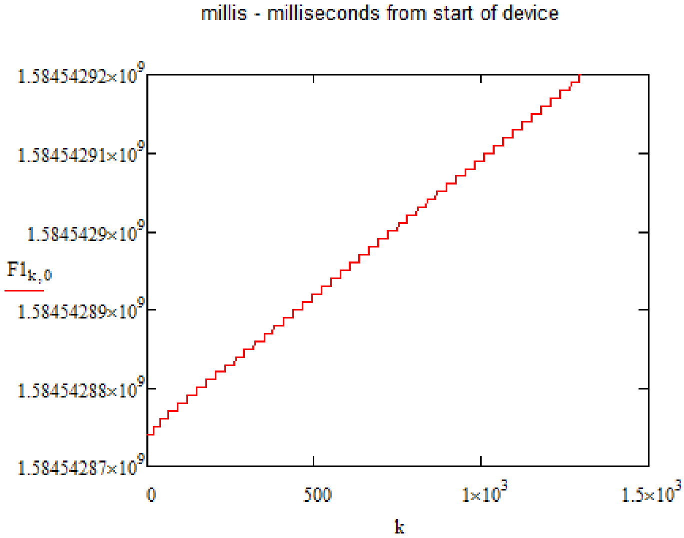


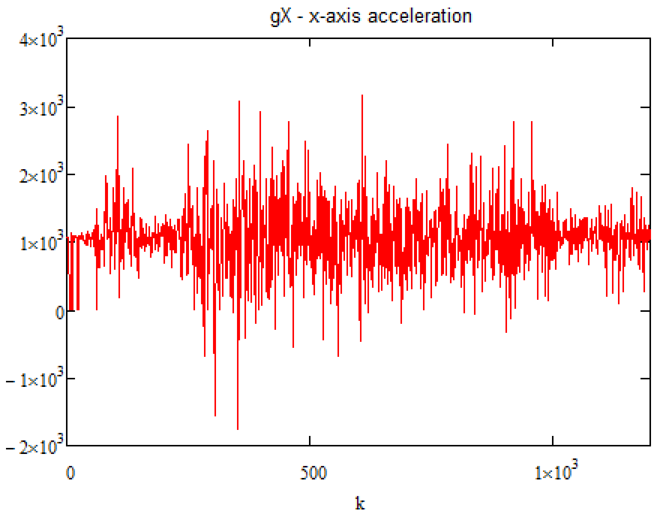
1×10^4
5×10^3
0
− 5×10^3
0
500
1×10^3
1.5×10^3
X, k

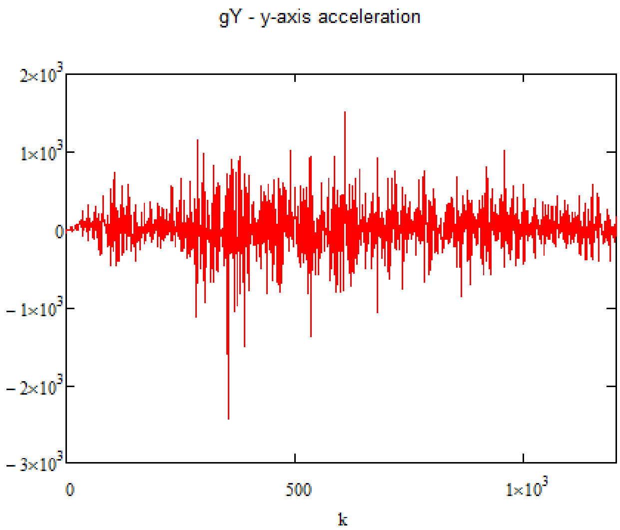


угол
путь
50
0
− 50
- 100
0
100
200
300
400
500
i

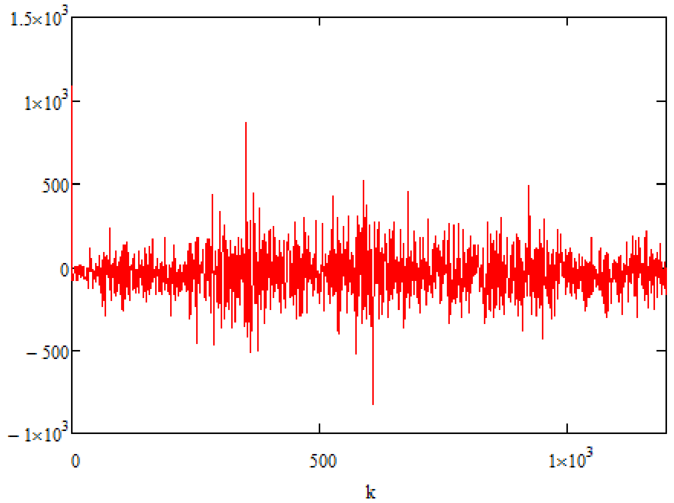
Appendix 2. Graphs



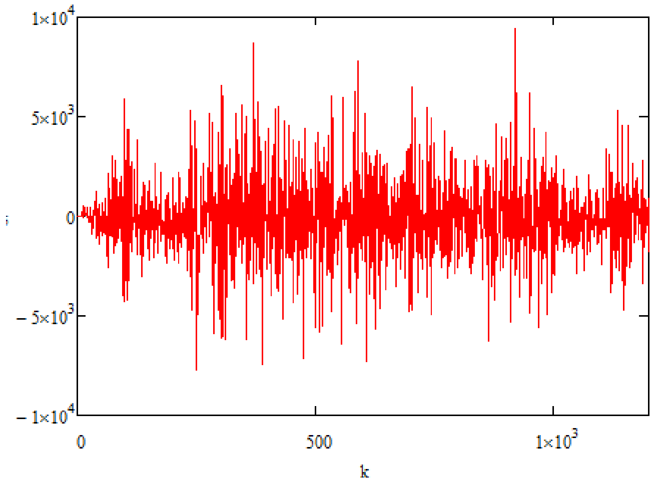




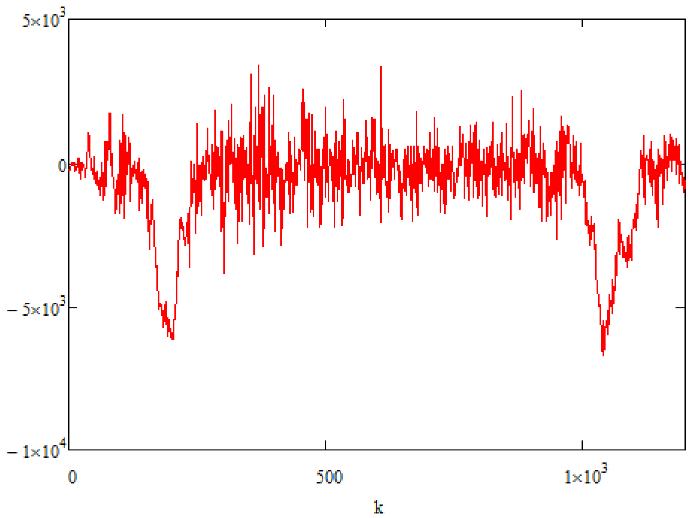
gZ - z-axis acceleration

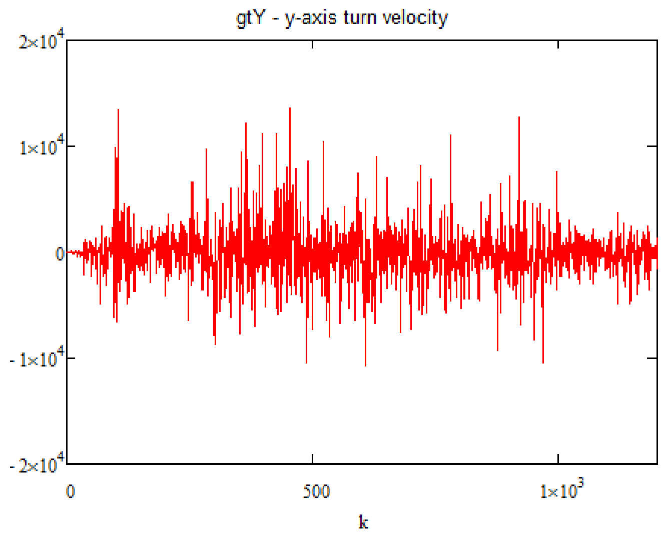


gtX - x-axis turn velocity

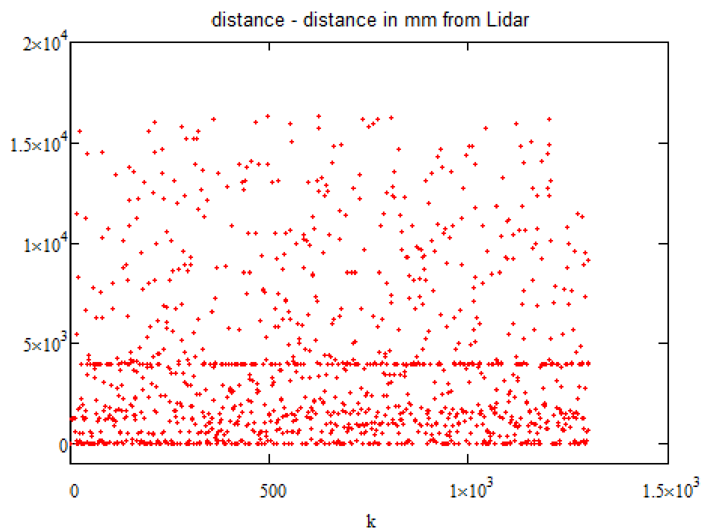


gtZ - z-axis turn velocity

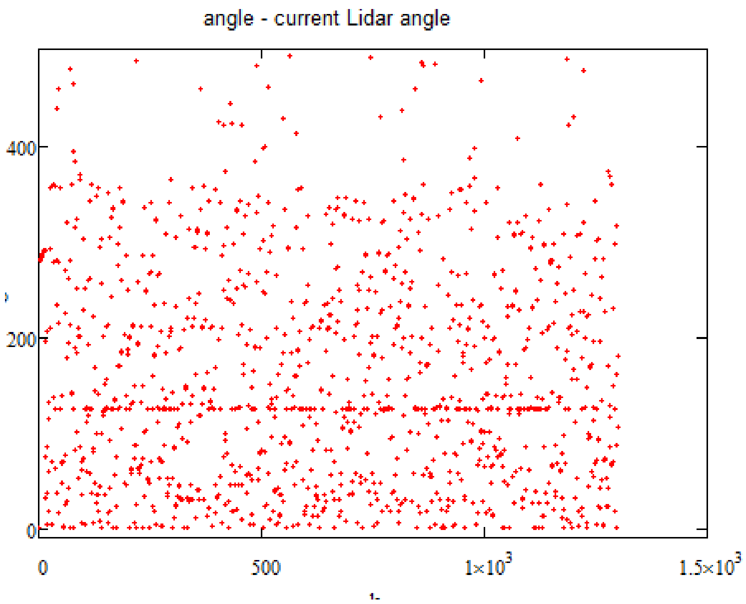




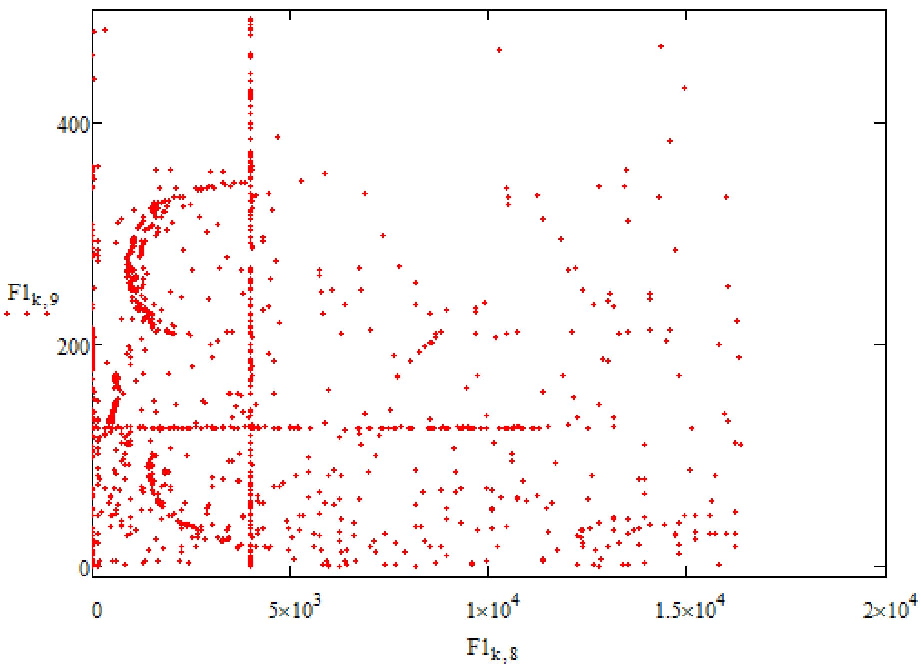
gtY - y-axis turn velocity
2×10^4
1×10^4
0
- 1×10^4
- 2×10^4
0
500
1×10^3
k

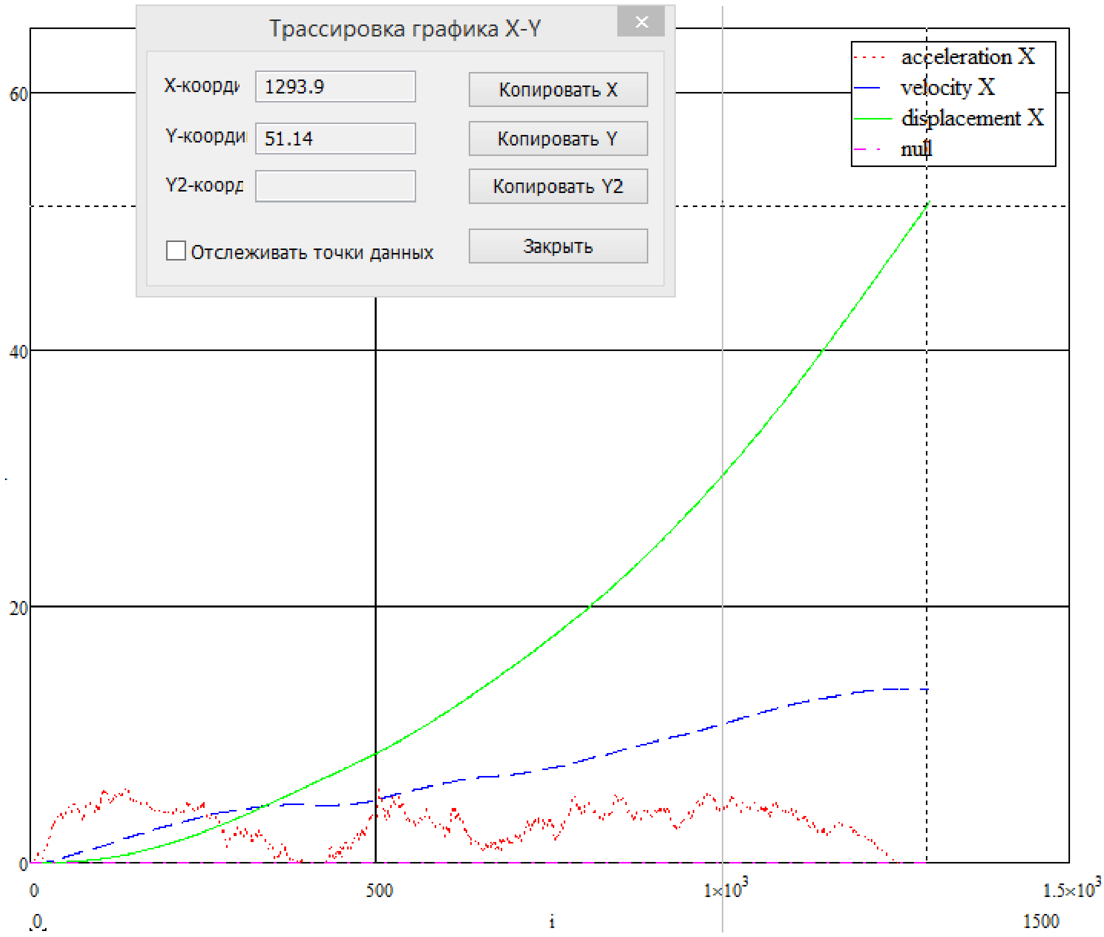


distance - distance in mm from Lidar
2×10^4
1.5×10^4
1×10^4
5×10^3
0
0
500
1×10^3
1.5×10^3
k

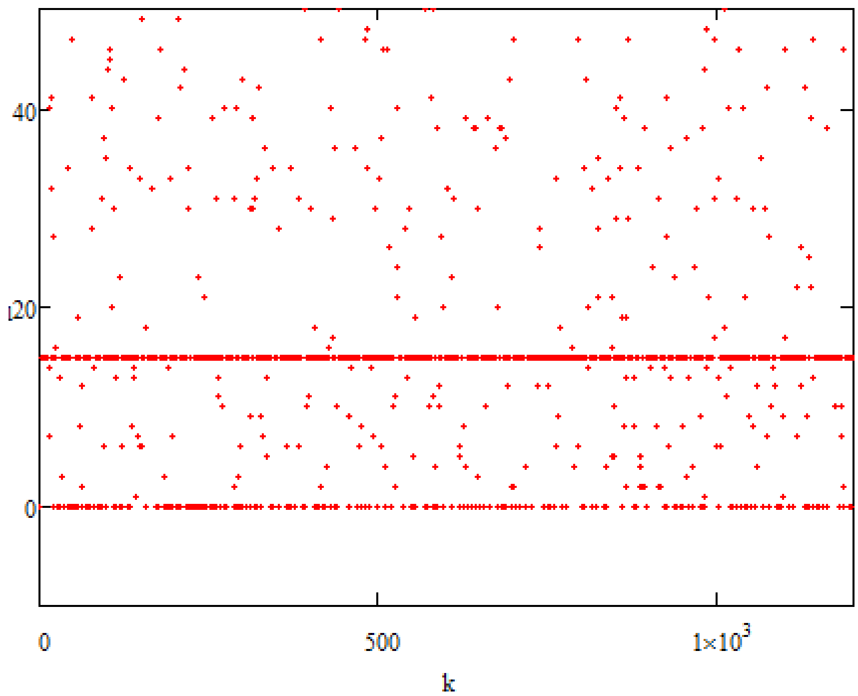


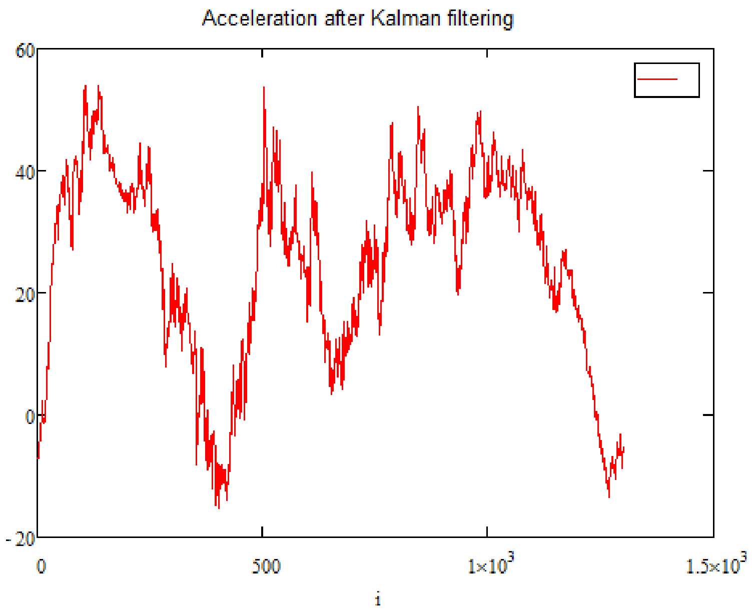
angle - current Lidar angle
400
200
0
0
500
1×10^3
1.5×10^3

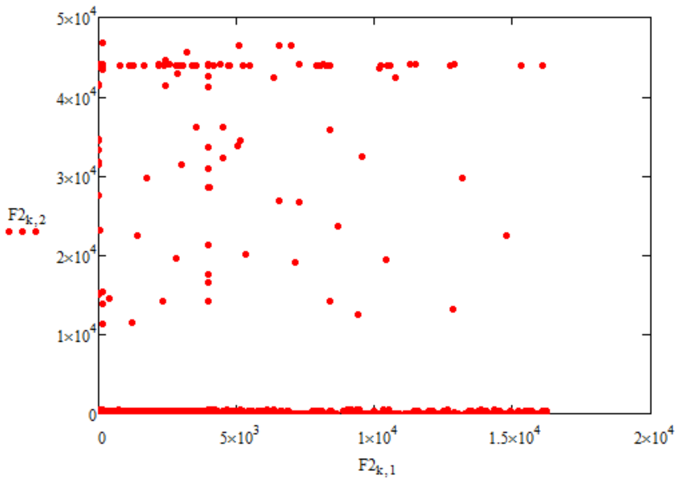

400
200
0
F1k, 9
0
5×10^3
1×10^4
1.5×10^4
2×10^4
F1k, 8

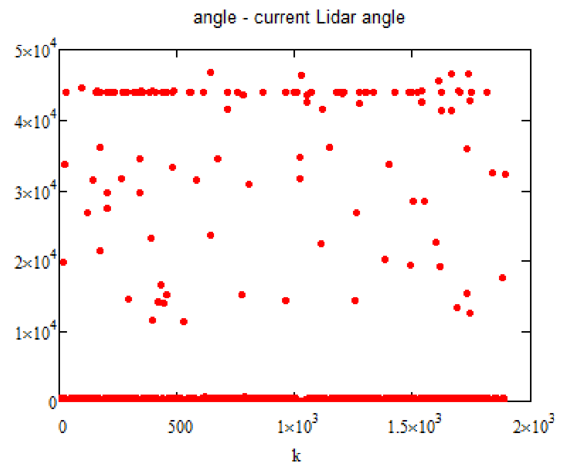


quality - Lidar quality indicator




Acceleration after Kalman filtering
60
40
20
0
- 20
0
500
1×10^3
1.5×10^3
i


5×10^4
4×10^4
3×10^4
2×10^4
1×10^4
0
F2k,2
0
5×10^3
1×10^4
1.5×10^4
2×10^4
F2k,1


angle - current Lidar angle
5×10^4
4×10^4
3×10^4
2×10^4
1×10^4
0
0
500
1×10^3
1.5×10^3
2×10^3
k

Appendix 3. Calculations

-29.92	591.5	60.08
-31.03	9792.5	58.97
-67.72	25.5	22.28
207.16	3971.5	297.16
253.02	2840.75	343.02
36.81	6351.5	126.81
-60.33	15311.5	29.67
-60.12	11328.5	29.88
266.53	2877.25	356.53
267.59	3310.75	357.59
-89.39	128	0.61
-89.39	1344	0.61
207.3	5770	297.3
-78.47	2807.25	11.53
-66.14	9423.5	23.86
220.13	3871	310.13
-7.89	9551.5	82.11
-63.14	2127.5	26.86
24.66	3970.5	114.66
-88.08	3968	1.92
-54.69	3977.75	35.31
-37.48	1960.5	52.52
-35.02	1487.5	54.98
-85.5	3977.25	4.5
-47.75	3910.5	42.25
201.86	0	291.86
202.92	11448.75	292.92
0		
0		
0		
-72.84	3987.25	17.16
0		
-4.06	1527.25	85.94

0		
-20.8	3980.25	69.2
-63.66	2380.5	26.34
-62.58	2404.75	27.42
0		
0		
0		
0		
-49.77	2327.25	40.23
0		
0		
-22.55	4047.5	67.45
0		
0		
188.05	0	278.05
-31.81	10831.5	58.19
256.44	1103.5	346.44
-30.22	3008.5	59.78
-32.47	4431.5	57.53
204.28	0	294.28
205.34	0	295.34
268.41	1928.5	358.41
-36.17	6351.5	53.83
0		
0		
-15.52	3649.5	74.48
0		
-3.25	978.25	86.75
-2.05	954.5	87.95
-0.91	64.5	89.09
0		
0		
-62.31	1915.75	27.69
-61.27	1923.75	28.73
0		
0		
0		
230.83	2313	320.83
-46.87	1941	43.13
0		
0		
0		
247.75	9295.5	337.75
0		
0		
0		

0		
-24.52	2126	65.48
0		
210.58	5568	300.58
0		
0		
-88.78	2432	1.22
0		
-64.77	14159.5	25.23
0		
0		
34.94	3973	124.94
-56.77	1642.25	33.23
-55.7	9869.25	34.3
0		
0		
0		
0		
0		
-40.2	787.5	49.8
0		
0		
0		
249.33	4007.25	339.33
-38.44	12367.5	51.56
0		
0		
0		
185.08	3975.75	275.08
191.88	2164	281.88
-37.75	13772.5	52.25
-85.27	7263.25	4.73
0		
-34.22	2383.5	55.78
-11.03	189.25	78.97
0		
-89.45	3136.5	0.55
245.45	1515.25	335.45
-41.58	0	48.42
-47.48	15747.25	42.52
-9.56	3970.5	80.44
0		
0		
0		
251.14	1728	341.14
-33.92	1570.5	56.08

-33.03	4431.5	56.97
0		
0		
-41.06	14799.5	48.94
0		
0		
198.31	1453.25	288.31
-88.14	3011.75	1.86
-14.62	1577.25	75.38
-89.41	3968	0.59
0		
-36.78	2383.5	53.22
0		
214.05	3976.75	304.05
-1.73	1606.25	88.27
0		
225.17	2294.25	315.17
-31.2	3264.75	58.8
0		
0		
-84.92	8142.25	5.08
230.3	1306.75	320.3
0		
0		
-67.56	11599.5	22.44
-69.2	7247.5	20.8
0		
242.92	3722.5	332.92
0		
0		
32.77	3976.25	122.77
0		
0		
0		
185.11	4.5	275.11
-83.42	3973	6.58
0		
208.78	1302.5	298.78
0		
-78.02	4483.75	11.98
-76.94	4185.75	13.06
-5.83	1278.25	84.17
-4.56	1272.5	85.44
0		
0		
0		

0		
-64.69	2674.25	25.31
-63.59	1008.75	26.41
0		
0		
0		
0		
0		
233.34	3976.75	323.34
-44.89	3756.25	45.11
0		
181.66	1107.75	271.66
253.3	5057.75	343.3
254.34	5238.25	344.34
0		
-27.94	3663.5	62.06
0		
0		
194.52	1142.5	284.52
195.56	1139.25	285.56
3.75	0	3.75
4.81	1736.5	4.81
0		
347.17	2266.75	347.17
17.5	1280	17.5
83.48	1278	83.48
0		
41.42	4815.5	41.42
0		
0		
0		
0		
315.36	1612.5	315.36
316.38	873.75	316.38
23.83	14287.5	23.83
0		
0		
0		
40.78	4030.25	40.78
11.5	8015.5	11.5
0		
0		
0		
0		
54.38	4047.5	54.38
0		

122.77	3980.25	122.77
0		
317.2	3973.25	317.2
42.95	1096.5	42.95
382.02	2458.25	382.02
14.3	0	14.3
0		
83.53	19.75	83.53
0		
299.63	1274.5	299.63
300.73	1290.75	300.73
301.75	22.5	301.75
13.22	1957.25	13.22
0		
0		
0		
314.14	1534.75	314.14
315.11	2839.25	315.11
27.84	2745	27.84
0		
0		
0		
282.98	3972.25	282.98
63.27	7247.5	63.27
118.44	3971	118.44
77.03	3972.25	77.03
54.03	1581.25	54.03
26.14	5824.5	26.14
0		
43.34	2383.5	43.34
0.56	128	0.56
0		
0		
287.72	1156.25	287.72
288.73	1163	288.73
7.86	0	7.86
78.17	4234	78.17
0.78	2496.5	0.78
0		
0		
46.06	12111.5	46.06
44.67	9615.5	44.67
302.28	1303.5	302.28
22.06	0	22.06
0		
0		

316.69	3973.75	316.69
0		
27.14	1615.5	27.14
0		
0		
327.66	4023.5	327.66
0		
136.95	3971	136.95
0		
340.58	3677.25	340.58
341.64	6854.75	341.64
0		
0		
1.06	1664	1.06
0		
0		
0		
0		
10.39	394.5	10.39
85.55	128	85.55
0		
0		
44.89	3973.25	44.89
17.78	3973.75	17.78
112.34	3972.75	112.34
0		
0		
-254.77	3974.25	105.23
31.98	2397.25	31.98
33.08	16221.25	33.08
0		
0		
46.66	9942	46.66
0		
15.64	8911.5	15.64
16.27	335.5	16.27
0		
0		
59.77	1464	59.77
0		
0		
0		
0		
0		
21.06	4687.5	21.06
39.16	12879.5	39.16

314	1522.75	314
87.81	6223.5	87.81
23.45	3791.5	23.45
0		
0		
0		
61.81	7503.5	61.81
0		
0		
0		
0		
397.09	3724.5	397.09
0		
0		
0		
0		
0		
1.02	0	1.02
67.03	1380.5	67.03
65.33	5711.5	65.33
5.81	13188	5.81
14.75	1296	14.75
80.81	1293.25	80.81
5.94	5118.25	5.94
36.72	10703.5	36.72
19.08	0	19.08
20.14	1274.25	20.14
0		
0		
0		
0		
312.11	3980	312.11
23.72	10191.5	23.72
24.2	1123.25	24.2
0		
324.77	13391.5	324.77
0		
0		
0		
0		
50.73	1605.5	50.73
51.81	1579	51.81
52.86	1562.5	52.86
0		
279.14	1071.5	279.14
358.34	0	358.34

359.42	1344	359.42
65.17	1373.5	65.17
66.33	3986.75	66.33
0		
0		
0		
0		
0		
0		
0		
0		
0		
0		
315.8	2053	315.8
316.86	13507	316.86
0		
23.3	15311.5	23.3
34.81	15183.5	34.81
0		
0		
0		
0		
0		
53.39	1530.5	53.39
90.47	4111.5	90.47
0		
5.63	33.25	5.63
2.11	2161.25	2.11
68.64	1327	68.64
0		
64.83	3975	64.83
0		
9.31	1216	9.31
84.61	1251.25	84.61
85.69	5470	85.69
0		
0		
304.39	1717.25	304.39
0		
0		
37.44	5583.5	37.44
0		
24.03	16079.5	24.03
0		
43.45	11983.5	43.45
43.7	4687.5	43.7

331.56	2508.75	331.56
332.59	2622.75	332.59
0		
0		
0		
273.92	1346.5	273.92
0		
82.53	11087.5	82.53
0		
0.02	128	0.02
9.38	2344.75	9.38
74.31	0	74.31
0		
53.95	3151.5	53.95
292.08	1486.75	292.08
293.14	1501.75	293.14
294.23	1518.5	294.23
13.25	0	13.25
6.45	3972.75	6.45
0		
0		
0		
38.78	10703.5	38.78
21.81	2142.5	21.81
53.91	2127.5	53.91
31.3	2392.5	31.3
46.41	6349	46.41
26.69	8642.75	26.69
334.23	2647.25	334.23
48.11	1661.5	48.11
0		
0		
1.38	128	1.38
0		
0		
0		
0		
0		
0		
71.8	12111.5	71.8
282.66	1167	282.66
3.7	0	3.7
3.41	0	3.41
39.45	2767.5	39.45
0		
296.5	1281.75	296.5

17.48	1229.75	17.48
0		
22.25	7610.75	22.25
0		
312.28	3996.75	312.28
0		
48.69	3970.75	48.69
45.11	4431.5	45.11
324.88	2058	324.88
0		
24.34	11712.5	24.34
393.03	3972.25	393.03
0		
52.19	3974	52.19
47.56	6223.5	47.56
0		
0		
272.66	1136	272.66
273.73	11556.75	273.73
0.83	0	0.83
1.91	0	1.91
66.8	1325.25	66.8
4.02	4710.25	4.02
70.27	6223.5	70.27
71.86	9153.75	71.86
7.09	2560	7.09
0		
0		
116.88	3974.75	116.88
87.52	1224.25	87.52
0		
0		
53.81	15055.5	53.81
75.36	3242.75	75.36
0		
0		
0		
71.64	16079.5	71.64
41.27	1781	41.27
42.41	1738.75	42.41
43.48	12264	43.48
366.56	3970.25	366.56
34.25	719.5	34.25
0		
0		
0		

84.33	3972.5	84.33
0		
0		
310.34	3979.75	310.34
24.34	16079.5	24.34
0		
0		
0		
324.34	4004.75	324.34
136.14	3975.25	136.14
0		
0		
0		
136.06	3969.75	136.06
134.75	3969.75	134.75
0		
50.78	1547.75	50.78
52.19	756.25	52.19
0		
0		
0		
278.8	1181.25	278.8
25.47	3973.25	25.47
0		
0		
284.28	1210	284.28
1.31	128	1.31
78.92	1234.5	78.92
57.09	3974.5	57.09
297.58	178.5	297.58
0		
0		
0		
0		
293.2	14534	293.2
0		
0		
0		
0		
325.2	2106.25	325.2
0		
0		
0		
0		
53.31	3980.75	53.31
51.94	1524.25	51.94

22	6735.5	22
0		
0		
0.91	0	0.91
7.02	7879.5	7.02
4.02	5491.25	4.02
65.38	3983.5	65.38
38.38	128	38.38
0		
0		
0		
43.88	2511.5	43.88
303.33	5067.5	303.33
13.36	4724.75	13.36
34.36	3972.75	34.36
0		
0		
70.09	3974.5	70.09
353.22	3974.5	353.22
75.22	6735.5	75.22
25.41	131	25.41
0		
0		
328.06	12111.5	328.06
406.2	8846.25	406.2
0		
0		
56.22	1452.5	56.22
0		
0		
0		
36.98	3919.5	36.98
3.86	0	3.86
74.94	3973	74.94
0		
0		
290.34	38.75	290.34
18.98	0	18.98
85.22	1219	85.22
0		
0		
0		
16.41	4115.75	16.41
0		
0		
0		

21.41	14671.5	21.41
0		
0		
0		
0		
0		
76.22	4175.5	76.22
114.45	3971	114.45
0		
0		
59.41	1424.25	59.41
60.52	6479.5	60.52
25.56	15567.5	25.56
0		
1.08	128	1.08
0.02	12879.5	0.02
0		
119.97	3975.25	119.97
0		
292.97	1269	292.97
150.33	6084.5	150.33
0		
0		
306.28	1432.5	306.28
0		
0		
0		
0		
0		
0		
0		
0		
34.44	4018	34.44
368.41	5764.75	368.41
0		
334.23	2577.5	334.23
47.59	1685.75	47.59
25.78	207.5	25.78
0		
36.69	11599.5	36.69
0		
292.23	133.25	292.23
0		
36.83	1231.5	36.83
1.28	128	1.28
11.64	8655.5	11.64

55.39	8271.5	55.39
0		
16.48	1207.5	16.48
0		
0		
43.92	15951.5	43.92
310.27	4303.5	310.27
0		
66.36	3972.75	66.36
0		
0		
0		
57.75	3663.5	57.75
0		
0		
25.64	7232.5	25.64
0		
335.53	2725.5	335.53
48.55	1648.5	48.55
50.02	795.75	50.02
0		
0		
356.83	0	356.83
363.14	3973.25	363.14
0		
0		
0		
37.14	10831.5	37.14
3.94	0	3.94
78.66	1263.25	78.66
52.86	5967.5	52.86
298.63	12499.5	298.63
0		
42.3	2767.5	42.3
310.98	1516.75	310.98
312.06	1532	312.06
0		
20.77	4559.5	20.77
21.88	12623.5	21.88
37.67	1743.5	37.67
325.47	2010.5	325.47
326.58	8406.75	326.58
40	1961.75	40
41.06	4026.25	41.06
0		
36.47	13007.5	36.47

341.27	11489.75	341.27
0		
0		
0		
35.77	4815.5	35.77
16.98	4469	16.98
0		
0		
0		
0		
22.63	3348.75	22.63
0		
0		
38.13	12495.5	38.13
58.86	1157.25	58.86
65.92	2767.5	65.92
0		
334.13	2661.5	334.13
336.52	2766.25	336.52
0		
0		
0		
277.17	1139.75	277.17
349.95	1989.5	349.95
64.56	1785	64.56
0		
0		
11.13	0	11.13
12.2	3968	12.2
78.13	4997.75	78.13
0		
0		
0		
0		
0		
0		
21.73	4815.5	21.73
0		
0		
311.47	1518.75	311.47
0		
0		
0		
0		
0		
30.14	3975.75	30.14

302.44	515.25	302.44
0		
0		
0		
55.05	1561.25	55.05
129.09	132.25	129.09
0	3200	0
0		
290.48	5914.75	290.48
39.84	14543.5	39.84
0		
0		
0		
0		
0		
303.38	1352.25	303.38
304.38	1366.75	304.38
305.45	11982.5	305.45
0		
0		
0		
123.06	14357.25	123.06
39.11	10127.5	39.11
0		
30.06	3973	30.06
0		
0		
0		
43.61	1832.25	43.61
0		
0		
0		
272.61	3279.5	272.61
0		
0		
0		
0		
37.16	3151.5	37.16
6.41	0	6.41
311.48	3973	311.48
0		
140.84	9350.75	140.84
0		
377.64	3972.75	377.64
0		
3.19	10181.5	3.19

0		
40.25	3279.5	40.25
63.92	3972.75	63.92
144.95	3972.5	144.95
319.55	1763	319.55
404.41	3971	404.41
0		
0		
47.03	13344.5	47.03
0		
0		
0		
0		
274.33	16202.5	274.33
347.13	5415.5	347.13
355.92	1452.25	355.92
61.03	1435.25	61.03
0		
64.8	3977.5	64.8
288.13	1193.5	288.13
289.16	1203.5	289.16
290.22	0	290.22
8.84	3968	8.84
0		
0		
0		
14.17	4777	14.17
0.61	128	0.61
0		
45.19	13391.5	45.19
274.06	3973	274.06
358.67	7874.5	358.67
0		
0		
319.56	1825.75	319.56
32.31	2665.5	32.31
0		
84.61	6469.75	84.61
140.17	3971.25	140.17
0		
0		
354.63	4032	354.63
0		
0		
0		
0		

287.53	1215.25	287.53
288.53	128	288.53
84.28	3973	84.28
0.2	128	0.2
0.59	128	0.59
39.84	3791.5	39.84
142.05	3984.5	142.05
90.05	3972.75	90.05
0		
308.16	1510	308.16
309.2	1535.75	309.2
0		
0		
322.88	1987.75	322.88
0		
0		
0		
0		
0		
337.5	3578.5	337.5
338.59	3547.75	338.59
339.66	3610.25	339.66
340.69	3802	340.69
51.14	1575.75	51.14
0		
0		
0		
0		
352.42	3973.25	352.42
0		
306.81	3976	306.81
293.97	11968.5	293.97
428.3	3972.75	428.3
0		
0		
45.16	3973	45.16
20.05	3376	20.05
0		
166.64	3970.75	166.64
0		
312.2	1571.5	312.2
0		
25.91	10458.25	25.91
26.27	4303.5	26.27
0		
37.31	15183.5	37.31

327.11	1223.75	327.11
24.42	15439.5	24.42
0		
0		
0		
53.83	1870	53.83
0		
0		
41.63	448.75	41.63
15.14	4865.5	15.14
38.23	7247.5	38.23
0		
0		
44.63	3978.5	44.63
309.25	6597.25	309.25
0		
0		
0		
335.63	2701.75	335.63
336.69	2800	336.69
337.72	2921.75	337.72
338.77	3044.25	338.77
339.81	3202	339.81
340.86	3379.25	340.86
341.92	3567.75	341.92
0		
0		
0.13	128	0.13
90.19	10512.75	90.19
0		
37.2	12623.5	37.2
77.81	1551.25	77.81
78.88	1545.75	78.88
79.97	1539.75	79.97
5	5033.25	5
0		
282.86	3974.25	282.86
0		
89.44	1527.5	89.44
0		
0		
0		
307.81	1760	307.81
28.73	2672.75	28.73
24.92	11983.5	24.92
0		

0		
321.98	2083.5	321.98
75.17	15567.5	75.17
22.97	1615.5	22.97
0		
0		
47.41	1757.25	47.41
0		
0		
0		
99.64	12642.25	99.64
0.16	128	0.16
63.44	1449.5	63.44
64.52	10000.75	64.52
0		
0		
314.17	1.25	314.17
78.64	448.5	78.64
119.13	10331.75	119.13
305.84	10343.5	305.84
0		
0		
0		
0		
0		
112.19	3977.75	112.19
0		
0		
21.94	10703.5	21.94
0		
324.44	1856.75	324.44
135.48	9157.5	135.48
47	14145.75	47
0		
15.59	8463.5	15.59
0		
338.47	2937.75	338.47
53.52	13647.5	53.52
0.23	14400.5	0.23
0		
343.08	64	343.08
1.39	8399.5	1.39
70.69	12224.5	70.69
0		
12.06	0	12.06
13.13	0	13.13

78.73	15296.5	78.73
0		
0		
20.39	3971.75	20.39
0		
0		
312.14	759.25	312.14
0		
0		
0		
325.13	1937.75	325.13
326.16	4740.75	326.16
39.67	2019	39.67
40.77	1976.5	40.77
0		
0		
0		
0		
42.2	3535.5	42.2
341.31	3980.75	341.31
0		
0		
0		
0		
0	2176	0
0		
0		
0		
16.86	0	16.86
4.2	5243.75	4.2
0		
303.28	3804.5	303.28
23.73	3681	23.73
0		
0		
0		
49.78	7043.5	49.78
29.28	2989.25	29.28
74.42	3971	74.42
0.42	3971	0.42
0		
42.09	1873.25	42.09
25.2	3535.5	25.2
0.78	128	0.78
0		
54.11	1563.75	54.11

0		
0		
0		
0		
42	3973.5	42
0		
0		
0		
0		
10.86	0	10.86
11.94	0	11.94
77.53	1329.5	77.53
0		
60.67	16207.5	60.67
45.14	466.25	45.14
1.27	5071.5	1.27
0		
0		
20.52	3321.75	20.52
21.39	3174.5	21.39
84.39	3973.25	84.39
0		
0		
0		
0		
79.25	15311.5	79.25
75.78	7887.5	75.78
0		
0		
0		
0		
140.63	1604.75	50.63
114.77	11727.5	24.77
0		
0		
369.08	1116.5	279.08
370.11	3008.25	280.11
382.13	1214.25	292.13
91.19	128	1.19
90.61	128	0.61
99.16	3973	9.16
130.34	9039.5	40.34

402.44	9167.5	312.44
422.98	3972.25	332.98
368.98	1988.25	278.98
416.36	2082	326.36
417.42	1256.25	327.42
116.83	14671.5	26.83
136.83	3975.25	46.83
90.02	128	0.02
142.72	2255.5	52.72
130.63	5455.5	40.63
103.02	3026.75	13.02
384.89	3973.25	294.89
402.44	1524.25	312.44
403.44	1549.75	313.44
404.52	8043	314.52
380.09	3978.5	290.09
407.73	1654.5	317.73
152.33	3994.25	62.33
386.52	6599	296.52
124.84	1999.5	34.84
173.09	0.25	83.09
108.39	1529	18.39
174.3	15808.5	84.3
401.69	1497.5	311.69
402.69	1525.75	312.69
403.8	15695.5	313.8
115	2892	25
110.16	719.5	20.16

414.56	1966.75	324.56
128.39	2018.5	38.39
143.48	2639.5	53.48
362.14	1096.25	272.14
142.13	4040.5	52.13
97.61	14784.5	7.61
150.84	11983.5	60.84
97.13	0	7.13
388.88	1296.25	298.88
389.94	1318.25	299.94
138.38	5297.75	48.38
403.33	1609.25	313.33
404.38	1644.25	314.38
173.44	1359.5	83.44
170.73	10319.5	80.73
139.33	12431.5	49.33
416.41	3998.75	326.41
145.27	9792.5	55.27
161.39	1321.75	71.39
164.42	18.75	74.42
144	13647.5	54
380.69	1222	290.69
381.75	1233.25	291.75
101.98	3535.5	11.98
169.45	9024.5	79.45

134.61	10575.5	44.61
136.36	6479.5	46.36
110	14031.5	20
130.14	13391.5	40.14
412.31	2010.75	322.31
125.45	1975	35.45
126.53	3506.75	36.53
491.44	3972.25	401.44
139.75	1580.5	49.75
107.27	9920.5	17.27
360.63	1121.75	270.63
408.98	1242	318.98
90	3456	0
167.83	1281	77.83
141.8	10831.5	51.8
511.14	452.75	421.14
106.78	0	16.78
107.86	0	17.86
108.95	0	18.95
102.3	8399.5	12.3
129.8	15439.5	39.8
129.56	8015.5	39.56
399.8	1493	309.8
212.36	13835.75	122.36
156.17	335.5	66.17
426.5	2127.5	336.5
434.41	4724.75	344.41
157.31	1332.75	67.31

158.45	8134.5	68.45
94.02	4745.25	4.02
151.31	2767.5	61.31
377.42	9312	287.42
98.19	0	8.19
164.38	128	74.38
135.3	16079.5	45.3
393.02	1347.25	303.02
105.17	4472.75	15.17
120.5	779.5	30.5
420.05	3046	330.05
144.31	14671.5	54.31
435.72	4749.75	345.72
436.8	5534.5	346.8
437.86	5581.25	347.86
150.41	4047.5	60.41
144.36	6552.75	54.36
369.08	4672.25	279.08
163.16	1336	73.16
164.2	19	74.2
177.3	3975	87.3
145.05	3983.5	55.05
393.13	324.5	303.13
130.75	7887.5	40.75
104.34	3973	14.34
129.84	10901.5	39.84
406.67	1623.5	316.67
130.38	14287.5	40.38

125.28	3978	35.28
135.41	1794	45.41
168.5	10574.75	78.5
149.52	1480.75	59.52
114.66	921.5	24.66
369.39	84.25	279.39
91.39	3968	1.39
224.94	3972.5	134.94
144.94	13775.5	54.94
119.67	3549.75	29.67
133.16	4001.75	43.16
95.73	6531.25	5.73
433.59	4496.75	343.59
434.63	4874.25	344.63
447.8	15555.75	357.8
103.97	4762.25	13.97
105.06	2823.25	15.06
91.16	6351.5	1.16
405.25	3975.25	315.25

126.64	6607.5	36.64
140.75	7887.5	50.75
93.08	12869.5	3.08
442.59	13874.75	352.59
208.25	4646.75	118.25
150.41	9551.5	60.41
148.63	79.5	58.63
384.58	1549.25	294.58
105.72	2592.25	15.72
90.06	13632.5	0.06
112.59	3043.25	22.59
114.02	2906	24.02
132.89	13269.5	42.89
123.42	2239	33.42
124.52	3654.75	34.52
168.78	3977.75	78.78
213.08	9423.25	123.08
106.38	1280	16.38
173.05	1316.5	83.05
134.2	3407.5	44.2
450.38	3973	360.38
131.47	2255.5	41.47
111.52	3919.5	21.52
408.47	1646.25	318.47

409.53	2006.75	319.53
129.94	1991	39.94
109.05	12750.25	19.05
414.27	3971	324.27
423.77	1762	333.77
137.39	25.75	47.39
90.55	1856.5	0.55
166.23	3973.5	76.23
461.67	3974.75	371.67
121.13	3972.5	31.13
168.13	14272.5	78.13
110.14	3660	20.14
412.19	2239.75	322.19
123.28	2279.5	33.28
125.22	2218.75	35.22
116.98	335.5	26.98
139.56	1696.25	49.56
360.36	8106.5	270.36
145.94	1947.25	55.94
160.56	1384	70.56
161.58	0	71.58
128.06	8015.5	38.06
109.16	0	19.16
110.23	2688	20.23

94.55	5324.25	4.55
123.22	3979	33.22
129.27	2029.5	39.27
114.53	4943.5	24.53
114.61	3983.5	24.61
110.17	11343.5	20.17
108.59	9039.5	18.59
146.22	1564	56.22
367.06	3972	277.06
445.91	16079.5	355.91
136.06	8911.5	46.06
380.58	4027.75	290.58
168.88	1336.25	78.88
95.92	5033.25	5.92
396.69	505	306.69
184.64	3970.5	94.64
448.92	3972.5	358.92
412.16	11471.5	322.16
419.58	2125	329.58
172.19	3974.5	82.19
128.19	3974.25	38.19
173.05	3973.25	83.05
441.53	0	351.53
156.83	1426	66.83
94.02	8218.5	4.02

90.63	7296	0.63
105.14	4865.5	15.14
106.25	2829.5	16.25
90.44	3968	0.44
136.7	7503.5	46.7
407.19	1570.25	317.19
556.3	5123.5	466.3
120.89	2491	30.89
448.84	3968	358.84
375.02	1086.5	285.02
376.06	10526.25	286.06
447.98	1342.5	357.98
170.72	183.25	80.72
142.67	3279.5	52.67
143.73	12495.5	53.73
391.78	1239	301.78
179.2	1325.25	89.2
368.28	11597.25	278.28
433.48	1753.25	343.48
139.8	1723.25	49.8
140.89	1697.25	50.89
368.2	1053.5	278.2
369.23	1057.25	279.23
370.31	1059	280.31
441.3	9991.5	351.3
394.3	3975.5	304.3
422.81	3975.75	332.81
375.27	189.5	285.27
90.61	7168	0.61

143.16	5312.5	53.16
464.92	3972.5	374.92
403.09	2012	313.09
166.36	834.75	76.36
91.3	128	1.3
131.7	4010.5	41.7
106.19	12239.5	16.19
360.52	1016.25	270.52
91.53	10432.5	1.53
368.22	1045.5	278.22
448.61	9187.25	358.61
449.69	2324.75	359.69
90.16	13376.5	0.16
105.03	10442.75	15.03
178.64	1316.5	88.64
91.78	3968	1.78
90.72	1344.5	0.72
413.81	2379.5	323.81
136.3	4.25	46.3
434.7	0	344.7
140.48	4021.75	50.48
134.84	207.5	44.84

92.7	11494.75	2.7
154.31	1531	64.31
166.17	11215.5	76.17
414.86	3980.5	324.86
94.16	10738.75	4.16
133.53	9295.5	43.53
110.38	6095.5	20.38
360.3	1417.5	270.3
94.09	11260.25	4.09
442.95	0	352.95
148.44	1637	58.44
145.44	5071.5	55.44
146.48	13903.5	56.48
378.28	1459.5	288.28
91.78	4010.25	1.78
137.08	10703.5	47.08
393.23	0	303.23
133.38	5275.25	43.38
172.41	3970.75	82.41
186.41	724	96.41
136.53	14159.5	46.53
136.36	41.5	46.36
416.63	2480.75	326.63

90.78	8576	0.78
433.55	1234	343.55
433.78	4760.25	343.78
166.36	14543.5	76.36
179.28	1390.5	89.28
143.56	11840.5	53.56
120.95	2729.75	30.95
122.06	2654.25	32.06
111.78	16207.5	21.78
91	15424	1
415.53	14936	325.53
128.97	2248.25	38.97
144.44	1615.5	54.44
132.48	3974.75	42.48
372.81	1488.75	282.81
203.38	3994.25	113.38
138.03	11343.5	48.03
393.16	0	303.16
99.61	1424	9.61
173.36	1436.25	83.36
392.42	20.25	302.42
140.38	2752.5	50.38
114.17	3676	24.17
91.25	3200	1.25

155	3983.5	65
435.11	6398	345.11
436.28	6394.25	346.28
150.5	3975	60.5
150.64	3151.5	60.64
94.52	7117.25	4.52
91.5	2176	1.5
93.13	2442.75	3.13
167.39	1485.5	77.39
422.25	0	332.25
423.47	3977.25	333.47
130.73	2511.5	40.73
205.38	8983.25	115.38
146.8	1616	56.8
366.2	1351.25	276.2
367.31	2256.75	277.31
439.34	1688	349.34
153.09	1669.5	63.09
154.16	1652.5	64.16
139.13	3973.75	49.13
90.3	1216.5	0.3
404.19	960	314.19
410.23	2015.75	320.23
425.41	2676.25	335.41
138.59	2056.5	48.59

107.25	4160.5	17.25
360.95	1297.25	270.95
439.97	0	349.97
432.22	2024	342.22
154.77	3975.75	64.77
94.27	6965.75	4.27
91.13	3968	1.13
449.02	2303.75	359.02
163.09	1583	73.09
149.55	15446	59.55
422.61	2212.25	332.61
134.97	2192.75	44.97
94.36	12835.75	4.36
371	1355.25	281
90.59	128	0.59
166.23	24.25	76.23
385.55	1460.5	295.55
386.66	1488	296.66
394.72	257.25	304.72
99.11	4398	9.11
166.17	3973.75	76.17
94.2	10222.25	4.2
113.69	4631.75	23.69

114.77	4673.75	24.77
	128	1
416.02	1776.25	326.02
128.66	5471.5	38.66
90.45	3968	0.45
132.72	207.5	42.72
430.92	3992	340.92
228.2	3975	138.2
161.06	3972.5	71.06
149.06	4015.25	59.06
437.34	3983	347.34
379.31	1411.75	289.31
380.34	15183.5	290.34
408.89	3206.5	318.89
135.44	1615.5	45.44
106.94	3898.75	16.94
102.41	130.75	12.41
94.98	8357.25	4.98
425.19	3766.25	335.19
95.27	6522.75	5.27
360.14	1316	270.14
361.23	1347.75	271.23
362.28	3981.5	272.28
409.33	3981.5	319.33
141.11	12239.5	51.11
94.34	9409.25	4.34
378.39	1234.25	288.39
189.39	3980.5	99.39
94.17	2879.25	4.17
126.63	320.5	36.63
104.95	3275.25	14.95

106.02	10575.5	16.02
404.7	4530.75	314.7
131.77	3949.75	41.77
132.84	13488	42.84
444.73	8385.75	354.73
147.16	5277.5	57.16
177.27	12879.25	87.27
170.64	0	80.64
401.69	829.5	311.69
418.06	2993.25	328.06
131.63	3198.25	41.63
402.44	3974.25	312.44
90.75	13775.5	0.75
162.64	1103.5	72.64
169.66	13001.5	79.66
380	6805	290

158.69	10447.5	68.69
138.69	3970.5	48.69
440.77	3816	350.77
204.13	3976.75	114.13
360.52	7744	270.52
139.22	2555.75	49.22
140.31	975.5	50.31
142.28	25.25	52.28
92.03	3975.5	2.03
116.22	7119.5	26.22
160.39	3971	70.39
152.56	3919.5	62.56
143.52	3202.25	53.52
371.36	4109.5	281.36
158.17	2283.25	68.17
377.64	4932.25	287.64
378.61	14031.5	288.61

91.89	9536.5	1.89
471.17	474.5	381.17
106.84	10828.25	16.84
122.22	1658.75	32.22
123.27	7375.5	33.27
111.64	15695.5	21.64
111.88	6848.5	21.88
134.69	8527.5	44.69
140.17	3974.25	50.17
438.09	3939.5	348.09
379.05	1541	289.05
90.59	128	0.59
139.92	11727.5	49.92
107.19	2231.5	17.19
108.28	2187	18.28
110.38	11983.5	20.38
146.11	8527.5	56.11
91.48	3968	1.48
428.83	6647	338.83
143.89	4024	53.89
440.48	3977.25	350.48
396.28	9443	306.28

158.02	1489	68.02
472.56	128.75	382.56
97.88	4502.5	7.88