TECHNIQUES AND CRITICAL TECHNOLOGIES APPLIED FOR SMALL AND MINI UAVS – STATE OF THE ART AND DEVELOPMENT PERSPECTIVES

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The technology and techniques applied in small and mini Unmanned Arial Vehicles derive from full scale UAV and flying model technology. Requirement for the technology applied is based on high reliability request linked with limited dimensions and take-off weight. Airframe structures, propulsion systems and take-off and landing techniques are described in this paper. Analysis of strength and weaknesses and development perspectives of these techniques are presented also. The paper describes briefly the control systems, flight data acquisition units and telemetry links.

Foreword

Recent development and miniaturization of electronics technology has generated opportunities to reduce the size and weight of Unmanned Aerial Vehicles. Arisen space was acquired by full size UAV technology and techniques with flying models origin. The full size UAV equipment dimensions were reduced to small space compartment requirements, when the flying model technology had to be selected in order to improve low reliability. Synergy of these two separate technologies created the new class of vehicles – the mini and small UAV. Diversification between mini and small UAVs is based on the vehicle take-off weight – the mini UAV weight ranges from 5 up to 18 kg, the small UAV - 18 up to 200kg. Correct application of technology and techniques in the mini and small UAVs strongly depends on a planned aircraft mission. The performance limits are similar, however scaled down, like those known at full size UAV or manned aviation. The aircraft design is a compromise and balance between features opposite to each other. Selection of given techniques limits the number of available options e.g. the way of take-off and landing technique sets requirements for airframe structure. The other important factor is propulsion system selection based on the endurance and speed requirements. That is why the technology and techniques chosen by a designer have to be very carefully selected, to fulfil assumed requirements.

1. AIRFRAME STRUCTURE

The mini and small UAVs structures are derivatives of flying models structures and light aircraft technology. They include composite, wooden (plywood/balsa) and polystyrene structures. The metal structures are employed very rarely. Limited number of metal structure are mainly applied in the hot section of gas exhaust part of airframes, because of their heat resistance. The UAV history has encountered a few flying target drones fully made of aluminum alloys. The airframe structure technology depends on the following parameters: complexity of shape, required accuracy of geometry, flight load envelope, take-off/landing techniques and cost. The only comparison tool of similar size structures made of different materials is the weight to lifting surface ratio (WS).

Composite structures

Composites are the most popular technology employed in small UAV structures. This technology provides high accuracy, good quality of surface and repeatability at average WS ratio. The biggest advantage of composite technology is possibility of airframes manufacturing with very complicated shape. Disadvantage of this technology is high entry cost barrier related to mould preparation. The composite technology manufacturing process consists of:

- 3D CAD shape design,
- CNC mould milling,
- Wet lay-up/ Prepreg laminating,
- High temperature curing,
- Off mould fettling/dressing.

3D CAD shape design

The first stage of composite airframe manufacturing process is the design of a virtual 3D shape of structure. There are many software tools designated for this task, however two the best known are CATIA and Unigraphics. These systems allows to design very complex free form shapes and to verify surface smoothness. The output of 3D system includes program for a CNC machines converting the virtual geometry into existing real airframe shape.

CNC mould milling

There are many approaches for creating a real shape of airframe. The most common is CNC milling of 3D male mock-up (plug), which is a tooling for female mould manufacturing. The special temperature/stress stabilized materials are required to avoid distortion during machining process.

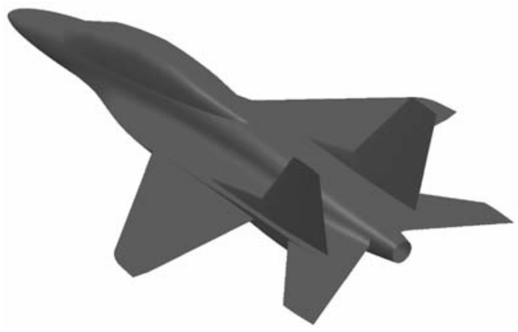


Fig. 1. Virtual 3D shape of research SUAV designed within the Unigraphics CAD System [1]

Fig. 2. CNC milling of 3D fuselage male mould of a small UAV

Accuracy of composite mould based on CNC milling of 3D male mock-up (plug) depends on: CNC milling machine accuracy, mock-up material and rigidity of a mould structure. It varies between +/-0.6 up to +/-0.2mm. The other method employing CNC milling and EDM shaping of female metal mould provide much more better accuracy (below +/-0.2mm), but it is more time/labour consuming, therefore it is much more expensive. The third option is a hand made mock-up base on CNC cut cross sections, however it is limited to ruled shapes e.g. trapezoid wing. The accuracy of hand made method is around +/-0.2mm.

Taking composite materials as a whole, there are many different material options to choose from in the areas of resins, fibre and cores, all with their own unique set of properties such as strength, stiffness, toughness, heat resistance, cost, production rate etc. However, the end properties of a composite part produced from these different materials are not only function of the individual properties of the resin matrix and fibre (and the core in sandwich structures), but are also function of the way in which the materials themselves are designed into the part and also the way in which they are processed. The most popular material are glass fibre reinforced composites (GFRC) and carbon fibre reinforced composites (CFRC) based on epoxy resin systems. CFRC has a higher stiffness to weight and strength to weight ratio than GRC, but it is also 8-10 times more expensive and has poorer impact characteristics, which in many cases limits the SUAV airframes. The material which improves impact characteristics is Kevlar fibre reinforced composite (KFRC), therefore it often is used together with CFRC in so the-called hybrid structures. The lowest WS ratio of composite airframe starts at 13g/sqdm.

Wet lay-up/Hand Lay-up

Resins are impregnated by hand into fibers which are in the form of woven, knitted, stitched or bonded fabrics. This is usually accomplished by rollers or brushes, with an increasing use of nip-roller type impregnators for forcing resin into the fabrics by means of rotating rollers and a bath of resin. Laminates are left to cure under standard atmospheric conditions.

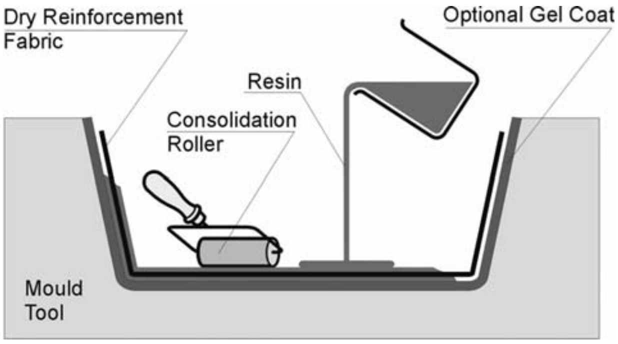


Fig. 3. Wet lay-up/Hand Lay-up process

Vacuum Bagging

This is basically an extension of the wet lay-up process described above where pressure is applied to the laminate once laid-up in order to improve its consolidation. This is achieved by sealing a plastic film over the wet laid-up laminate and onto the tool. The air under the bag is extracted by a vacuum pump and thus up to one atmosphere of pressure it can be applied to the laminate to consolidate it.

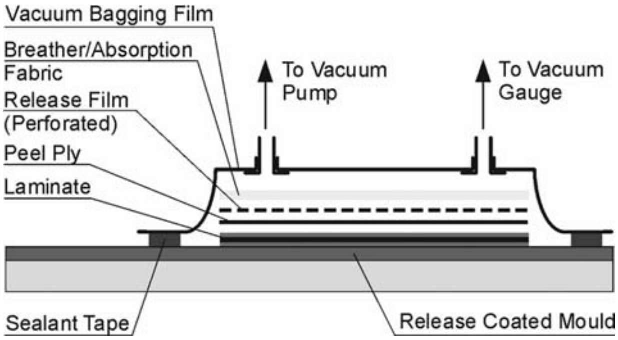


Fig. 4. Vacuum Bagging process

Prepreg Moulding

Fabrics and fibres are pre-impregnated by the materials manufacturer, under heat and pressure or with solvent, with a pre-catalysed resin. The catalyst is largely latent at ambient temperatures giving the materials several weeks, or sometimes months, of useful life when defrosted. However to prolong storage life the materials are stored frozen. The resin is usually a near-solid at ambient temperatures, and so the pre-impregnated materials (prepregs) have a light sticky feel to them, such as that of adhesive tape. Unidirectional materials take fibre direct from a reel, and are held together by the resin alone. The prepregs are laid up by hand or machine onto a mould surface, vacuum bagged and then heated to typically 120-180°C. This allows the resin to initially reflow and eventually to cure. Additional pressure for the moulding is usually provided by an autoclave (effectively a pressurised oven) which can apply up to 5 atmospheres to the laminate.

Cure Monitoring

The process by which a liquid thermosetting pre-polymer is turned into a rigid solid is called „cure". Cure comprises a complex set of chemical reactions, usually heat activated, which gradually elongate and crosslink the original pre-polymer molecules. This process is accompanied by a gradual and then sudden rise in the viscosity of the resin. The time at which this sudden rise of viscosity is noted coincides with gelation of the resin and indicates the formation of a 3D molecular network. Further reactions tighten up this network, increasing its stiffness up to a point where no more reactions can take place (at a given temperature). The network is then said to have vitrified. The regions of gelation and vitrification in the resin are of great practical significance in the processing of fibre reinforced composites in which the thermosetting resin is used as the matrix separating and supporting the fibres.

Wooden /composite reinforced structures

Plywood and balsa wood are still used in light airframes of mini UAVs. Wooden structures are considered as a old fashion technology, however with a small reinforcing support of composites for main structure parts like spars, they have the lowest WS ratio of all other structures. That is why this technology is still employed at the airframe with the highest weight requirements. The another important factor is a zero entry cost. That is the reason why wood structures are often use for single prototype airframes.

Expanded Polystyrene (EPP) structures

Expanded Polystyrene technology is taken from packing industry, where it is commonly used for shock/impact protection of goods during transportation. The EPP manufacturing process starts with polystyrene injection to the female mould of a product shape at higher temperature and pressure. When temperature cools down, the material achieves the shape of mold. The output product has a rigid structure, acceptable surface quality and the density of only 50kg/m3. The process preparation is similar to composite technology including CAD/CAM and similar entry cost barrier (mould tooling), however a cost of the structure is only 1-5% of cost of all other technologies. The EPP airframes because of their very good impact characteristics and low WS ratio combined with very low cost gained a large share in flying model industry. The only EPP disadvantage is its low durability. We should expect that the EPP technology will be transferred to mini UAV, when they become more popular and higher volume production would be required.

Fig. 5. Wooden /composite reinforced structure

Fig. 6. Expanded Polystyrene (EPP) airframe

Concluding, if one compare a minimal weight to lifting surface ratio of similar a small unmanned aerial vehicle airframe made in 3 abovementioned structure technology, it can written:

Composite - 13 g/dm^2 = 1,3 kg/m^2
advantage: high accuracy, high strength and durability,
disadvantage: high coast of tooling, high labour consumption of serial production, mean WS ratio.

Expanded Polystyrene - 10 g/dm^2 = 1 kg/m^2
advantage: the lowest cost of serial production, high impact absorption,
disadvantage: high coast of tooling, low durability, mean WS ratio, low accuracy.

Wood+ composite reinforcement - 5 g/dm^2 = 0.5 kg/m^2
advantage: high strength lowest WS ratio, zero cost of tooling,
disadvantage: high labour consumption of serial production, low/mean accuracy.

For comparison let write here some values of WS ratios for gliders and heavier UAVs:
PW-5 (GFRP): 8 kg/m^2; PW-6 (GFRP): 10 kg/m^2; PW-103 MALE UAV (CFRP): 6.4 kg/m^2; PW-114 HALE UAV (CFRP): 5.7 kg/m^2.

2. TAKEOFF AND LANDING TECHNIQUES

Take-off and landing techniques are one of the most important issue of mini and small UAVs, because they limit an airframe loads. Correct selection of take-off and landing technique could save or add additional weight and consequently extend or reduce endurance. Most of the techniques come from flying models including hand launch and detachable trolley or skids techniques, but there are solutions specially developed for UAVs, like launchers for take-off and parachutes for landing.

Non retractable and retractable landing gear

Landing gear is the most traditional way for taking-off and landing, however due to many disadvantages they are rarely applied techniques for small and mini UAVs. The main disadvantage of landing gears based technique is the runway access requirement, which limits UAV mission to an airport area only. The retractable landing gear systems are complex and heavy mechanical devices, therefore their application is limited only to UAV requiring smooth and low drag configuration. The UAVs equipped with retractable landing gear have to be equipped with pneumatic or hydraulic systems, which additionally increases the take-off weight.

Hand Launching

The hand launching is the simplest method of take-off procedure, however it is limited only to UAV up to 5-8 kg depending on the operator physical conditions. Such a UAV has to be equipped with landing device - skid or a parachute.

Launcher

The main advantage of the launcher system is possibility to start a heavy UAV without runway access. There are two sort of launchers: rubber type and a compressed gas propelled type launcher. The system selection depends on the take-off weight of the UAV. The rubber launcher could provide sufficient energy for the UAV up to 50kg. In the case of compressed gas launcher the only limits are: the size (length) of the takeoff ramp and maximum acceleration which could be applied to the UAV airframe.

Fig. 7. Hand launching mini UAV- POINTER

Fig. 8. Small UAV takes off from the rubber launcher

Detachable trolley

Detachable trolley technique is used to reduce the aircraft take-off weight. UAV starts on trolley platform, then trolley is detached and remains on a runway. Unfortunately this technique also requires a paved runway and UAV has to be equipped with landing skid or a parachute.

Parachute landing

Parachute systems are becoming standard equipment in most small UAVs. The systems are used as a standard landing procedure (eliminates the runway access requirement) or as a recovery device for hazardous states or both. There are several different methods of parachute extraction: gravity, spring catapult, compressed air/water mixture and pyrotechnic devices. Disadvantage of parachute systems is deceleration appearing during parachute deployment applied to the airframe. There are several ways to eliminate the deceleration effect (e.g. two stage deployment), however airframe has to be designed to survive the parachute loads.

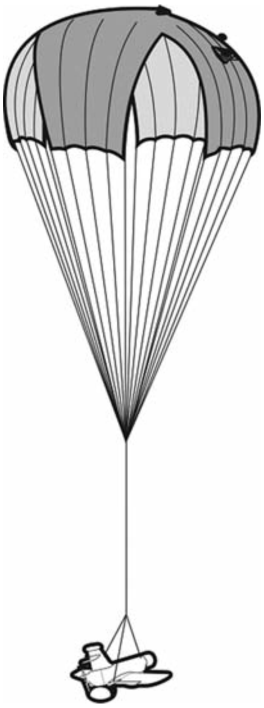


Fig. 9. UAV parachute landing

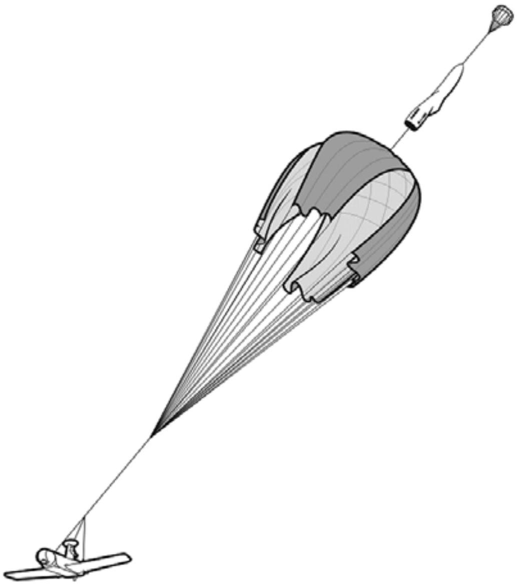


Fig. 10. Parachute deployment

Concluding, lets browse through all take-off and landing systems pointing out their strength (advantages) and weaknesses (disadvantages).

Fixed landing gear

Advantages: the simplest take-off and landing procedure.

Disadvantages: required runway access, increases the take off weight of UAV, generates drag.

Retractable landing gear

Advantages: the simplest take-off and landing procedure.

Disadvantages: required runway access, increases the take-off weight of UAV.

Hand Launching

Advantages: runway is not needed.

Disadvantages: applied for light mini UAVs only, must be combined with any landing devices as skid or parachute.

Launcher

Advantages: runway is not needed,

Disadvantages: additional logistics affords required.

Detachable trolley

Advantages: reduce the aircraft take-off weight and drag.

Disadvantages: required runway access, must be combined with any landing devices as skid or parachute.

Parachute landing system

Advantages: runway is not needed for landing, parachute could be used as a recovery system.

Disadvantages: loading of airframe during parachute deployment could be high.

3. PROPULSION SYSTEMS

Propulsion system employed in SUAV are usually taken from flying model technology. The selection of power unit is based on UAV speed and endurance requirements. There are following types of power units:

Combustion piston engine

A large number of piston engine for flying models is available for mini and small UAV. The engines displacement varies from 0.16 cm^3 up to 680 cm^3, generating the power from 0.05 up to 60 HP. Basing on statistics one could assume that the static thrust generated from 1 HP is around 2.5 kg. The combustion piston engines use two kind of fuel: methanol based and gasoline based mixtures. The methanol-fed unit has higher output and but lower efficiency (higher fuel consumption), that is why their application is only limited to aircraft requiring high payload to weight ratios. The gasoline engines has a lower output performance, but their fuel consumption is much lower the methanol engines. Because of that, the gasoline engines are broadly applied in mini and small UAVs. Especially long endurance UAV employs gasoline piston engines. The mini and small UAVs piston units employ constant pitch propellers, therefore their thrust is decreased with increase of flight speed and limited to about 100m/s TAS.

Tab. 1. Comparison of static thrust and fuel consumption of several gasoline piston engines

Engine	Displacement [cm^3]	Power [hp]	Static thrust * [N]	SFC kg/HP/hr	SFC *kg/hr/kg	Unit Weight [kg]
3W 24	24	2.5	61.25	0.95	0.38	1.6
3W70	68.8	6.5	159.25	0.8	0.32	3
3W 150	150	16.5	404.25	0.75	0.30	4.5
3W 200	200	19.5	477.75	0.65	0.26	5.5
3W 684	680	60	1470	0.6	0.24	17

** – calculation based on experience data – 2.5kg of static thrust per 1hp of engine power*

Electric motors

Tremendous improvement in electric propulsion system is recently observed. It takes places mainly because of development of brushless motors and Lithium-Polymer cells. The brushless motors have higher efficiency in comparison to brushed ones, which for the geared down motors achieves 80-90%. The 500g weighting unit could continuously withstand 1.5 kW input power, which means that taking into account its 80% efficiency, one could obtain 1.2kW of the mechanical output. The number of engines can be multiplied, supplying moment to one propeller shaft. The small UAV electric power plants employs constant pitch propellers, therefore their thrust is decreased with increase of flight speed and limited to about 100m/s TAS.

Tab. 2. Static thrust and energy consumption of high output electric motor

Motor	Unit weight [kg]	Efficiency [%]	Input [kW]	Output [kW]	Static thrust* [kg]	SFC* kg/hr/kg**
Hacker C50 XL	529 g	80	1.5	1.2	4.08	2.06

**) calculation based on experience data – 2.5kg of static thrust per 1hp of engine power.*

***) SFC calculation based on battery built of 20 (10s2p - 10serial/2 parallel) Li-Po cells 3.7V, 2.2Ah, 42g supplying current of 40A at 37V. Weight of the battery pack is 840g.*

The electric motors are the fastest developing power plants among other propulsion units, especially because of the fast development of battery cells. We should expect the SFC parameter will be reduced by 50% every 2 years time. This means that within 4-5 years SFC parameter for electric propulsion systems will be lower then gasoline piston engines.

Turbine jet engine

Turbine jet engine is the only propulsion system for short endurance UAV requiring the flight speed above 100m/s. Units applied to small UAV are derived from the flying model designs. Most of the units are simple designs with single stage centrifugal compressor, angular combustion chamber and single stage axial turbine wheel.

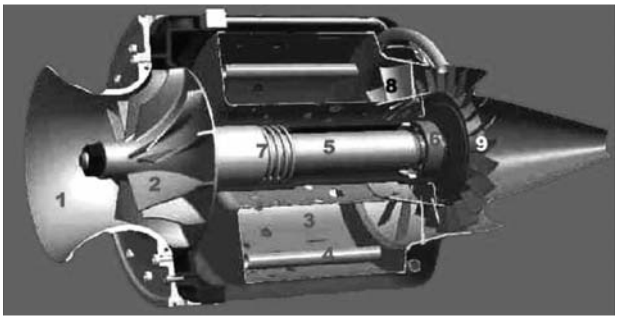


Fig. 11. Cross section view of small turbine jet engine

All of them are controlled by microprocessor unit managing start sequence, running and shut off/cool down sequence. The thrust of commercially available units starts from 40N up to 480N, unfortunately all of them have low pressure ratio which consequently means low efficiency and high fuel consumption. There is also available a limited number of custom made, small bypass turbofan engines and afterburner units, however due to limited application these units have not proved their reliability.

Tab. 3. Comparison of thrust and fuel consumption of several small turbine jet engines

Engine	Thrust [N]	SFC kg/hr/kg	Unit Weight [kg]
SWB-100	476	1.31	5.5
SWB-35	151	147	3.4
JETCAT P160	160	1.5	1.5
JETCAT P120	120	1.37	1.5
JETCAT P60	60	1.49	0.9
AMT Olympus HP	230	1.61	3.8
AMT Pegasus HP	167	1.68	3.07
AMT Mercury HP	88	1.94	2.25

Concluding, we could observe that the best SFC parameter still belongs to the gasoline piston engines, however their application is limited to about 100m/s. We should expect that within the near future, SFC parameter for electric propulsion systems will be lower then gasoline piston engines. The father development of small turbine jet engine technology could also bring SFC reduction, especially in the high speed UAV application.

Piston gasoline engine (SFC kg/hr/kg: 0.24 - 0.40)
Advantage: high thrust, low fuel consumption.
Disadvantage: thrust decrease with increase of speed, high vibration level, noise, propeller torque to be trimmed.

Electric motors (SFC kg/hr/kg: 2)
Advantage: high thrust, possibility of energy regeneration in flight (solar power), low noise (prop and gear box), high potential of farther development, possibility of output control within 0 up to 100% range during the flight, average vibration level.
Disadvantage: thrust decrease with increase of speed, propeller torque to be trimmed.

Turbine jet engine (SFC kg/hr/kg: 1.3 -1.9)
Advantage: high thrust, constant thrust with increase of speed, low vibration level.
Disadvantage: high fuel consumption (low endurance), high noise, fire risk.

4. CONTROL SYSTEM

The are two main type of UAV control systems - remotely and autonomously controlled systems (autopilots). Autopilot system are beyond the scope of this paper. Only a few commercials autopilot units are available (e.g. Micropilot, successfully applied in several UAVs).

Remotely controlled system

Usually the only difference between flying model and maturated UAV remote control system is range, reliability and link-up/link-down capabilities. The flying model control systems have power output up to 1W. Such output provides the operational range up to 2-3 km, which exceeds operator visual capabilities. For the UAV application the output power could be increased, which consequently increases the operational range. The number on channels is limited by a transmission signal time gate. The reliability of flying models systems is achieved by several methods. One is the so-called advanced Code Modulation. The transmitter codes the control signal in a programmed way, then it is decoded by the onboard receiver. If the decoded signal does not fulfil a programmed pattern, it is considered as a transmission dysfunction and a programmed control surface deflection is applied. The control is reactivated when a correct signal is received.

The other option to increase reliability, is application of the active stabilizing infrared (IR) unit. The unit is a two-axis, four-sensor control-stabilization system that is plugged into control system of UAV. It does not have moving parts and uses infrared IR heat sensors to control the model's roll and pitch. The system has two components: a sensor head that is attached to the underside of UAV and a controller unit that is installed inside. The sensor head has four IR heat sensors that face left, right, forward and aft. The sensors read how much IR heat is present in the four directions. The controller unit evaluates the IR heat information and adjusts the controls to keep the IR heat values equal for all four sensors for normal straight-and-level flight. Infrared heat is a much better source for control input than visible light because IR heat is not affected as much by cloud cover. The controller is plugged into the RC receiver system between the receiver and servos. Once it has been calibrated, the unit did not need calibration again unless the weather changes drastically. Since the unit works by reading the differences in IR heat levels rather than light intensity, it works equally well in bright sunlight or overcast conditions. The unit work also at night.

Fig. 12. Co-pilot sensor head [11]

Onboard control computer

The complex plane configuration with higher number of control surfaces employs control surfaces deflection sequences to control aircraft in all channels. Longitudinal control for example requires deflection of 6 control surfaces then just single elevator. If the given surfaces is responsible for control in two different channels e.g. longitudinal and lateral and surface deflection is correlated with flight parameter e.g. flight speed or AOA, the situation becomes more complex. To control such an airplane the onboard computer system is necessary. The computer unit controls the surfaces deflections in a current flight mode with a given control input.

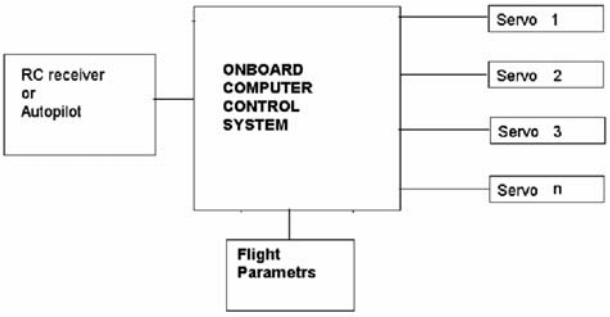


Fig. 13. Small UAV control system architecture

Onboard power supply system

Selection of the onboard power supply systems is a challenge for all flying objects including UAVs. Because of the fact that the total energy amount is always limited, the correct energy management is always the most important factor. The UAV power supply systems could be divided into two main categories. The first, systems based on the accumulated energy sources – chemical accumulators and the second, the systems including onboard power generators or other power generating devices e.g. solar panels. The power management is mainly oriented on energy saving issue and on providing energy according to the priority of circuits. For example, in case of energy shortage the management system switches off less important systems to provide the sufficient energy for the control system. The advanced small and mini UAVs are equipped with custom made power supply systems, specially tailored to provide energy for all onboard systems. Less complex UAV employs derivatives of a flying model power supply systems. The system is consisted of power sources - accumulators (Li-Po cells offers the best capacity to weight ratio) and power management module. The power management tasks includes:

- Voltage regulation - onboard units require different voltage then a nominal accumulator voltage,
- Switching off a depleted or failed power sources,
- Short circuit eliminator. It switches off the particular receiver if current exceeds given value,
- High current circuit eliminator. High current goes directly to the power receiver, not through control units,
- Control signal amplifier. It amplifies a control signal for actuators (servos).

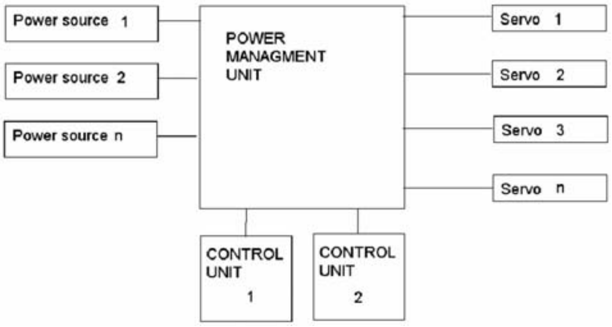


Fig. 14. Power management system architecture

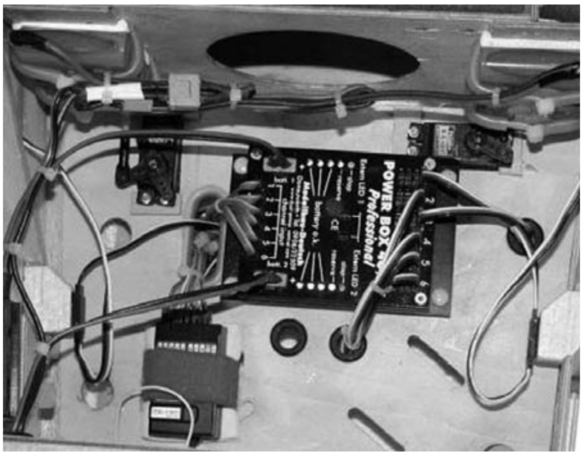


Fig. 15. Example of power management unit installed on a UAV

Actuators and Servos

The mini and small UAVs are equipped with EMA (Electro–Mechanical Actuators) to deflect control surfaces. Depending on the size and flight speed of UAVs the different type of actuators are used. Industrial type servos (e.g. Tonegawa Seiko) or upper class model (JR, Baker, Voltz, Hitec) digital servos are installed. There is a common procedure to install two or more actuators on most important control surface to increase the safety margin in case of actuator failure. Such installation requires additional units (e.g. onboard computer), which parallels the neutral point and travel of all actuators installed on the same control surface. Selection of actuators for particular application should be based on servo parameters corresponding to control surface loads and given unit type failure statistics.

Tab. 4. Comparison of typical mini/small UAVs servos parameters

Actuator type	Weight [g]	Max Torque kG/cm[V]	Speed [sek/60deg]
Tonegawa Seiko PS-050	280	66 [6v]	0.29
Tonegawa Seiko SPS-105	780	190[12v]	0.3
HITEC 805	62	24[6v]	0.15
HITEC HRS-5995TG	152	25[6v]	0.19
JR DS 8411	50	11[6v]	0.19

5. FLIGHT DATA AQUSITION SYSTEMS AND TELEMETRY LINKS

Sensors Array

Speed

The flight speed could be measured by one of the following method: pressure indicator, GPS and fan anemometer. The pressure speed indicator proved to be the most reliable unit for the speed range of 20m/s and up. GPS speed indication could be used only for reference purposes. The fan anemometer is the most accurate device for very low (0-20m/s), constant speed measurements.

Altitude

The altitude measurements are very similar to speed indications and they could be measured by one of the following method: pressure indicator, GPS and ultra sound distance sensor. The pressure altitude indicator is most reliable, but it needs to be temperature compensated. GPS altitude indication could be used only for reference purposes. The ultra sound distance sensor is applied for the altitude measurement during touch down procedure. It measures the distance between UAV and runway or ground.

Linear acceleration and Pitch, Roll and Yaw indicators

The unit measuring angular rates is called inertial measuring unit (IMU). The IMU is a miniature, gyro-enhanced system. Its internal low-power signal processor provides drift-free 3D orientation as well as calibrated 3D acceleration, 3D rate of turn (rate gyro) and 3D earth-magnetic field data. The IMU is an excellent measurement unit for stabilization and control mini and small UAVs.

Control surface deflection

Control surface deflection could be measured directly by potentiometer's linked with the control surface or indirectly by measuring a servo signals. The potentiometers method is much more accurate because it does not accumulate all errors generated by control linkage, however requires additional device to be installed onboard

Thrust sensing

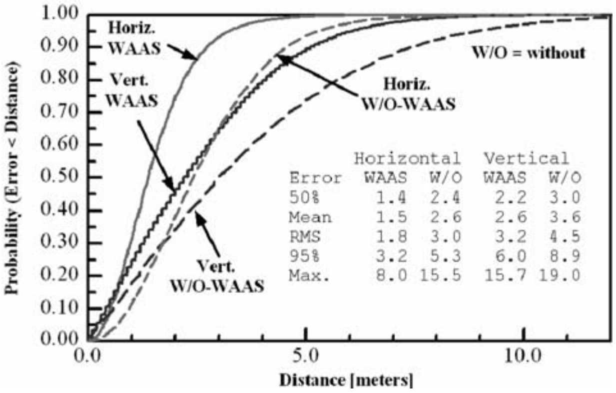
The thrust could be indicated directly (more accurate) and indirectly based on the engine rotation (RPM). The direct method is based on force indicator located on the engine mount. The RPM thrust sensing needs to be correlated with current flight speed and the propulsion system speed characteristics, which complicates this method.

Tab. 5. UAV Flight parameter sensor tolerances

Parameter	Tolerance
Altitude	±5m (±0.5m)
Airspeed	±1m/s
Linear acceleration	±0.08g
Angel of attack (AoA)	±0.5deg
Angular rate indicator	0.3deg/sek
Thrust	±1N
Control surface deflection.	±0.5deg

Positioning system

The most of the UAV navigating system employs Global Positioning System (GPS) for navigation. The accuracy of the GPS depends on the number of acquired satellites, however the receivers with WAAS system offer better accuracy then 5 meter. GPS navigation systems can provide a heading accuracy of 0.05°. Both location and heading values mentioned above are satisfying numbers for navigating purposes.



	Horizontal		Vertical	
Error	WAAS	W/O	WAAS	W/O
50%	1.4	2.4	2.2	3.0
Mean	1.5	2.6	2.6	3.6
RMS	1.8	3.0	3.2	4.5
95%	3.2	5.3	6.0	8.9
Max.	8.0	15.5	15.7	19.0

Fig. 16. Accuracy of the GPS Garmin 76 receiver with WAAS technology [14]

Flight data recorders

There are several commercially available small size flight data recording systems. They vary in size, weight and number of logging channels and sampling frequencies suitable for application in mini and small UAVs. According to the authors experience the 24 channel logger with 50 Hz sampling rate is sufficient device for most flight analysis. The higher sampling rate could be necessary for high detailed analysis of highly dynamical flight manoeuvres.

There are three possible approaches:

- Transmission of complete information to the ground and storage in the ground station,
- Storage in the onboard data acquisition system with transmission of information necessary for control only,
- Storage in the onboard data acquisition system and transmission of complete information to the ground.

First approach allows to acquire the information even from flights ended with crash, but it is quite sensitive to the electromagnetic and transmission jamming. Second approach provides high quality of data, but in the case of crash the data may not be recovered at all unless the data recording system is strong enough (and heavy). The third approach provides both safety and quality, but weight and power consumption of the system are the greatest.

Telemetry links

The main task of telemetry link is to provide information about UAV flight parameter from UAV to the ground station. The provided information are used for control, navigation, flight mission purposes, etc.

Radio modems

Radio modems links are the low cost solution for mini and small UAVs. The device with a 1W transmitter output working at 2.4 Ghz band provides a reliable UAV – ground station downlink up to 32 km. Downlink device offers the transmission speed of 9600 up to 19200 bps, which is quite sufficient number to transmit flight data parameters.

Cellular phone station network

There are a successful attempts of employing cellular phone station network for flight data transmission. Advantage of this methods is elimination of high output onboard transmitters, however the application of such equipped UAV is limited only to areas with well developed cellular phone station network.

Commercial telemetry systems

The Eagle Three Company has offered telemetry and logging system which is a complete solutions for setting up, monitoring and demonstrating of unmanned platforms. This system is capable to measure and transmit flight position, course, ground speed, GPS altitude, distance to ground station. The system has limited range due to the low transmitter output, however it is a good tool for short range UAV applications.

Fig. 17. The Eagle Three - the onboard flight data acquisition unit [12]

Fig. 18. The Eagle Three telemetry link terminal [12]

6. CONCLUSION

Further development of electronics devices and an increase of propulsion system efficiency will drive small and mini UAVs technology improvement. One can expect increase of capabilities of the small and mini systems. The electric propulsion system will probably become the leader among other propelling units. It will take place because of the rapid development of battery cells and possibility of energy regeneration in flight. The quality of small onboard sensing devices could be also improved, which will provide another application possibilities.

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ABBREVIATIONS

UAV – Unmanned Aerial Vehicle
SUAV – Small Unmanned Aerial Vehicle
WS – Weight to lifting Surface ratio
GFRC – Glass Fibre Reinforced Composites
CFRC – Carbon Fibre Reinforced Composites
KFRC – Kevlar Fibre Reinforced Composites
3D – Three Dimensional
CAD – Computer Added Design
CAM – Computer Added Manufacturing/ Machining
CNC – Computerized Numerical Control
EDM – Electronic Discharge Machine
EPP – Expanded Polystyrene
SFC – Specific Fuel Consumption
TAS – True Airspeed
IR – Infrared
RC – Radio Controlled
EMA – Electro–Mechanical Actuator
AOA – Angle of Attack
IMU – Inertial Measuring Unit
GPS – Global Positioning System
WAAS – Wide Area Augmentation System

Z. Goraj, M. Szender

TECHNIKA I KRYTYCZNE TECHNOLOGIE ZASTOSOWANE W MAŁYCH I MINIATUROWYCH UAV'S – STAN OBECNY I PERSPEKTYWY ROZWOJU

Technika i technologia wykorzystywana w małych i miniaturowych UAV's pochodzi z pełnowymiarowych obiektów UAV i techniki modeli latających. Wymagania stosowanej technologii są oparte na żądaniach osiągnięcia wysokiej niezawodności połączonych z niedużymi wymiarami obiektu i jego małą masą startową. Artykuł opisuje konstrukcje płatowców, zespołów napędowych oraz techniki startu i lądowania. W artykule zawarta jest również analiza silnych i słabych punktów tych technik oraz perspektywy ich rozwoju. Artykuł opisuje pokrótce systemy sterowania, systemy zbierania danych lotnych oraz łącza telemetryczne.

З. Горай, М. Шендер

ТЕХНИКА И КРИТИЧЕСКИЕ ТЕХНОЛОГИИ ПРИМЕНЯЕМЫЕ В НЕБОЛЬИШХ И МИНИАТЮРНЫХ ДПЛА – НАСТОЯЩЕЕ СОСТОЯНИЕ И ПЕРСПЕКТИВЫ РАЗВИТИЯ

Техника и технология применяемые в небольших и миниатюрных ДПЛА приняты с полноразмерных объектов ДПЛА и техники летающих моделей. Технические условия применяемой технологии основываются на требованиях достижения высокой надёжности в сочетании с небольшой стартовой массой. В статье описаны конструкции планеров ДПЛА силовых установок а также техники старта и посадки. Статья содержит также анализ сильных и слабых пунктов этих техник, а также перспективы их развития. В статье описаны вкратце системы управления, системы сбора полетных данных, а также телеметрические каналы (связи).