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SOKOL Unmanned Aerial System

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Abstract

The SOKOL unmanned aerial system is intended for the military, police and the integrated rescue system operations. The system consists of the light small SOKOL unmanned airplane, the catapult launcher with the rubber bungee cords and the control system whose main part is the ruggedized PC tablet. The system features versatility, compactness and robustness that allow performing different missions at adverse weather and terrain conditions. The SOKOL meets the actual status of the Czech legislation of the UAV operations.

Keywords:

Unmanned aerial system, unmanned aerial vehicle

Nomenclature

UAS – unmanned aerial system
UAV – unmanned aerial vehicle, part of the UAS, flying vehicle itself

1. Introduction and motivation

A need for a simple, universal and affordable reconnaissance aerial system suitable for the operations of the military and police forces and the elements of the integrated rescue system was identified a long time ago. Apart from its evident military use, the typical examples of its civil applications are e.g. the search for persons in distress, the surveillance of hazardous places (large industrial accidents, spots of fire) or surveillance of events with large concentration of people, such as big concerts or sport events. In comparison with the airplanes and helicopters with crew on board, they should be available almost immediately, at much lower cost and without risk for their crew.

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Such system should be continually ready for operation also in any unforeseen emergency case. It should be easily transportable, quickly deployable and easy to operate even at adverse conditions. The system should be sufficiently universal to be easily equipped with different useful loads according to the requirements of the mission. Future integration of new useful loads and sensors should not pose any difficulties. And last but not least, its development, manufacturing and operational costs should be very low to enable the operational deployment of sufficient amount of the system units on the territory of the Czech Republic and thus to assure the system immediate availability.

Despite a long tradition of the development of the unmanned aerial systems in the Czech Republic, such a system was not available. This was the key reason why the development was supported by the Ministry of Interior of the Czech Republic.

The airplane – carrier of the useful load – and its remote control system are the fundamental components of the whole unmanned air system. This paper is focused on the development and description of these two components.

2. Development of the Airplane

2.1. Requirements

The system should be employable at very different operational conditions and under time pressure. A comprehensive detailed list of requirements on the whole system was drafted at the initial stage of the system development. The main requirements on the airplane segment of the system in general form can be listed as follows:

- universal system capable to carry different useful loads; typical useful loads were defined – their nature, required field of view, mass and dimensions, necessary interfaces, ease of their installation,
- flight performance – especially operational speed, range of operational altitudes, climb ratio, endurance, take-off length, landing length,
- flight qualities – highly stable flying platform with responses to control inputs suitable for the remote control,
- capability to operate including take-off and landing at difficult conditions, such as adverse weather and rough terrain,
- capability to independently automatically terminate the flight if needed,
- simplicity and ease of operation,
- reliability,
- rapid deployment, ease of the transport and ease of the assembly to operational configuration from transport configuration,
- low requirements on operator and ground crew training and experience,
- safety of operation even in the environment of civil population and urban areas,
- ease of modifications,
- low weight,
- small dimensions,
- low development costs,
- low manufacturing costs,
- low operational cost including maintenance costs.

2.2. Development of the Configuration

2.2.1 Design Space

The requirements, as usual some of them contradictory, were thoroughly analysed and several configurations were systematically evaluated. The design space of the assessed configurations was intentionally broad to make sure that the most of possibly promising configurations would be taken into account. Conventional and unconventional configurations equipped with tractor or pusher power units were evaluated.

One of the unconventional configurations – high-wing monoplane with pusher power unit at the end of the fuselage nacelle and V-tail unit on the tail-boom – was selected as optimum that met the requirements in the best manner.

2.2.2 Modular Concept

A modular concept was used due to the requirements of ease of the transport, ease of assembly and ease of modifications. The airplane can be easily disassembled into the six main parts – the left and right wings, the fuselage with the power unit, the tail-boom and the left and right the tail-units (Fig. 1). The time necessary for assembly or disassembly is in the order of minutes and the assembly does not require any specific tooling or crew capabilities. It is very easy even at adverse weather conditions when the ground crew is gloved. The modular concept also features evident advantages for the reparations.

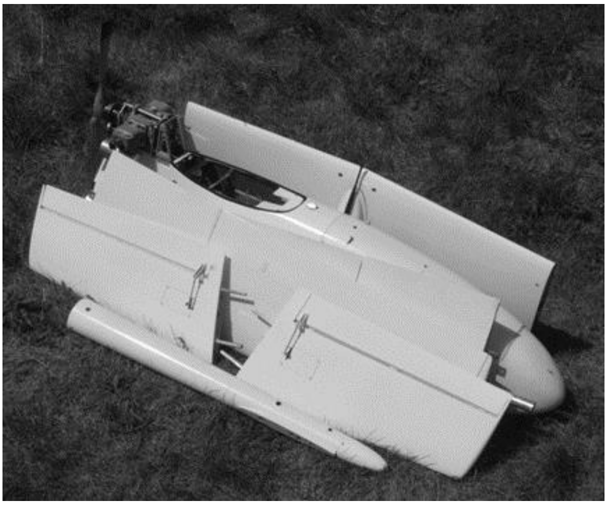

Fig. 1 SOKOL disassembled for transport

2.2.3 Fuselage and Position of the Useful Load

The useful load was positioned into the forward part of the fuselage or in the very nose of the fuselage. This position provided unrestricted field of view of optical sensors in the most important directions forward and obliquely towards the ground in the direction of the flight. This position also facilitates the changes of the sensors according to the mission to be performed. It also features perspective development potential for the future development of the modular forward part of the fuselage with quickly interchangeable modules with different useful loads.

2.2.4 Wing

The high-wing configuration decreases the risk of damage of the airplane during its landing in rough terrain. An optimized airfoil section was developed especially for the SOKOL wing at VZLU. The airfoil features high lift-to-drag ratio, low moment and low sensitivity to external contamination by insects and rain at the operational Reynolds numbers of the airplane. The wing shape, the wing area and the volume of the V-tail were subjects of the computational aerodynamic optimization with required flight performance, flight qualities and mass as optimization criteria.

2.2.5 Tail-Unit

The requirement to avoid the contact with the ground implied the tail-boom inclination up to prevent the tail-boom from the contact with the ground. The V-tail kept free space for the opening of the landing parachute.

2.2.6 Landing Devices

The landing gear was designed in a simple form of a reinforced fuselage belly. A conventional undercarriage was evaluated as unsuitable for the rough terrain and also as a source of the aerodynamic drag penalty.

A possibility of the landing on the parachute was also incorporated. The parachute system is composed of the extracting parachute and the main landing parachute. The parachutes are stored in the box positioned in the upper part of the fuselage. The parachute hinge is placed in such a way that the airplane during descent poses in the position suited for the smooth landing without danger of the potential damage due to the contact with the ground.

2.2.7 Power Unit

The pusher propeller power unit was chosen as a consequence of the useful load in the forward part of the fuselage. Moreover, the pusher does not contaminate the sensors by its exhaust gases and leaking oil.

The requirement of the endurance for several hours excluded the use the power unit equipped with an electric motor. The two-stroke air-cooled flat engine was evaluated as the optimum solution due to its simplicity, reliability and low cost, even at the penalty of slightly higher specific fuel consumption. The fuel consumption penalty has not been very significant as the airplane operates at nearly constant flight regime for the most of its mission.

The powerful engine of 4 kW was selected because of the requirement of operations in urban areas and in narrow valleys; these requirements implied the necessity of high climb ratio. The installation of another power unit is optional, especially an engine with lower power output, lower specific fuel consumption and lower mass can be a viable option, if the high climb ratio is not required. The engine position in the upper rear part of the fuselage was evaluated as convenient trade-off with respect to the centre of gravity position, the axis of the thrust position, the engine cooling, the propeller efficiency and the free space for the opening of the landing parachute.

The fixed-pitch propeller was chosen because of its simplicity and thus reliability, low weight and low cost. The high power output and the limited space between the engine shaft and the tail-boom necessitated three-blade propeller to efficiently transform the power to the thrust, instead of a larger two-blade propeller.

2.2.8 Catapult Launcher

The catapult-assisted take-off has been preferred because it makes possible the take-off nearly in any terrain, even in the urban areas.

The SOKOL is light and easily transportable vehicle, so its catapult launcher has to be of adequate mass and adequate transport simplicity. The catapult performance should match the SOKOL vehicle performance and operational mode at minimum cost, minimum work expenditure, minimum transport requirements and at uncompromised safety. Several take-offs should be possible during an operation without refilling propellant (propellant in general sense).

The catapult using a bungee cord as a source of energy for the take-off was chosen for its simplicity, ease of operation, low-cost operation and safety. The rocket-assisted take-off was rejected mainly for safety and operational cost reasons and for complicated storage of the rockets. The high-pressure hydraulic or compressed-air catapults were not selected due to their mass, safety reasons and dependency on the external energetic sources and their cost. The electric systems were rejected for their cost and dependency on the external energetic source.

2.2.9 Structural Sizing and Regulations

The airplane was structurally sized according to all expected operational loads with sufficient safety factor. Relevant parts of EASA CS-VLA standard were used as reasonable bases for the computational determination of the loads acting on the structure and for the check of the structural strength.

The structure of the airframe was designed mainly of carbon and glass fibre reinforced plastics. The analyses resulted in the final combination of composite materials that provided optimum value from the point of view of the mass, quality of surfaces, robustness and sturdiness, ease of reparations and reasonable manufacturing cost. The two critical fundamental parts, the wing and the tail-boom, were experimentally tested to verify their real strength. If required, structure of glass fibre reinforced plastics only is prepared, cheaper at the cost of the mass penalty.

The Civil Aviation Authority of the Czech Republic supervised the whole process of the development and testing to be sure that the airplane is conforming to all lawful regulations.

2.3. Wind Tunnel Testing

Since the unconventional configuration was selected as optimum, there were limited possibilities to verify aerodynamic computations using experience with similar aircraft or using handbook references. Therefore the wind tunnel testing of the model of the airplane was performed in VZLU 3mLSWT low-speed wind tunnel [1], see Fig. 2.

The model was in the ½ scale and was equipped with power unit consisting of an electric motor and two-blade propeller, the all control surfaces, i.e. the ailerons and the ruddervators on the tail-unit were adjustable.

The forces and moments acting on the model were measured using six-component internal strain-gauge balance [2-4]. A specific testing technique was applied for the simulation of the effects of the power unit that enabled to fulfil similar requirements of the thrust coefficient of the power unit [5].

The measurement of the aerodynamic characteristic of the airplane including the characteristics important for stability and controllability were carried out. Testing of the efficiency of the control surfaces positioned on the V-tail and the testing of the effects of the operation of the power unit on the aircraft stability and controllability were especially important. The data were used as the inputs for the computation of the flight performances, flight qualities and for the development of the airplane automatic control system.

The testing provided valuable and reliable data which confirmed or improved previous results of aerodynamic optimization. The quality was ensured among others by the test Reynolds number close to the operational Reynolds number. All usual wind tunnel corrections were applied [6].

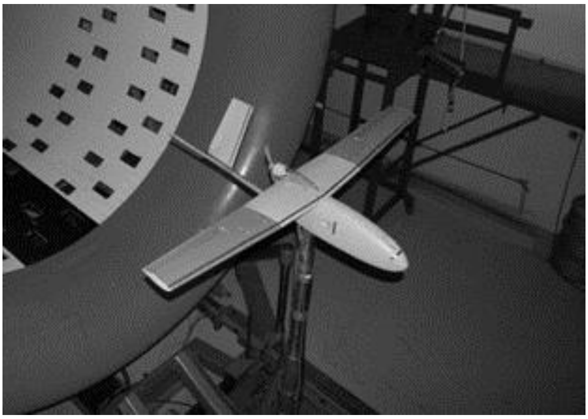

Fig. 2 Wind tunnel testing of the model in ½ scale

Separate extensive testing concerned the power units. Many combinations of different piston engines and different propellers were tested in the VZLU 1.8mLSWT low speed wind tunnel. The main reason of the tests it was the lack of the data of the thrust and the specific fuel consumption at different flight speeds, as this data were not available from the engine producers. The wind tunnel testing proved to be much more accurate than the previous estimates based on the very sparse data of the engine manufactures.

2.4. Flight Tests

The extensive flight tests confirmed the correctness of the computed SOKOL performances, stability, controllability and functionality of the automatic control system and the performances of the catapult launcher (Figs 3, 4).

3. Description of the SOKOL System

3.1. General Description

The airframe structure fully meets the current aviation design requirements, namely EASA CS-VLA “Certification specification for light airplanes”. The vehicle complies with climatic resistivity requirements, which allows fail safe operation in all standard meteorological conditions in the Czech Republic, i.e. at environmental temperature from –25 °C up to +40 °C.

Fig. 3 Preparations for catapult launch

Fig. 4 Take-off

The system is able to perform a fully automatic flight, which requires minimum pilot's capability for control and it imposes minimum demands on operation service. he air platform satisfies conditions of disassembly for the easy transportability. The time necessary for preparation to ready-to-operation state from transport state does not exceed 15 minutes in summer and 20 minutes in winter time.

The design conforms to the methods of usage in the field conditions and it is safe in case of malfunction. The advantage is its ability to be upgraded on the basis of user operational experience and rise of new requirements. Basic dimensions and performance properties are:

Wing span	3.30 m
Bearing surface	1.25 m^2
Mass	21 kg to 24 kg
Maximum engine power	4 kW
Minimum speed	55 $km \cdot h^{-1}$
Maximum speed	180 $km \cdot h^{-1}$
Cruising speed	90 $km \cdot h^{-1}$
Rate of climb	7 $m \cdot s^{-1}$
Endurance at 90 $km \cdot h^{-1}$	4.5 h

The ZDZ 80 two-stroke two-cylinder piston engine of displacement of 80 cm^3 (Fig. 5) of Czech production with fixed two blade was selected on the basis of the performed wind-tunnel measurements of the thrust and the fuel consumption. Fuel is the 95 octane car petrol (gasoline) mixture with synthetic oil in the 40:1 ratio.

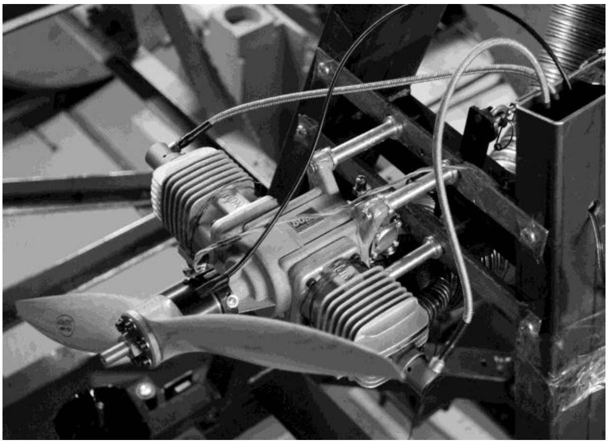

Fig. 5 Power unit measured in wind tunnel

3.2. Control System

3.2.1 General Description

On the basis of aerodynamic and mass characteristics, the mathematical state model describing airplane movement was created and then used for the design of the semiautomatic and automatic control systems.

The damper of short-period oscillations for semiautomatic control was designed and the autopilot for stabilization and attitude angles control was developed. Concurrently higher hierarchical level of control with help of the PID regulators – stabilization and air speed control, vertical speed stabilization and altitude control (with limitation of attitude angles and control surfaces deflections) - was solved.

With respect to future requirements, the control system can control on-board camera and/or other devices of the useful load. Unified control interface for operator was designed that can incorporate any future useful load and function. The control system was designed in such a way that the UAV control is very easy for the operator, thus also the mission fulfilment is very easy to manage.

3.2.2 Semiautomatic Control Mode

The semiautomatic flight mode is used mainly during the missions when the airplane has to be controlled by operator, who exercises full control authority of its operation. The semiautomatic mode can be used when the radio connection between the airplane and the ground control station is established.

This mode allows the operator to issue “left, right, up and down“ orders to the system. On-board sensors evaluate airplane position and autopilot control loops prevent the airplane from so-called irregular attitudes. It means for example that bank angle cannot exceed 30° value and climb or descent ratios cannot exceed 7 $m \cdot s^{-1}$. It is possible to change these values in dependence on user's requirements. When values of maximum climb ratio cannot be reached, e.g. due to achievement of altitude where engine is not able to provide the necessary thrust, the system sets automatically the optimum value for the airplane and actual conditions.

The mode allows to enter commands for so-called state functions control (landing parachute release, user sensors functions switching-on and off, engine switching-on and off).

3.2.3 Automatic Control Mode

It is possible to program waypoints of required flight path before or during flight. The azimuth, altitude, start and stop of on-board sensors function and style of flight through waypoints can be changed for any waypoint at any time. The waypoints can be entered using coordinates (less easy option) or operator can designate the desired point by "click" by the mouse on the digitized map. Number of waypoints is not limited. The following flight modes can be performed automatically:

- circling – the airplane circles around set point and automatically adjusts sweep;
- return – the airplane returns automatically to the take-off place;
- automatic landing – the airplane approaches automatically to ¨the place of landing and lands;
- automatic "scanning" of designated area.

3.2.4 Emergency modes

The control system responses automatically on the predefined emergency situations and their occurrence are announced by optical symbol on the operator's console and by voice report (using the installed voice generator).

The emergency situations can be divided into the situations which do not endanger flight safety and allow continuing flight with certain limitation and precautions, and the situations which threaten the flight. Examples of not threatening situations:

- minimum flight speed;
- low fuel amount;
- GPS out of service.
- Examples of the threatening situations when the control system initiates parachute deployment:
- alternator out of service;
- any servo is out of order;
- engine unintentionally stopped,
- critical power of on-board network.

The SD card is included into the on-board HW part of the control system and on-board airplane parameters are recorded on it for their eventual post-analysing after landing. The ground part of the control system comprises an extra SW for post mission analysis of flight parameters from the SD card and for the flight simulator dedicated for operators training.

3.2.5 Device for Flight Termination

The emergency system is an integral part of the unmanned aircraft control system. This system must react in the case of emergency situations, namely in the cases of danger for persons and/or property. It must be also able to inform operator in such emergency case, that operators can manage themselves during the flight without use of the emergency means.

Long-term experience of the designers concerning the management of emergency situations of UAS was fully exploited. The designed system features all well-proven solutions from previously designed emergency systems, as e.g. optical and acoustic signalization including voice information about the current situation. The system is an effective tool for emergency situation management, which utilizes parachute landing system activated by electronic system.

3.2.6 On-board Control System Basic Components

- ARM9 16 bit microprocessor;
- axes sensor of angular speed;
- 3 axes accelerometer;
- static and cumulative pressure sensor;
- GPS receiver including antenna;
- communication module 868 MHz;
- 8 GB SD card.

3.3. Radio Transmitting System

The radio transmitting systems operate on the basis of digital data transmitting. The system consists of two mutually independent subsystems. Each subsystem provides bidirectional data transfer between air platform and ground control system. This system provides control signals transmitting from ground on aerial platform board and vice versa, telemetry data transmitting from board, carrying information about current situation. In the test period, the communication is on frequency with so-called general approval, i.e. 2.4 GHz. It is possible to implement transmitting system in accordance with requirements of the customer.

Both radio transmitting systems have been designed to meet the requirements of optimum dimensions for the embedding with respect to ensure reasonable power parameters. Their operations were designed in the way which complies frequency requirements according to valid frequency diagram.

3.4. Remotely Controlling Station

The control station is installed into van body of cross-country vehicle. The data transmitting system aerials are connected to the van body as well. Ground control system consists of ruggedized PC tablet allowing deflecting individual control surfaces, i.e. ailerons, ruddervators, and engine controls including the air choke.

The tablet can be taken out from mobile control station. The tablet, when it is outside, is placed on the tripod allowing the operator to control UAV without necessity to keep the tablet in his/her hands or to have it hanging on his/her neck. This practice allows an easy control and free operator movement together, so he/she can watch UAV during flight.

3.5. Performance and Limitations

UAV may be operated at wind speed not exceeding 10 $m \cdot s^{-1}$. It is prohibited to take-off in icing conditions. It is possible to carry a camera or other sensor or device of maximum mass of 3.5 kg in the front part of fuselage or of 1 kg in the nose.

4. Conclusions

The ground tests, the flight tests and the operation exercises confirmed that the AUVIS SOKOL system met all fundamental requirements. The main advantage is its universal modular concept with considerable potential for future applications and modifications, rapid and easy deployment, ease of operator and ground crew training and low cost.

As the development of the system was supervised by the Civil Aviation Authority of the Czech Republic, the operations in the civil airspace are possible according to the lawful regulations and the use of the system in the urgent cases should not be restricted or even prohibited by legislation issues.

Acknowledgement

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