Challenges and perspective with using a group of small combat unmanned aerial vehicles

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Abstract: *The article discusses the features of small unmanned aerial vehicles, perspectives, directions for the development of unmanned aerial vehicles with integrated combat units. The development trends of unmanned aerial vehicles indicate the direction of the use of the unmanned aerial vehicle in the group of small unmanned aerial vehicles operating on the principle of autonomous management. The main problems are related to solving management and groupwork tasks in the group, which leads to the use of group intelligence methods. The possibilities of group use of unmanned aerial vehicles are analyzed. One of the main goals of small drone technology is to create energy sources with high energy capacity and power. The exchange of information within a group of unmanned aerial vehicles requires the use of group-based intelligent methods based on self-organized decentralized management. Such methods are based on the self-organization of movement and communication in a group of insects, fish or birds. The analysis shows that the development trends of small-scale drones are primarily driven by advances in micro and nano technology, new approaches to aerodynamics and management, the creation of high-capacity power supplies and engines, creating autonomous micro and nano systems for navigation and communication using agreed integrated concepts. The direction of new technologies for use in the group of small unmanned aerial vehicles based on the principle of autonomous control is revealed. An* *algorithm for organizing interaction in a group of unmanned aerial vehicles is presented and the relevant tasks are discussed.*

Key Words: *drone, micro- and nano systems, integrated combat unit, aircraft, management, aviation technology*

1. INTRODUCTION

One of the advantages of an unmanned aviation systems is the ability to create a small-sized aircraft. According to the US International classification of unmanned aerial vehicles includes the following classes of small unmanned aerial vehicles: nano, micro and mini drones [1], [2]. The class of nano unmanned aerial vehicles (UAV) includes devices weighing less than 25 g, such as: RoboBee, PD-100 Black Hornet, CX-10C, Mite2 and others. It is one of the growing emerging directions. The class of micro drones includes devices weighing less than 5 kg, such as: Wasp 1, Honeywell, MD4-200, Black Widow, Cyber Bug, and others. The take-off weight of mini unmanned aerial vehicles is in the range of 5-150 kg. This class includes Skylark I-LEX, RQ-14 Dragon Eye, FQM-151 Pointer, RQ-11 Raven, AeroVironment RQ-20 Puma, Scorpio, T-15 Arcturus, Bluebird Aero Systems Boomerang, EMT Aladin, Desert Hawk, Globiha and others [3], [4], [5], [6].

Table 1 – Performance of selected nano class UAV

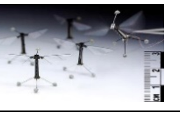
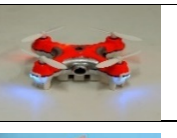
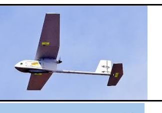
UAV Type	Unit measures, cm	Wings flap, times p/s	Weighs, gr	Speed, km/h	Range, km	Flight Time, min	UAV
Robo Bee	3 (1.2in)	120	0.08 (0.0028 oz)	-	-	-	
PD-100 Black Hornet	10 × 2.5 (4 × 1in)	-	18	21	1.6	20	
Quadcopter	62 x 20	-	15	-	0.03	4	
Mite 2	36 x 24.5	2x electric motor	213	16-32	-	30	

Table 2 – Performance of selected micro class UAV

UAV Type	Wingspan, m	Engine type	Weighs, kg	Speed , km/h	Range, km	Flight Time, min.	UAV
Wasp 1	1	electric	1.3	20-50	5	50	
Honeywell	-	piston	8.39	70	3	40	

Black Widow	0.40	electric	3	38-53	17	30	

Table 3 – Performance of selected mini class UAV

Type	Wingspan, m	Engine type	Weighs, kg	Speed, km/h	Range, km	Flight Time, hr	UAV
Skylark I-LEX	1.2	electric	7.5	35-60	10	1.5	
RQ-14 Dragon Eye	1.1	electric	2.7	65	5	1	
FQM-151 Pointer	2.74	electric	4	70	7	1	
RQ-11 Raven	1.37	electric	1.9	30	10	1.5	
RQ-20 Puma	2.8	electric	5.9	80	15	2	

One of the main goals of small drone technology is to create energy sources with high energy capacity and power. If the use of an elongated fixed wing is effective for traditional aircraft, in the case of small unmanned aerial vehicles it is more daring to use small extension, rotary or moving wing designs. The priority of using small elongated wings leads to the use of the “flying wing” aerodynamic scheme [7], [8], [9]. There is a wider choice of flight principle for nano and micro flying machines. Aircraft, helicopter, flywheel, flexible circuits are used. The configuration of the winged flying machine, which failed to prove successful for traditional flying machines, gives us a completely different result in the case of small unmanned aerial vehicles. The creation of such a flying machine is based on the application of the principles of biomechanics of flying analogues (birds, insects). Interesting results are achieved by using flexible and folding wing schemes. In the case of small-sized appliances, such an approach does not create constructional difficulties and makes it even more compact for operation [10], [11], [12], [13].

Navigation issues are no less important. GPS is one of the best navigation devices, but its weight is a hindrance when used in small drones. The development of microgyroscopes and navigation systems is a priority. Currently, the priority areas are the transition from remote mode control of unmanned aerial vehicles to a more autonomous one. Small drones can be successfully used in military affairs [14], [15]. For example, reconnaissance in a densely populated area. The use of such devices is a priority when performing highly risky combat missions. Small unmanned aerial vehicles can shorten or minimize the time to deliver intelligence information to the military. Such a simple aircraft can be personalized and used by a soldier directly in combat conditions [16], [17], [18]. The advent of small drones has led to the development of new doctrinal approaches and systems to fight against them. Modern air defense systems are designed to detect traditional large-sized aircraft. Small unmanned aerial vehicles have a small surface reflection coefficient, which is why it is very difficult to identify them on the radar [19], [20]. Clearly it is possible to create locators that will be able to detect flying machines with a small coefficient of surface reflection, but at the same time other disruptive factors are created, such as information overloaded in the form of bird tracking [21], [22], [23], [24].

2. MATERIALS AND METHODS

The characteristics and different capabilities of small drones require different approaches to their creation and development. With the development of nano and micro technologies, the capabilities of such devices are increasing. Small unmanned aerial vehicles have control features. Automated control is a priority for the management of such devices. They are faced special requirements for maneuverability and handling as they have to fly at low altitudes, near difficult terrain and in confined spaces in city conditions. Small unmanned aerial vehicles can withstand relatively large overloads, allowing for better maneuverability. The future of small unmanned aerial vehicles largely depends on advances not only in micro- and nano systems, but also in aerodynamics, as well as in power plants, navigation and communications.

Matching challenges depend on size, volume, and stringent weight limits. Accordingly, the methodology for designing such aircraft should be different. Limitations on the size and mass of small unmanned aerial vehicles force the use of integrated systems.

For example, a wing can also function as an antenna, a power supply can function as a fuselage, and so on. The small aerodynamic forces and moments of small-sized unmanned aerial vehicles create an unfavorable picture to ensure their stability, especially in the event of wind.

Achieving the maneuverability and stability of such aircraft will require the use of fast-acting autonomous systems. An important question is the power plant. Small unmanned aerial vehicles will have high energy and power requirements. Low acoustic performance is equally important.

The required engine power can be reduced by increasing the aerodynamic characteristics of the aircraft, wing loading and engine efficiency. But the most effective is to reduce the weight of the aircraft, which is associated with the creation of small sizes and large energy sources.

As mentioned above, one of the major drawbacks of small drones is the difficulty of communicating with the operator. Because a small unmanned aerial vehicle has the small amount of energy it needs to operate the transceiver.

Antenna dimensions are also limited. One way to solve this problem is to use the principle of “hierarchical control”, the essence of which is that the connection to the central control point has only one or a few unmanned aerial vehicles, which transmits commands to the units of its subgroup.

Obviously, the connection distance between the aircraft in the group is small and therefore the energy costs for providing the connection are small. The exchange of information within a group of unmanned aerial vehicles requires the use of group-based intelligent methods based on self-organized decentralized management.

Such methods are based on the self-organization of movement and communication in a group of insects, fish or birds. The connection between the unmanned aerial vehicles in the group is established only at a certain point in time at close range. Unmanned aerial vehicles make decisions about current operations through data collected by itself and from neighboring aircraft.

3. RESULTS AND DISCUSSIONS

Recently, concepts of a system consisting of a combat unmanned aircraft complex with integrated warhead have been actively developing. It is known that military drones have been developed most successfully in the field of reconnaissance. They provide the opportunity to receive the necessary information in the operational mode and to quickly impact the targets with other means of combat. Clearly, integrating the "reconnaissance" and "attack" components into one module reduces reaction time and increases mobility. But the weight and capacity of such combat equipment is limited. On the other hand, military technology is well known for its cruise missile, which is similar in principle to an unmanned aerial vehicle. Nevertheless, it is still a combat missile, intended for flight on only one route.

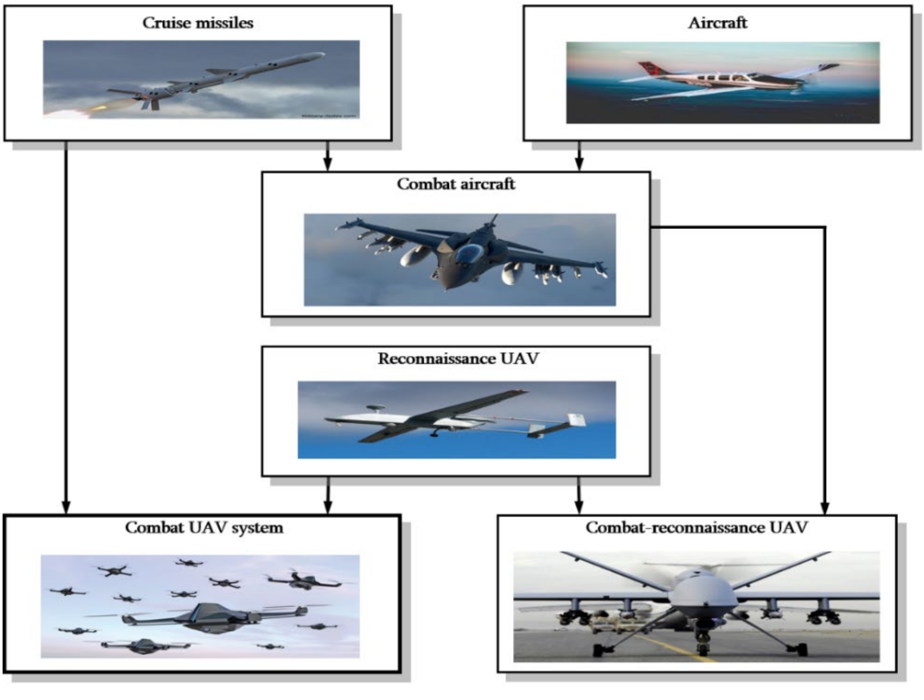


Fig. 1 – Concept scheme of an combat unmanned aerial vehicle system with integrated integrated warhead

To reduce the above-mentioned shortcomings, it is possible to create an unmanned aerial vehicle with a warhead of the desired capacity integrated in the hull. Such an "unmanned kamikaze" will have two main requirements for the aircraft: reconnaissance and destruction by targeting it if it is found.

An unmanned aerial vehicle with an integrated warhead must be different from a combat-reconnaissance unmanned aerial vehicle: speed of operation, compactness, simplicity and specific mass of the warhead. In order to meet these requirements, it is advisable to place an unmanned aerial vehicle with a folding wing structure in a disposable launch container.

Examples of such unmanned aerial vehicles are: AeroVironment Switchblade, Uvision Hero-120, Synchronous Transfer Mode Alpagu 2, Pprioria Maveric Unmanned Aviation System and others.

The concept of these unmanned aerial vehicles is of particular interest for tactical missions in infantry units.

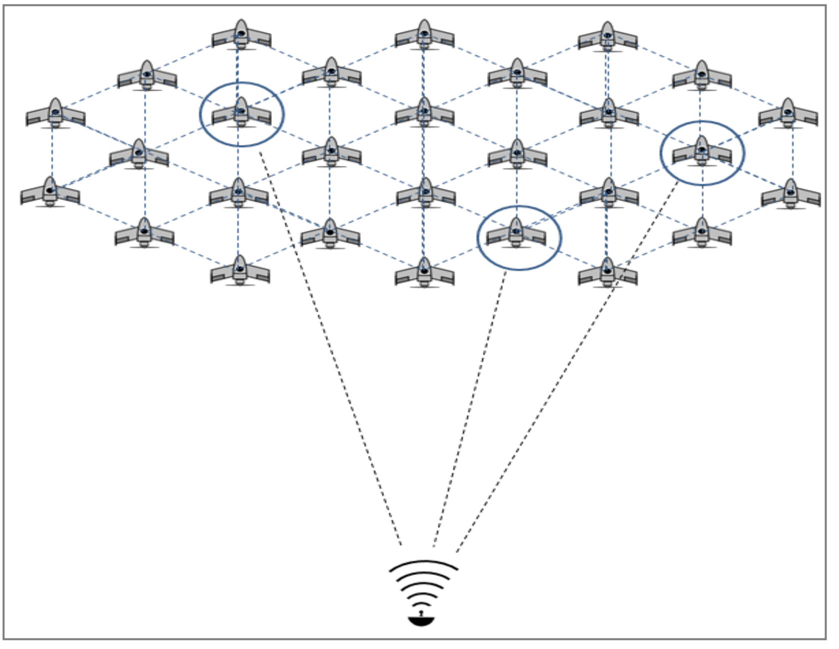


Fig. 2 – Principal scheme of management of a group of unmanned aerial vehicles

Successful completion of tactical tasks for infantry units significantly determines the probability of destroying the target. The best answer to this task is the group use of unmanned aerial vehicles.

An interesting technological solution in this regard is the control of one or more of these unmanned aerial vehicles from the ground control station. The rest of the unmanned aerial vehicles are controlled by relatively weak signals received from the leading unmanned aerial vehicle.

Introducing a group control model for small unmanned aerial vehicles, where:

$$r_i(i = 1 \dots N) \tag{1}$$

sets R unmanned aerial vehicles perform a set of tasks:

$$P = (P_1 \dots P_c) \tag{2}$$

However, the following conditions apply: all r_i $(i = 1 \dots N)$ unmanned aerial vehicles are the same. The condition of each drone is described by the vector value:

$$S_i = (S_{i1} \dots S_{ij}) \tag{3}$$

Each unmanned aerial vehicle can perform a limited number of actions denoted by the vector:

$$A_i = (a_{i1} \dots a_{ig}) \tag{4}$$

A single unmanned aerial vehicle can exchange information with $R_i \in R$ of a certain subset in a L – radius or sight zone. Each unmanned aerial vehicle can exchange information with $R_i \in R$ devices of a certain subset in the a L – radius zone or in the field of view. The $r_i \in R$ unmanned aerial vehicle knows the algorithms for changing its position according to its actions, as well as the actions and condition of other unmanned aerial vehicles of the $R_i \in R$ subset. This condition can be expressed by the following form:

$$\frac{dS_i}{dt} = f(S_i, A_i, S_{i1}, A_{i1} \dots S_{ij}, A_{ij}), \tag{5}$$

where: $S_{i1}, A_{ij} (j = 1 \dots L)$ is r_i in the field of view of the unmanned aerial vehicle current status and operation of the $R_{ij} \in R_i$ unmanned aerial vehicle. In the task set for the group $p_b \in P$ the authors mean to reach the state:

$$S_k^b = (S_{1k}^b \dots S_{Nk}^b), \tag{6}$$

where: N – is the number of unmanned aerial vehicles in the group, $S_{1k}^b (i = 1 \dots N) - r_i$ – is the target state of the unmanned aerial vehicle required to solve the P_b task and at which the minimum of $YY = F_b(S_1 \dots S_N)$ functionality is achieved. Given these conditions, the task of managing a group of unmanned aerial vehicles can be formulated as follows: determine the sequence of local actions of all $N = (A_1 \dots A_N)$ unmanned aerial vehicles that transforms the current state of the group to:

$$S_0 = (S_{10} \dots S_{N0}) \tag{7}$$

in front of the group:

$$P_b = P, S_1^b (S_{1k}^b \dots S_{Nk}^b) \tag{8}$$

the corresponding target state of the task and in which the minimum of function:

$$Y = F_b(S_1 \dots S_N) \tag{9}$$

is achieved:

$$\frac{dS_i}{dt} = f\left(S_i, A_i, S_{i1}, A_{i1} \dots S_{ij}, A_{ij}\right) \tag{10}$$

in terms of the relationship.

Here, S_{ij}, A_{ij} – is the state and action for $R_i \in R$ of the subset unmanned aerial vehicles, which come r_i into view of unmanned aerial vehicles. Group interaction can be represented by the following algorithm:

– all unmanned aerial vehicles in the group receive k -type assignments from the control station;

– each R_i unmanned aerial vehicle in the group determines or receives information about the current condition and local operations of the group unmanned aerial vehicle in the field of vision;

– based on the obtained data, the R_i unmanned aerial vehicle determines the state S_i^{min}, where the function Y_k^i takes the minimum value;

– R_i an unmanned aerial vehicle defines an action a_i aimed at converting its current state S_i to state S_i^{min};

– the R_i unmanned aerial vehicle implements a_i local action.

Consider the task of deploying unmanned aerial vehicles equally spaced in a group. Assume that m – is the minimum allowable distance between the devices, d – is the current distance R_i and R_j is the distance between the devices, and L – is the field of vision of each R_i device. Then in the case of $m < d < L$ the resultant force vector $F_{ij}(k)$ will be directed at the apparatus and the distance proportional to the distance $F_{ij}(k) \sim d$. Those unmanned aerial vehicles that detect a target and find themselves closest to it begin to move toward it.

Another F_M– motion vector will be added to the output power of such a leading unmanned aerial vehicle. Then the resultant force formula takes the following form:

$$F_i(k) = \sum_{j=1}^{n} F_{ij}(k) + F_{ib}(k) + F_{iM} \tag{11}$$

At this moment, the slave unmanned aerial vehicle again moves according to the same laws of gravity and attraction. Overall, the whole group moves in the direction of the goal. In the event that a group of unmanned aerial vehicles is required to bypass obstacles, then another component F_{iH} – must be added to the resultant force formula for the effect force on the vehicle – the vector of which is directed against the obstacle. Accordingly, the formula of the resultant force acting on the unmanned aerial vehicle will take the following form:

$$F_i(k) = \sum_{j=1}^{n} F_{ij}(k) + F_{ib}(k) + F_{iM} + F_{iH} \tag{12}$$

If one of the unmanned aerial vehicles in the group detects a target, the information could be transmitted to all the members of the group, but in the case of a limited connection, instead of transmitting the information, this unmanned aerial vehicle may start moving in the direction of the target and lead the whole group to target location. Nevertheless, despite the impressive prospects for the development of combat unmanned vehicles, it is important for air defense to provide reliable protection of the covered object by minimizing the number of combat UAVs that reach the line of guaranteed damage to the covered object. From this point of view, the group use of UAVs poses a rather real threat. Let's consider the conditionally elementary task of repelling the raid of a combat UAVs group on an object covered by an air defense missile system.

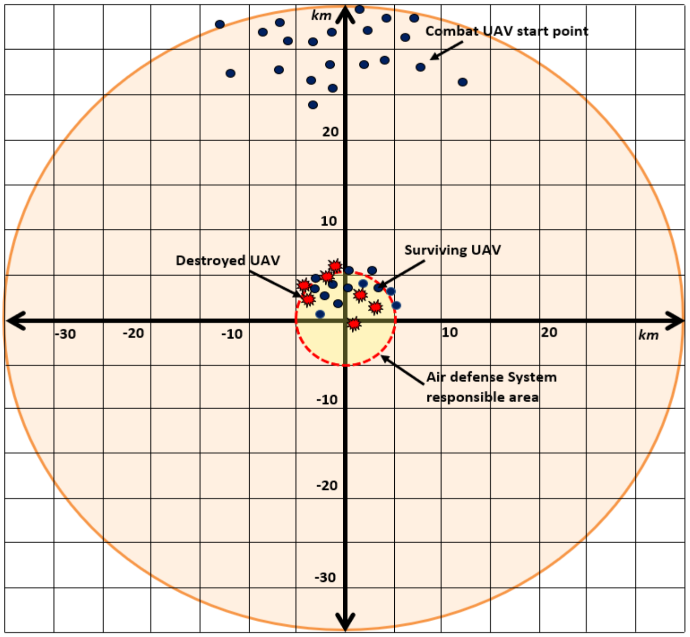


Fig. 3 – Combat UAV Group Attack Modeling Results

The covered object is a piece of terrain, in the center of which there is an air defense missile system. The task of the air defense missile system is to shoot down all air targets seeking to enter the zone of responsibility with a radius of 2 km (Figure 4) for the use of airborne weapons. At a distance of 25 km from the air defense missile system, there is a 10 – kilometer zone (light green ring) from which a disordered homogeneous target group of combat UAVs – Air Targets for air defense systems starts simultaneously. Each combat UAVs has its own number. The flight of each combat UAVs is carried out autonomously in the 90 ° sector and is not synchronized with other members of the group. Air Target is an aircraft-type combat UAVs with a launch weight of 10 kg. The detection range of air targets with the help of an optoelectronic system and a radar station that are part of the air defense missile system, depending on the flight altitude, is 1,500 ... 2,500 m. The number of air targets are 15 units flying at speeds from 100 to 300 km / h at altitudes of 200 ... 800m. The average value of Pdef. of air targets by the fire weapons of the air defense systems is 0.26. Air defense systems weapon stock is 16 units: 16 bursts of 100 shells each or 16 anti-aircraft missiles or their combination in different ratio. The priority of the goal is determined by the priority criterion, which is the minimum available time for the use of the means of destruction of the air defense missile system:

$$\bar{t} = min\left\{\frac{D\cos V}{V_t\cos\theta\cos\psi_t} + \frac{\psi_{turn}}{\omega_{turn}}\right\} \tag{13}$$

where: D – slant range to the target; V – is the elevation angle of the air target; V_t – target flight speed; θ – the angle of inclination of the trajectory of the air target; ψ_t – relative flight course of the air target; ψ_{turn} – the angle of misalignment of the axis of the weapons and the azimuth of the air target; ω_{turn} – the angular velocity of rotation of the axis of weapons. The physical time of the simulated raid of the group of the combat UAVs on the covered object was 10 minutes. The simulation resulted in the following conclusions:

1. Air defense systems did not provide cover for the object: 10 out of 15 combat UAVs entered the zone of responsibility of the air defense systems did not provide cover for the object: and were able to use the onboard means of destruction.
2. Air defense system used up all its ammunition, not fulfilling the task of covering object.
3. The use of several waves of attacks from groups of cheap combat UAVs can paralyze any air defense.

The above results, even with many assumptions taken into account, are a fairly clear illustration, that the group use of combat UAVs today is a serious factor for achieving military superiority at low cost. The development of technology for the group use of combat UAVs significantly complicates the conditions for the operation of air defense and requires a radical revision of the ideology of creating promising weapon systems and air defense weapons.

4. CONCLUSIONS

The analysis shows that the development trends of small-scale drones are primarily driven by advances in micro and nano technology, new approaches to aerodynamics and management, the creation of high-capacity power supplies and engines, creating autonomous micro and nano systems for navigation and communication using agreed integrated concepts. The peculiarities of such unmanned aerial vehicles also lead to the formation of different design methods. The direction of new technologies for use in the group of small unmanned aerial vehicles based on the principle of autonomous control is revealed. The main problems are related to the solution of group's management and communication tasks, which leads to the use of group intelligence methods. Unmanned strike technology is a natural way of development of aviation robotics, since it is the final link in the solution chain tasks in the conduct of military operations. A careful analysis of the features of the combat UAVs application, the results of modeling the group use of combat UAVs in the context of countering air defense and events in last military conflicts shows that the organization of the use groups of combat UAVs cannot do without competent specialists, advisory and technical assistance from technologically developed countries. This approach significantly reduces the cost of obtaining the desired result and allows low-cost testing of advanced weapons systems. Therefore, combat unmanned aerial vehicles in this process begins to play one of the key roles.

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