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DOI: 10.35117/A_ENG_22_03_02

The development of a concept of an unmanned glider-tug and cargo unmanned aerial vehicle with electric drive

Abstract: The article presents a few selected ideas for AUV usage which are being developed in Poland as well as the description of a project of an unmanned tug, a new technological solution which was submitted to the Patent Office in December 2017 and which has been being developed since then. The proposed towing system consists of a universal ground-based air traffic control station for unmanned flights, an AUV-tug and an additional control system placed on the towed object. The proposed solution aims at maintenance costs reduction and increase of performance of aircrafts with electric drive.

Keywords: UAV; Tug; Global Positioning System (GPS); Galileo

Introduction

The unmanned aerial vehicle (UAV) market is one of the economy's fastest-growing sectors. Along with the USA and Israel, Poland is one of the world leaders in designing and producing UAVs. According to independent sources [2], we are in third place in the world in terms of turnover in this sector of the economy. About 4,000 companies are operating in Poland. companies that produce entire systems or their components. According to the forecasts of the European Commission, civilian unmanned vehicles will constitute 10% of the global aviation market in ten years.

Domestic market analysis

The DroneII.com (Drone Industry Insights) portal dealing with analyzes of the global drone market regularly publishes reports on the state of the global UAV industry "The Drone Market Environment 2018", among several hundred companies, it lists four Polish companies that, according to DroneII.com, influence the formation and development of the global market. The following Polish companies were listed there:

1. DroneRadar:– in the UTM category (UAS Traffic Management)
2. DroneTech - in the Shows, Conferences, Events category

3. Drone House - in the Unmanned Platform Manufacturer category
4. Novelty RPAS - in the Unmanned Platform Manufacturer category

Dron House is a company that is the originator of an innovative UAV monitoring system via the GSM network. It is, among others, the creator of a multi-purpose structure called Bielik.

Novelty RPAS based in Gliwice is a manufacturer of unmanned systems. From the company's offer, it is worth highlighting the latest Ogar Mk2 industrial quadcopter, the Albatros airframe, and the skyMARK airship. In addition to unmanned platforms, Novelty RPAS creates separate components, and modules for independent use, including: GeoScanner (photogrammetry scanner), AgroScanner (multispectral photogrammetry), PostMan (transport handle), WatchDog (observation and inspection module), SnifferDog (air pollution detection and measurement module), CinemaArtist (professional aerial filming module). Many of these modules are taken into account when designing the project.

1. The Aquila drone by UAVS Poland Sp. z o. o. - source: [3]

DroneRadar is a company managed by " Dlapilota.pl sp. z o.o." is a refined and advanced system for reporting drone flights and monitoring traffic. In addition, users of the DroneRadar application on mobile devices can check the possibility of performing a flight in a given place based on Polish aviation law and the distribution of structures in the airspace.

DroneTech is the organizer of the DroneTech World Meeting international drone fair in Toruń. The company's activity has been noticed by the Dronell.com portal. Another type of drone application and the activity of Polish constructors in this field is the construction of drones used for freight transport. Drones for transporting parcels weighing up to three kilograms are built by Ritex from Lower Silesia. Thus, it enters the race to introduce drones to courier services with DHL or Swiss Post. Drones - small, light-flying robots for taking photos or videos from a bird's eye view. Photographers and filmmakers are interested in their offer, gadget lovers enjoy them. However, drones have much greater potential, which is currently used by the army and police, e.g. for the transport of explosives, traffic monitoring, etc. [1]. The potential use of this type of machine is to transport medicines in an emergency or deliver important documents. The time of their transport could be shortened two or even three times, depending on the terrain. Drones are already being used to coordinate rescue operations during natural disasters. These machines are also used to help people drowning in vast bodies of water where the time to reach other rescue services would be too long.

Another outstanding company is "UAVS Poland Sp. z o.o., whose flagship product is the Aquila drone.

Aquila - is an unmanned aerial vehicle in the helicopter system, weighing 32 kg, with a payload of 10 kg, it is a fully autonomous drone that performs an independent vertical take-off, flight along a defined route, and vertical landing. The proprietary antenna-tracker system allows you to maintain communication with the drone at a distance of up to several dozen kilometers. The main equipment of Aquila is an observation head with a thermal imaging camera, a classic daytime camera, and a laser rangefinder. The image is recorded both by the camera and transmitted together with the sound in real-time to the ground crowberry at a distance of up to 30 meters. The drone is able to stay in the air for about 2 hours and its maximum flight ceiling is 1500 m. The main rotor blade's span is 2 m. Aquila was designed and created to support mainly uniformed units such as the Fire Brigade, Border Guard, Police, Army, or Forestry. It can also be successfully used by geodetic companies to image the area or, for example, by companies from the energy sector to inspect transmission infrastructure.

The construction developed by the FlyTech UAV company, founded by graduates of the Rzeszów University of Technology, is also very interesting.

2. BIRDIE drone developed by graduates of the Rzeszów University of Technology in the field of Aviation and Space. Source [5]

BIRDIE - a drone based on an airframe with a rear pusher engine was developed by the FlyTech UAV company, founded by graduates of the Rzeszów University of Technology in the field of Aviation and Space. It was developed primarily with photogrammetry in mind. The basic equipment of the drone is a visible light camera, but other equipment can also be mounted on board, e.g. a multispectral or thermal imaging camera. Thanks to such equipment, BIRDIE is ideal for mapping the area, and creating its 3D model and topographic maps, after installing a multispectral camera, it can be used, for example, in agriculture to assess the vegetation of crops or in forestry - to test the quality of the stand. In turn, the use of thermal imaging will prove useful in technical inspections of infrastructure, e.g. gas pipelines, or in mining - when tracking gas leaks underground. The BIRDIE drone is relatively light (2.5-3.9 kg depending on the configuration) and has a short span (1.4/1.8 m) which allows for simple hand-held launches. A novelty on a global scale is the ability to switch from fixed-wing configuration to VTOL with the use of an attached module. The flight time in the airplane configuration is 60 minutes, in the VTOL configuration it is 40 minutes.

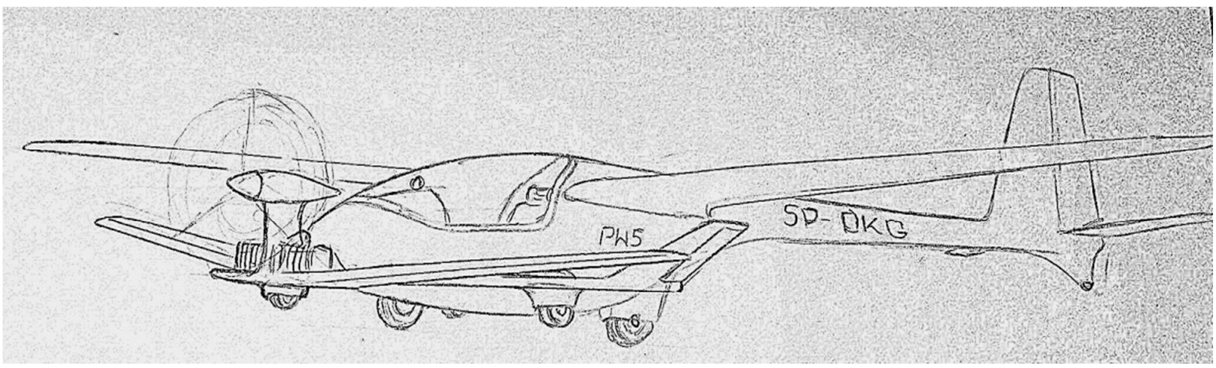
Another proposal, although different from the previous ones, is the subject of hoverbikes. This problem was also addressed in Poland. In 2016, before the Dubai police became interested in flying motorcycles, the Skynamo Aerospace company from a small Wojnicz (Tarnów district) presented the Hoverbike Raptor vehicle. As the main drive, our compatriots used not an electric engine, but a combustion engine with a power of as much as 380 hp, borrowed from the Suzuki Hayabusa track motorcycle.

Many companies, including the military, became interested in the vehicle. Unfortunately, Hoverbike Raptor is still in the design phase, while other similar projects have already entered the phase of testing and improving prototypes, or, like Hoverbike S3, are already at the stage of entering active service by the UAE police.

Unmanned tugboat - general description

The analysis of the basic parameters of drones operated by civilian and military users, which include flight endurance, lifting capacity, variety of tasks, the precision of task execution, flight monitoring, control system, and operational safety, leads to the search for new solutions. One of the attempts at a new application of unmanned aerial vehicles is the concept of a glider tug developed by employees of the State Higher Vocational School in Chełm. It was submitted to the Patent Office of the Republic of Poland in December 2017 under the number P.423710.

3. Polish Hoverbike Raptor. Source:[6]

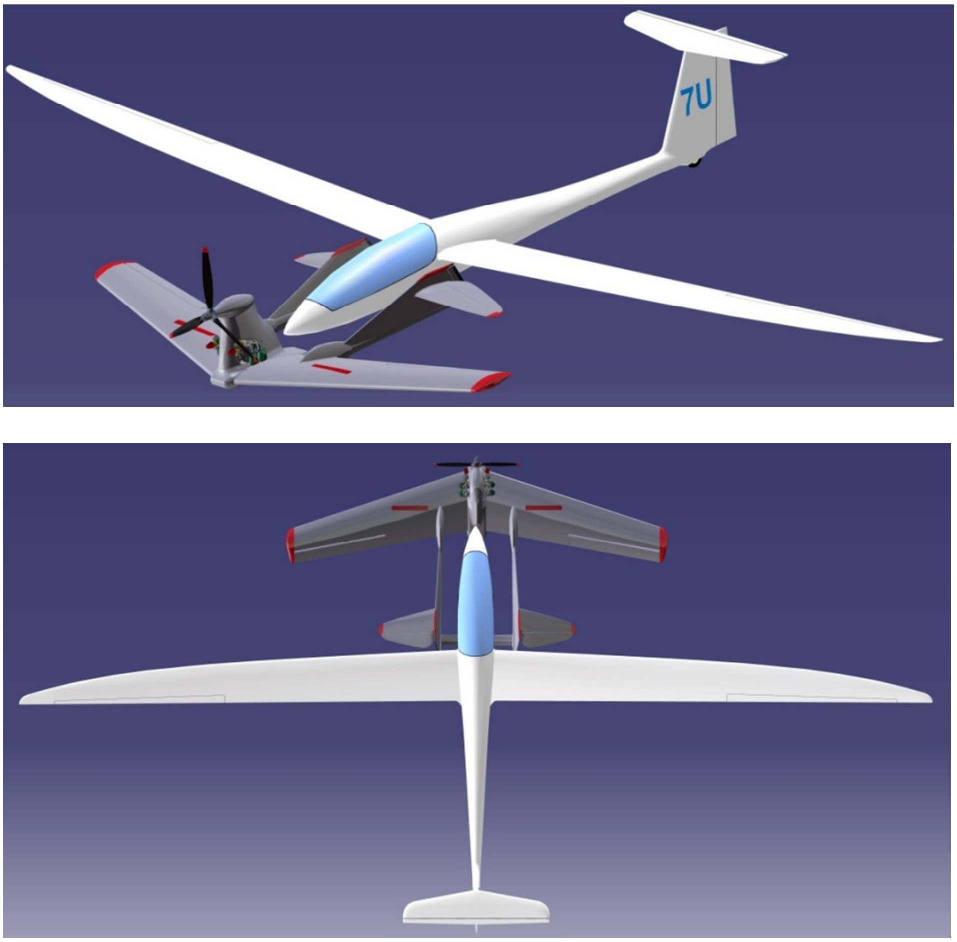


4. Sketch of the tug unit with a high engine turret and landing gear with a front support point and a butterfly tail and the PW5 glider. Source: T. Muszyński archive, tugboat version 1 from 2016

The traditional launch of a glider is usually done with the use of a towing aircraft or a winch. On some mountain gliders, it is also possible to accelerate gliders for take-off using rubber ropes or by locating the launch site in such a way that, under favorable conditions, the glider can reach a speed sufficient for independent flight by rolling down the slope. After reaching the appropriate height, the glider pilot releases the towing rope and the glider starts its independent flight

The use of each of these launch systems requires the participation of at least two additional entities. The lobby behind the plane is expensive, while other solutions have significant limitations. In the proposed solution, it is possible to reduce the size of the entities servicing the launch of the glider and it is possible to reduce the weight of the tug-glider assembly, which significantly reduces energy (fuel) consumption. The project aims to develop a tug integrated with a glider, controlled by a pilot in the take-off phase and capable of returning to the airport on its own.

The project of an unmanned aerial vehicle (UAV) - a tugboat, mainly gliders, has been developed since 2016, initially by Tomasz Muszyński. In 2017, Henryk Jafernik, Bartłomiej Kostowski, Łukasz Puzio, Arkadiusz Tofil, and Józef Zając joined the work on the project. The work resulted in a patent application by employees of the State University of Applied Sciences in Chełm. The first concept was based on an aircraft in a system with a pulling propeller, and two tail booms, between which the glider fuselage is mounted.



5. Combined glider and UAV-tug unit (version 1), Source: T. Muszyński archive

The essence of the solution is equipping the UAV with a glider attachment mechanism and a control system located in the glider, which enables the combined UAV and glider to be moved on the ground and their motorized flight. The solution includes a UAV tug, a ground flight control station, and, additionally, a control system located in the glider. The monitoring and control system was initially based on the GPS. Ultimately, the use of the GALILEO system is being considered. The UAV-tug consists of an airframe with airframe systems, a propulsion unit, a radio control - RC control system, an autopilot with a stabilization system and equipment - a camera with real-time image and sound transmission from the UAV to the operator, a flight monitoring system.

The initial stage consisted of the calculation of the stability of a UAV with an unusual layout with a short fuselage, a high lifted traction propeller, two tail booms, and an empennage located under the wings of the glider. Calculations were made in the XFLR5 program.

The tests carried out made it possible to select the wedging angles of the tails, and the angles of the tug wing relative to the glider. In addition, the centers of gravity were determined and the range of their change was determined. Based on these calculations, test models were configured and designed. The tugboat and glider models were subjected to verification tests in the air in flight. 36 flights were made during which the aerodynamic properties of the tug itself and the tug-glider assembly were checked.

Unmanned tugboat - model tests

Initially, it was assumed that it was sufficient to connect the glider with the tug based on the towing hooks existing on gliders - the front tow hook pulled behind the aircraft and the lower hook for the winch rope. It was also assumed to use several resistance points in the form of an air cushion.

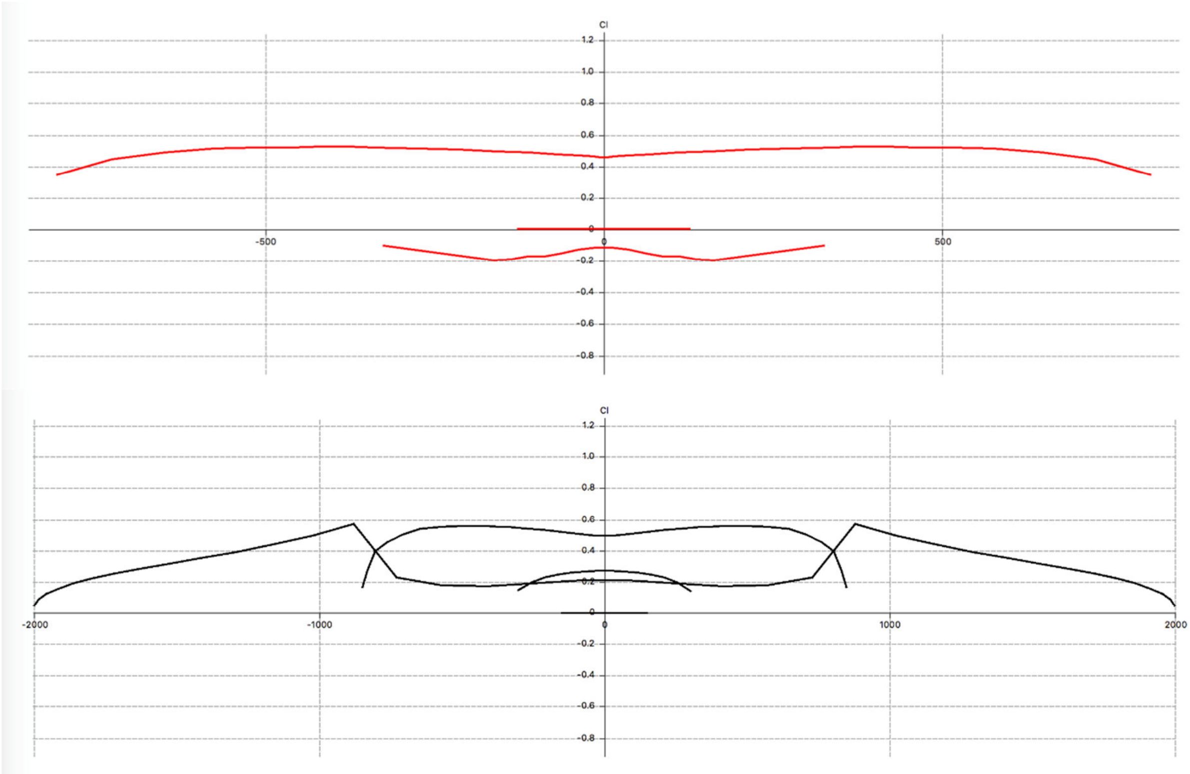
A model of a flying tug of gliders weighing about 3.6 kg and a span of 1.6 m was made.

A glider with a span of 5.1 m and a weight of 6.3 kg was used for towing tests. The tug was made according to design 1 in the low-wing layout, with a towing propeller, and two tail booms, between which the glider's hull was mounted. Already during the flight tests of the tug itself, it turned out that the propeller mounted on a high turret gives a strong pitching moment when accelerating. After several flight tests, it was decided to reduce the height of the turret to 90mm. When attaching the glider to the tug, it turned out that to obtain the wedging angle of the tug about the glider +2.5o during take-off, the landing gear structure should be changed to a system with a rear wheel. The rigid connection of the UAV with the glider was made based on two hooks - front and lower, as well as pillows encircling the fuselage. It was assumed that thanks to this solution it would be possible to fly a combined UAV unit and a glider using only the glider's control thrust.

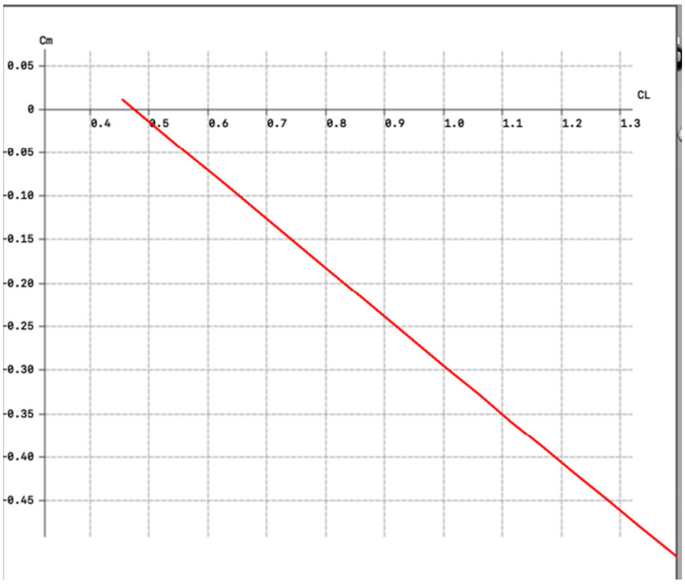
In practice, for level flight, it was necessary to control the tug's flaperons, which in this case supported the glider's elevator. Thus, the flight in the team had the properties of a system with three lifting surfaces, but it was more similar to the "duck" system than to the classic one. In addition, the "torsional" stiffness of the assembly turned out to be too low - when controlling the glider's roll, the rotation was not transferred to the tug. This led to the breakdown of both models.

As a result of unsuccessful flight tests, it was found that the torsional stiffness of the assembly is insufficient. Another concept was developed to stiffen the connection by adding overlays, mounted on the double vertical tail and resting on the leading edge of the glider's wing. This solution made it possible to significantly increase the torsional stiffness of the assembly and base the roll control during flight in the assembly solely on the control of the glider's ailerons, which are located more than twice as far from the axis of rotation as the ailerons of the tugboat.

In the third version of the prototype, it was also decided to move the vertical empennage away from the cockpit, which, with the slanted wing, allowed the tail booms to be shortened. In the full-size version, it will also make it easier to get into the glider.



6. Comparison of the lift distribution along the wingspan on the glider model without a tug (a) and the tug model-glider model (b). Source: T. Muszyński archive



7. Dependence of the moment coefficient Cm on the lift coefficient C1. Source: T. Muszyński archive

8. Model of the glider and UAV-tug unit - version 2 with lowered engine turret and landing gear with rear support point. Source: T. Muszyński archive

The next stage (about 12 months) will be the implementation of the actual technology demonstrator. The adopted concept will be verified with the results from the previous stages. after which a decision will be made on the configuration of the appropriate prototype of the UAV-tug product. It is necessary to check the control concept of the combined UAV unit and the glider and to test the method of detaching the glider during flight. A new UAV model weighing about 5 kg with an electric drive, powered by lithium-polymer batteries will be made. The forms of composite elements will be made with a simplified technology. At this stage, it will be necessary to initially check the characteristics of the adopted system in solo flights. With the participation of specialists, the scientific center will carry out aerodynamic tests as well as stability and controllability tests of the UAV-glider tug unit. The tests will mainly concern horizontal flight in the control unit. The adopted concept will be verified. This will allow to decide as to the configuration of the proper prototype of the UAV-glider tug. The results will be presented at a scientific conference and made public. In addition, it is necessary to work on the integration of many supporting systems, such as a camera system with a dedicated image processing system (Nvidia-based image computer), LIDAR laser scanner, auxiliary control system with autopilot, GPS stabilization, and navigation system, Galileo. The auxiliary onboard computer is necessary for system integration attempts when a specialized main computer dedicated to the UAV-tug is not made. It is also necessary to have a high-performance system for transmitting audio-video signals and a system for transmitting telemetry data. At the implementation stage, commercial problems should also be solved, i.e. companies selected for cooperation in the field of design, production, and sale of the developed product. An attempt to find shareholders based on the crowdfunding portal Indiegogo is being considered.

Currently, analyzes are being carried out on the use of electric and diesel units. The electric drive seems to be appropriate for a device used in training organizations educating pilots for a glider license. Preliminary calculations of the electric load show that in the case of a one-man glider tow, a flight duration of more than 15 minutes should be easily achieved, which should be enough for a 10-kilometer operating radius around the airport.

UAV-tug with a long flight endurance, powered by an internal combustion engine, with a total weight of approx. 160 kg, could be used in organizations where flights with longer flight endurance are needed. The description of the parameters of this project is summarized in Table **1**.

Table.**1**. Technical description (preliminary design of the diesel version) - BSP glider tug

Wingspan	**6 (m)**
Bearing surface	5,8 (m2)
Own weight	155 (kg)
Cruising speed	110 (km/h)
Maximum horizontal flight speed	165 (km/h)
Stall speed	50(km/h)
Take-up/run-up	60 (m)/100m
Engine	ROTAX 912 ULS
Engine power	100 (KM)
Fuel tank capacity	30 (l)
Fuel consumption during the flight in the team	15 (l/h)
Team maximum take-off weight	750 (kg)
Climb rate in assembly (600 kg)	5 (m/s)
Minimum horizontal flight speed in the assembly	70 (km/h)
Maximum horizontal flight speed in the team	100 (km/h)

At each stage of the project implementation, adjustments to the construction assumptions will be possible. The optimal solution will be selected to achieve the assumed flight characteristics of the combined UAV and glider. It will be necessary to precisely determine the characteristics of the system, and determine the optimal sizes of individual UAV elements, including control surfaces. For safety and legal reasons, the involvement of aviation legal organizations will also be necessary. It is assumed that the process of designing and manufacturing the airframe, power transmission system, and making the main onboard computer together with the UAV control system and navigation system will take 12 months. The last part is testing the prototype and adapting the finished product to the recipient's recommendations. In order to carry out the research, the research center will have to prepare a specialized stand, place the UAV TUG GLIDER team and the glider in it, configure the measurement system, and conduct tests.

Conclusion

Based on the mathematical model of the device, the results of wind tunnel tests and flight tests, control algorithms will be selected and fine-tuned. The control stabilization and artificial stability system will be programmed to support team flight and autonomous flight during arrival at the airport. According to the authors, the described product may be an interesting proposition for glider training centers and transport companies dealing with the delivery of small products in hard-to-reach areas. The same UAV - tugboat can be used as a trolley for towing gliders and a tug for transport systems delivering goods by air.

Due to the type of tasks performed, the basic control system should be autonomous. The manual RC system should have two transmitters. The first one should be placed in the flight control center. In the case of glider flights, the second control system should be made in the form of a small panel attached to the structure of the glider and should be able to control at least the thrust of the UAV engine. The basic monitoring and control system is proposed to be developed based on the Galileo satellite system.

Source materials

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