PECULIAR ASPECTS OF ROTARY-WING UAV COMPLEXES USED FOR AERIAL MONITORING MISSION

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Abstract. The paper analyses tasks and peculiar aspects of the fuel and-energy complex objects aerial monitoring. Type classification of such objects and application patterns of UAV systems are given. The requirements to the UAV system equipment are set forth. Performance capabilities of UAV systems are reviewed for the fixed-wing and rotary-wing aircraft options and their comparative analysis is given. The authors present one of the possible ways of the fuel-energy objects aerial monitoring based on Kamov Company's coaxial rotary-wing UAVs.

Introduction. In the present-day conditions reliability and safety of fuel and energy complex objects become the most important factors influencing both the economic efficiency and power safety of the national economy. These objects (main pipelines, transfer and service stations, storages, nuclear power stations, hydroelectric power stations, power transmission lines) are always under a risk of damage due to terrorist attacks, natural or man-caused catastrophes resulting in large economic losses. In this connection continuous on-line monitoring of the most critical and vulnerable facilities of the fuel and power industry is a task of primary importance. Unmanned fixed- wing and rotary-wing aircraft are now used for aerial surveillance of these facilities and the areas around them. The progress attained in the development of UAV systems allows performing these tasks at lesser costs while ensuring the required level of safety and reliability.

By now, there are known over 600 development programs of various UAV types for various applications including 80 programs of vertical take-off/landing unmanned air vehicles and integrated systems based on them.

Keeping in mind the existing tendencies in the development of the world aviation and using its own backlog on manned helicopters, Kamov Company is developing unmanned helicopters and integrated systems based thereon that are intended for different applications. These integrated systems can be effectively used for surveillance of fuel and energy complex objects. Different nature and length of these facilities and diversity of monitoring tasks require different systems of various sizes. Combining of individual systems into an integrated system is a natural step that enhances their efficiency. Creation of such integrated system is possible based on the analysis of the specific requirements of fuel and energy complex objects and the tasks to be performed by the aerial systems in the interests of the main Customers, with the principles of unification and typification being used for its development. Conceptual approach to the development of rotary-wing UAV systems for fuel and power industry facility surveillance and monitoring is discussed below.

1. FUEL AND ENERGY COMPLEX OBJECTS AND THEIR MONITORING TASKS

The main Customers for such aircraft systems are Gasprom, Transneft, Rosneft, RAO EES, Minpriroda etc. Each of them is powerful enough to develop its own aerial monitoring system but it would definitely be an unnecessary scattering of financial resources and take more time and effort because aerial monitoring tasks are practically similar. Besides, the objects to be monitored are usually very extended and located in the areas with poorly developed infrastructure that impedes its monitoring by traditional systems.

Location of fuel and energy complex objects is shown in fig. 1. All objects can be conditionally divided into three types:

- Type 1 - local objects (nuclear power stations, hydroelectric power stations, petroleum refineries and other objects of no more than 100 km length);
- Type 2 - regional objects (networks) of medium length (to 500 km);
- Type 3 - main objects (networks) of large length (2000-3000 km).

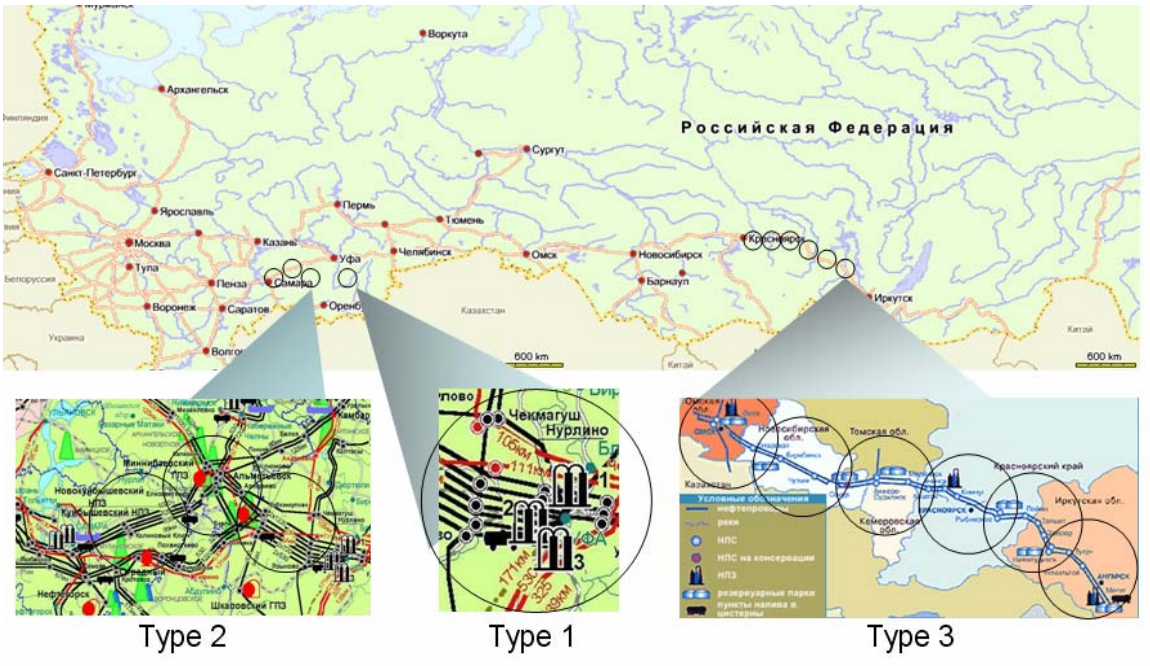


Fig. 1 Location of fuel and energy complex objects

Local objects in the European part of the country are interconnected by a dense transportation system while objects located in the Asian and Northern parts of the country where transportation infrastructure is poorly developed are very extended.

The main monitoring tasks for all three types of fuel and energy complex objects are very similar in nature and include:

- monitoring of pipelines and power lines and identification of their sections' emergency/pre-emergency status;
- industrial and ecological monitoring of territories and fuel/energy complex objects;
- security patrolling of fuel and energy complex objects;
- aerial photography and mapping of fuel and energy complex objects;
- aerial geological survey.

Specific character of fuel and energy complex objects aerial monitoring results from:

- fixed flight routes;
- technology effectiveness (typified application patterns) permitting automation;
- low altitude flight;
- extended routes;
- absence of developed transportation infrastructure;
- atmospheric turbulence in the surface layer;
- absence of reliable and steady radio communications;
- provision of safety and security.

2. SPECIFIC FEATURES OF ROTARY-WING UAV INTEGRATED SYSTEMS

What types of aircraft are preferable for using as aerial unmanned platforms?

It is well known that aerodynamic efficiency does not allow a helicopter to provide the same range and endurance as those demonstrated by a fixed-wing aircraft. However, for aerial monitoring other generic properties of a helicopter seem to be more important, i.e.

- a capability of monitoring fuel and energy complex object condition at hover or in a low speed/altitude flight;
- standard take-off and landing procedures using unprepared sites, including standard landing in case of engine failure;
- multiple application; absence of uncontrolled flight conditions (spin).

In this sense, coaxial helicopters are even more suitable for such applications due to their additional advantages including:

- higher aerodynamic efficiency of the main rotor system and absence of parasite losses on a tail rotor;
- absence of cross couplings in coaxial helicopter control channels making development of automatic flight control systems essentially easier;
- high maneuverability;
- aerodynamic symmetry allowing for helicopter operations at any wind speed and direction;
- effective mechanisms for reduction of vibrations and aerodynamic load oscillations transferred to the fuselage.

2.1. Efficiency of aerial monitoring. Aircraft aerodynamic performance is largely responsible for the efficiency of aerial monitoring. Specific factors primarily influencing the monitoring efficiency are application rate, quality of information obtained from the mission load sensors and reliable real-time information output. Let us examine these statements in detail. Unmanned fixed-wing aircraft are inferior to rotary-wing aircraft in application rate (number of failsafe take-offs and landings) and in the size of minimum required take-off/landing site area. Fig. 2 presents aircraft static losses at landing and comparative required areas of take-off/landing sites for unmanned fixed and rotary-wing aircraft.

The quality of information received on board the aircraft depends directly on resolution of sensors and distance to the object. Fixed routes with limited width typical for missions of extended fuel and energy complex object monitoring make a low altitude flight very advantageous because it allows using of simpler and less expensive sensors.

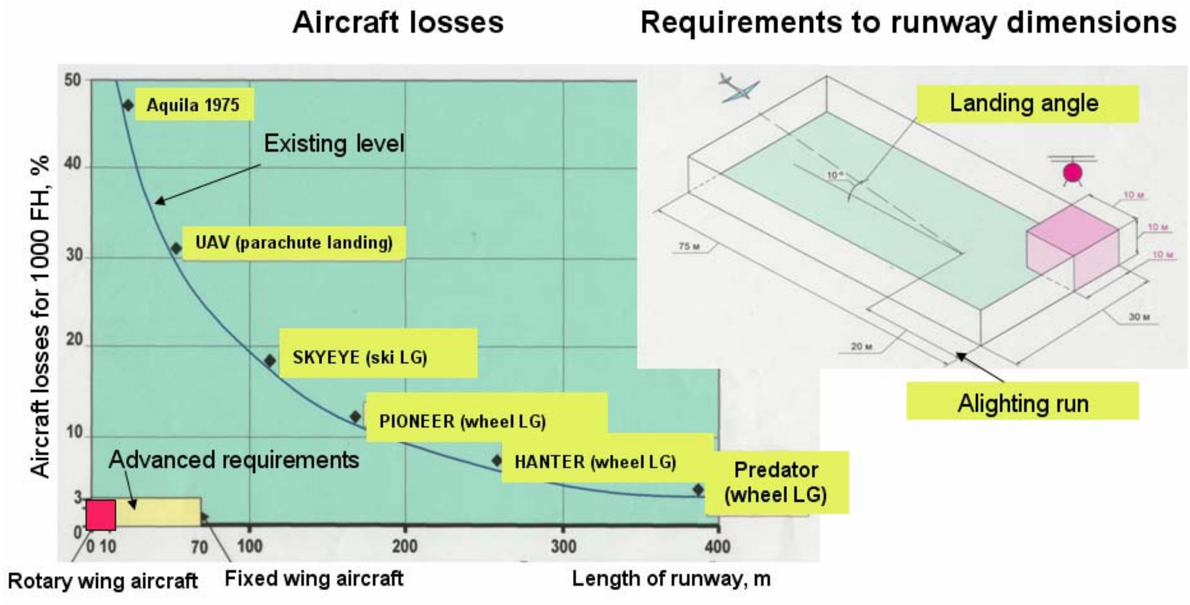


Fig. 2. Unmanned aircraft take-off and landing

Atmospheric turbulence in surface air causes continuous dynamic variation of the aircraft attitude and distortions in the information obtained from the sensors. Fig. 3 illustrates the influence of turbulence on the aircraft attitude at a vertical gust, i.e. demonstrates the ability of various aircraft configurations to maintain the attitude that is an important qualitative characteristic of monitoring.

As can be seen, fixed-wing aircraft demonstrate large overshoots in pitch. Qualitative estimations in fig. 4 show that they are 1.5-3 times higher than those typical for rotary-wing aircraft. The transient time is also 1.5 times more with the fixed-wing aircraft.

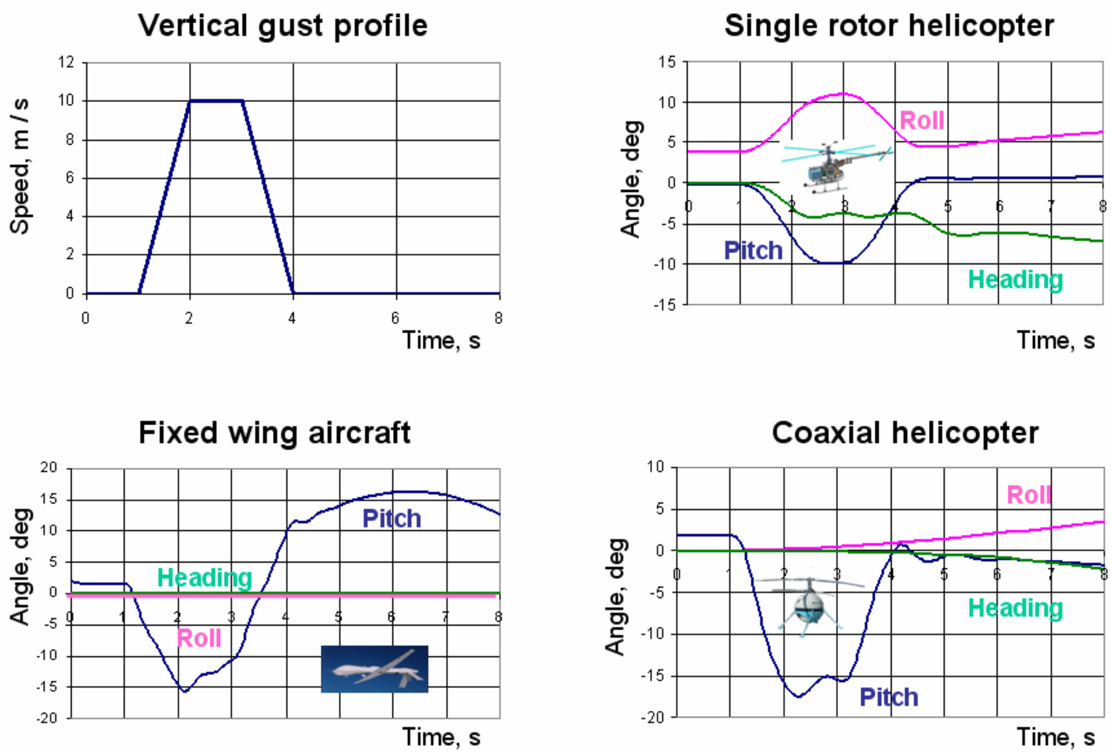
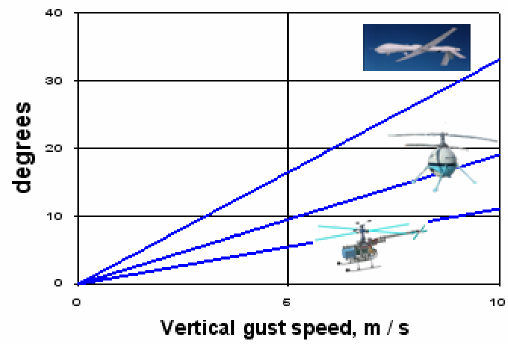


Fig. 3 Aircraft response to vertical gust

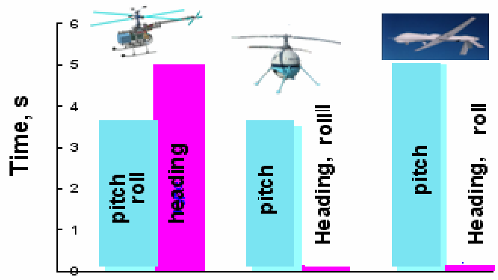
Pitch angle at vertical gust



Change of aircraft attitude at vertical gust

parameter			
pitch $\Delta\upsilon/\Delta V_Y$	1.1	1.9	3
heading $\Delta\psi/\Delta V_Y$	0.7	0.25	0
roll $\Delta\gamma/\Delta V_Y$	0.8	0.35	0

Transient period time at vertical gust



Cross-couplings at vertical gust

параметр			
Heading / pitch $\Delta\psi/\Delta\upsilon$	0.64	0.13	0
roll / pitch $\Delta\gamma/\Delta\upsilon$	0.73	0.18	0

Fig. 4 Aerial surveillance quality estimation

2.2. Rotary-wing UAV system application patterns. The potential advantages of unmanned fixed-wing aircraft in range and endurance in high altitude flight are limited in practice by the range of reliable radio communications capability. It is this parameter that the validity of on-line air monitoring data received on the ground during low altitude fixed-route flights depends on. The range of reliable radio communication between an aircraft and its ground control station is determined by the line-of-sight (direct radio visibility) that is limited by terrain relief and local obstacles as well as power and sensitivity of transceiver. Thus, in low altitude flight at the level of tree crowns when the ground station aerial is not more than 15m high the available radio communication range in flat country is around 30km. Fixed-route low altitude flight allows to use lighter and cheaper equipment of high resolution. Higher flight performance of coaxial helicopters in turbulent atmosphere permits them to perform aerial monitoring in low altitude flight over tree crowns, power line masts and other local obstacles. The problem of reliable communications can be solved by adoption of a suitable application pattern depending upon the object type and helicopter performance as described below.

Pattern 1 (fig. 5) - local objects (type 1) monitoring is more suitable for objects the length of which is less than the unmanned helicopter operation radius and radio communications range. This pattern can be used to provide for independent operation of unmanned helicopters by one mobile ground control station.

Pattern 2 (fig. 6) - monitoring of regional objects (networks) of average length (type 2) is more suitable for objects the length of which is less than the helicopter operation radius and the range of radio communications in low altitude flight is less than the object length. This pattern can be used to provide for independent operation of unmanned helicopters by one mobile ground control station and by intermediate relay stations.

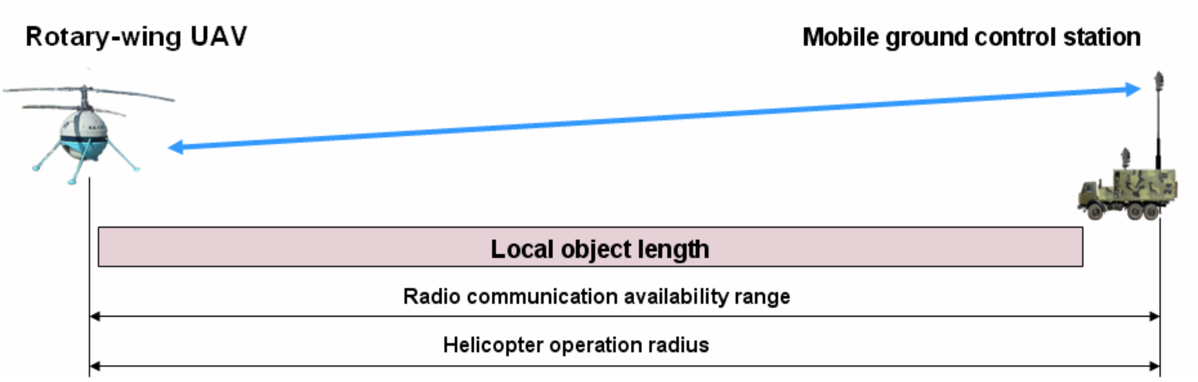


Fig. 5 Pattern 1. Local object (network) monitoring by an integrated system with a mobile ground control station

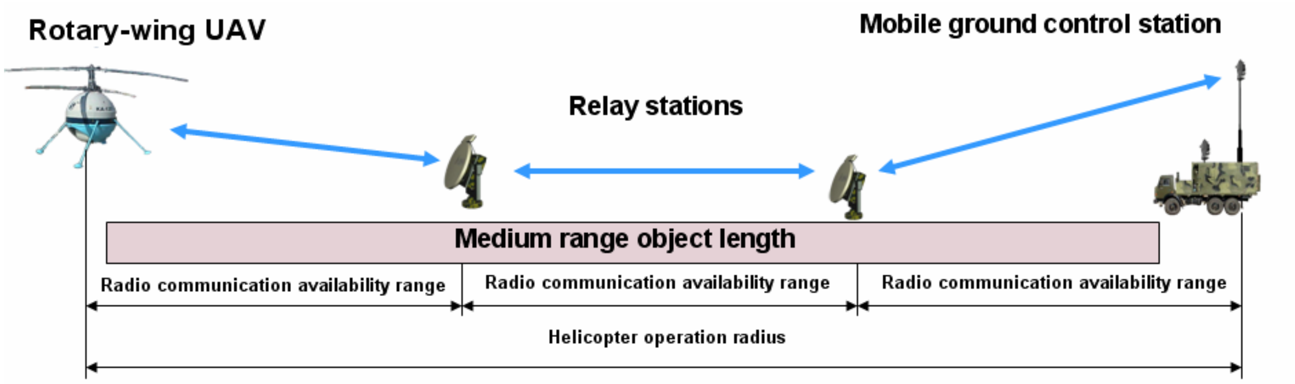


Fig.6 Pattern 2. Monitoring of regional objects (network) of average length using a mobile ground control station and intermediate relay stations

Patterns 1 and 2 envisage mobile configuration of rotary–wing UAV-based integrated system where ground control stations and helicopter ground service facilities (including fuelling) are accommodated on a self-propelled vehicle. It allows to position the ground facilities nearer to the center of the object from where the aircraft take-off and where they come back to get fuelled and maintained. When monitoring is performed over a difficult cross-country relay stations are installed along the patrolling route to ensure reliable communication between the helicopter and the ground control station. (Pattern 2).

Pattern 3 (fig. 7) - main line object (type 3) monitoring is most suitable for objects the length of which exceeds the operation radius of the unmanned helicopter while the available radio communication range is less than the helicopter operation radius.

Pattern 3 - monitoring of main line (network) of large length. It requires mobile and/or stationary configuration of rotary–wing UAV-based integrated system (with permanent ground control stations and ground service facilities) and intermediate relay stations. In this case helicopters can be controlled both by mobile and permanent ground control stations. A helicopter can take-off in one place and get fuelled to continue its operation in another place.

It is clear that the greater is the number of basing sites the higher is the monitoring mission cost but the cost of the unmanned helicopter operation diminishes as the required flight range becomes less. So the optimum solution should be selected as regards the number of basing sites and required operation range. If one takes into account the absence of transportation infrastructure, then provision with fuel, ground support and survival facilities becomes an important factor in the analysis of the system issues.

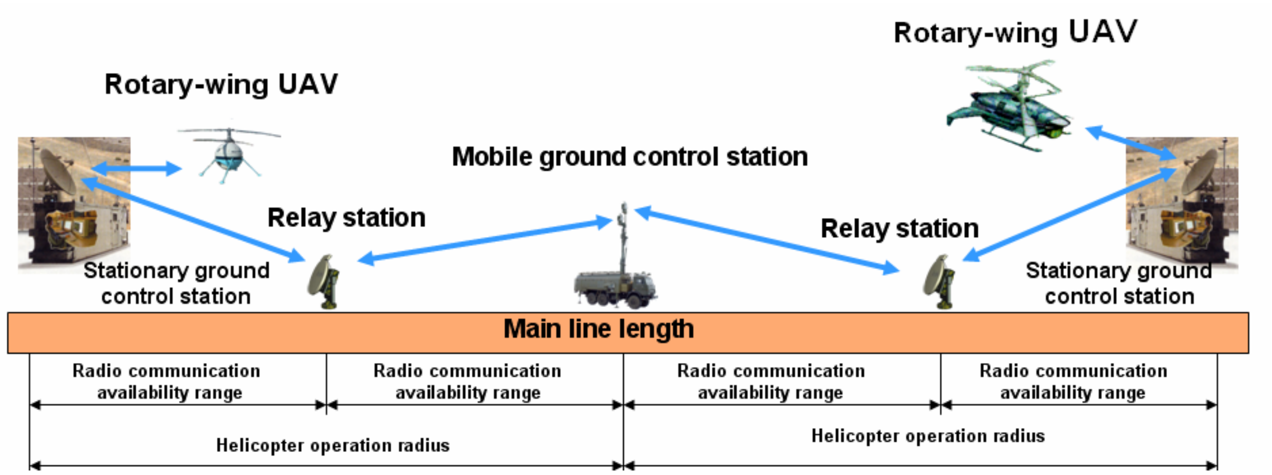


Fig. 7 Pattern 3. Monitoring of main line (network) of large length using a mobile/permanent ground control stations and intermediate relay stations

It can be understood from the said above that the helicopter and its typical application patterns (Patterns 1,2,3) allow solving the tasks of aerial monitoring on all fuel and energy complex objects in various geographic locations.

3. ROTARY-WING UAV SYSTEM

Reasoning from the above, an integrated system based on a rotary-wing UAV is offered for monitoring of fuel and energy complex objects. The system is based on coaxial helicopters of three dimension-types, i.e. for short-range, medium-range and long-range flights.

Composition and functional relations of rotary-wing UAV systems are presented in fig.8.

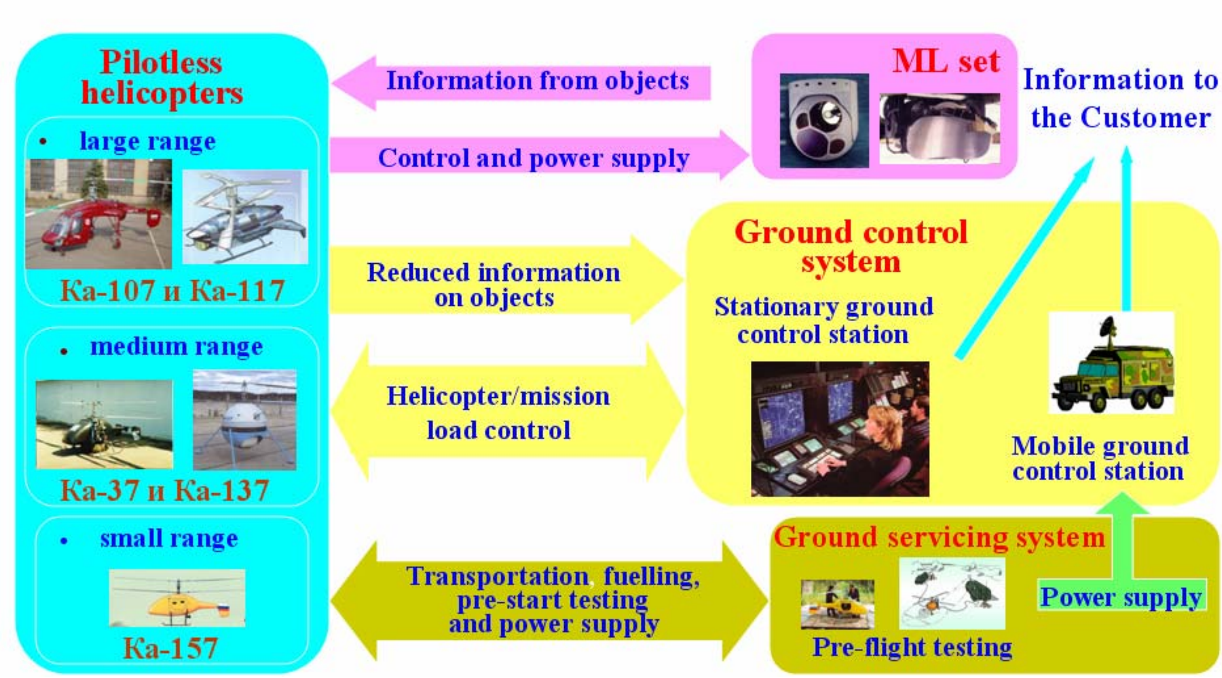


Fig. 8 Configuration and functional relations of rotary-wing UAV systems

Preliminary characteristics of such system are presented in the table.

Characteristics	Unmanned rotary-wing UAV systems		
	Large range	Medium range	Small range
1. **Purpose**	for all-weather 24-hour surveillance industrial and ecological monitoring		
2. **Composition**: • Pilotless helicopter,pc	1…2	1…5	1…3
• Mission equipment set	As per flight assignment		
• Ground control station	stationary	mobile	mobile
• Ground service facilities	truck and trailer	truck and/or trailer	trailer
3 **Performance data** • Max range, km	2000	500	100
• Max endurance, hrs	24	6	2
• Take-off weight, kg	3800	300	50
• Take-off weight, kg	400	80	15
• Max speed, km/h	220	175	110
• Altitude range, km	0…6	0…5	0…5
4. **Operational data** • Base location	stationary	mobile /stationary	mobile
• Service personnel, persons	5…8	3…7	2
• Take-off/ pad diameter, m	10	3	2

An integrated system based on a rotary-wing UAV envisages maximum unification of internal and external basic elements both for the helicopter and for their mission load equipment, ground control stations, communication links and software. Apart from the unified components, each rotary-wing UAV system comprises a specific component part meeting particular requirements of interface with information systems of the Customer. Such approach will provide considerable decrease of the total cost of the system development because the unified component part will constitute the main load and the specific component part will not cost much.

Rotary-wing UAV of short (to 100 km), medium (to 500 km) and long (to 2000 km) flight range with an interchangeable mission load of various configurations allow to solve multiple tasks in the interests of fuel and energy complex companies and other customers. Typical configurations of such mission load are shown in fig. 9.

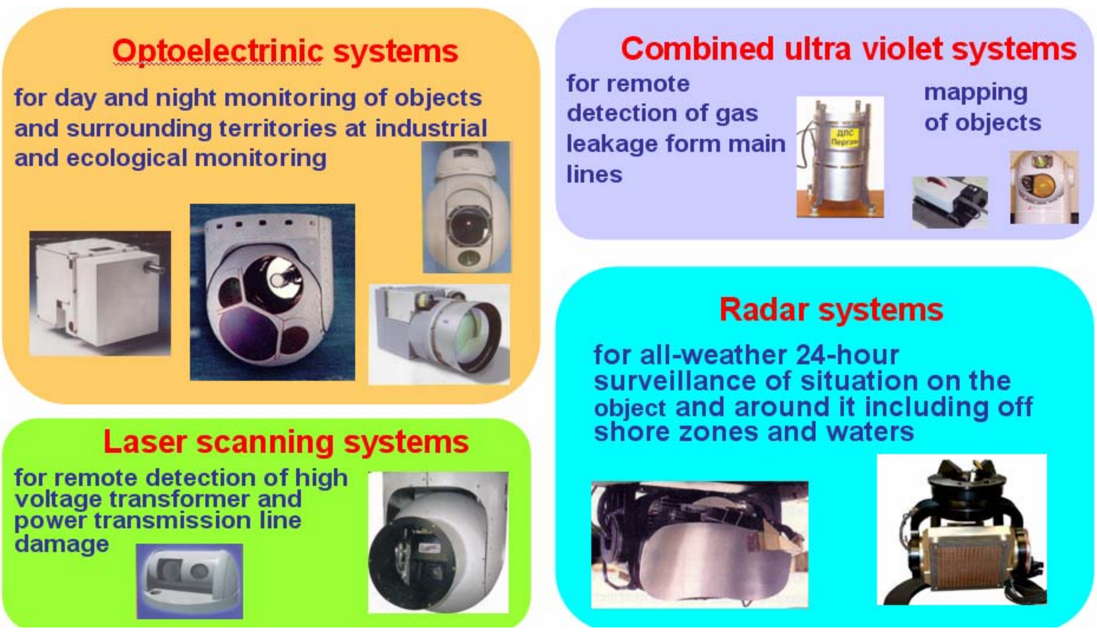


Fig. 9 Typical configurations of mission load for aerial monitoring

3.1. Long-range rotary-wing UAV system. A concept of an integrated system based on a long-range rotary-wing UAV is illustrated in fig. 10.

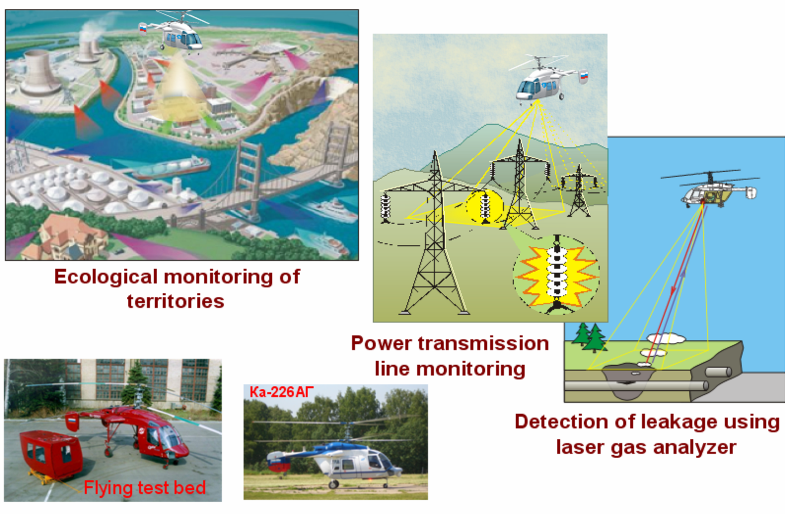


Fig. 10 Verification of the unmanned rotary-wing UAV main elements on a manned flying test bed

It is a well-known idea to try out the main elements of an unmanned rotary-wing UAV using a manned helicopter as a flying test bed. During test flights of this flying test bed it is possible to verify the most complicated and critical systems and to minimize the existing technical risks. Verification of the monitoring technology and mission equipment in the course of Kamov Ka-226 АГ helicopter trial operations will provide the required experience and allow to determine the requirements to the system elements and mission equipment.

Fig. 11 presents a long-range helicopter layout and illustrates its unification with the KA-226 helicopter. A high level of unification with the KA-226 helicopter units and systems ensures a high level of the project readiness and low development costs.

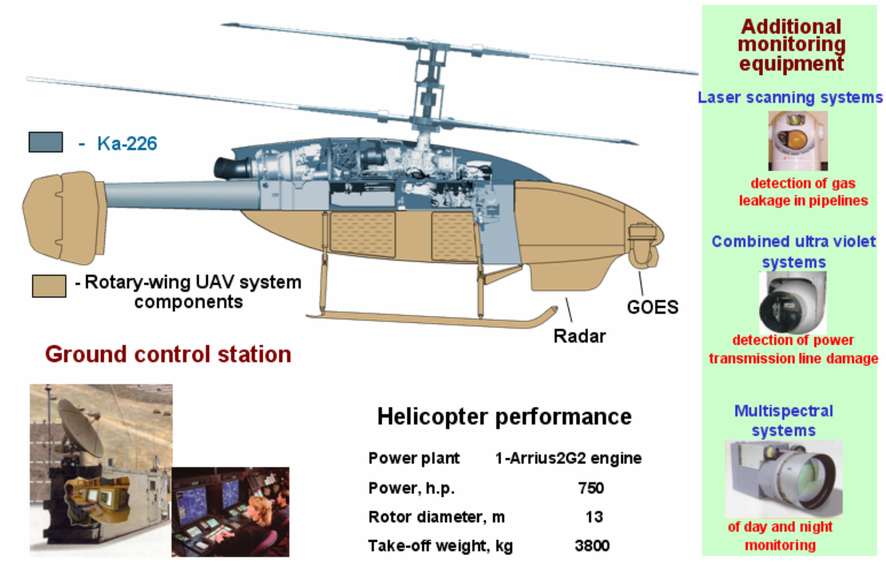


Fig. 11 Long-range rotary-wing UAV layout

3.2 Medium-range rotary-wing UAV system. Fig. 12 presents a multifunctional unmanned helicopter of a medium range, its equipment and functional relations. The helicopter can be accommodated on a special off-road vehicle (in a trailer or in a container). Interchangeable mission loads are also shown.

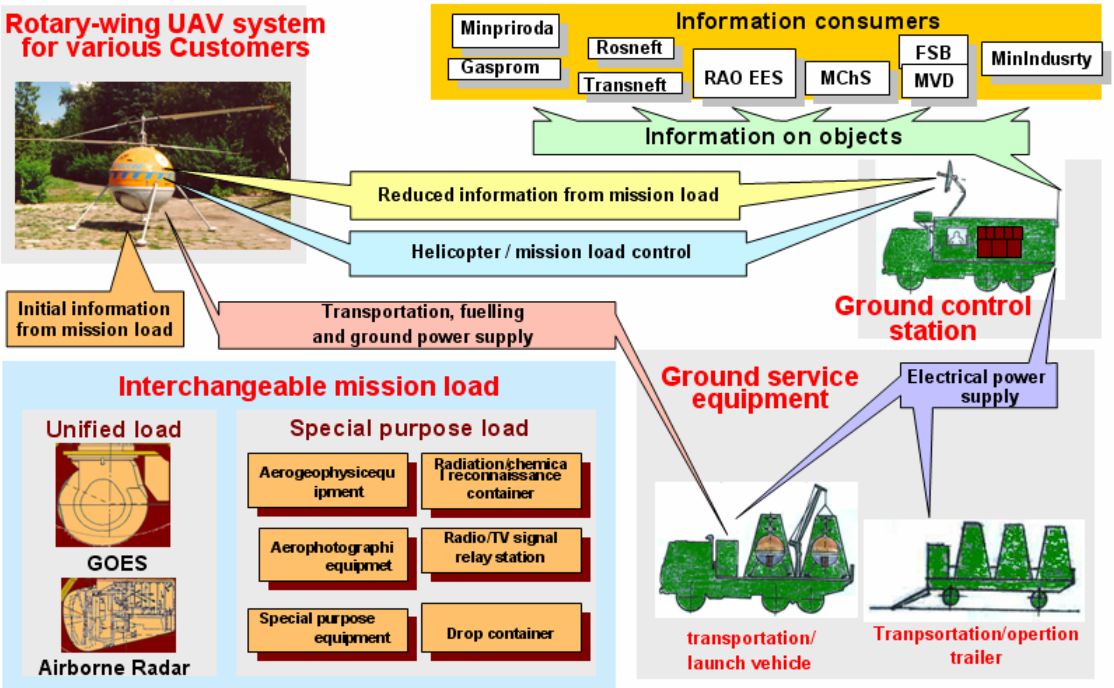


Fig. 12 Configuration and functional relations of a medium-range rotary-wing UAV system

There is a large backlog at Kamov for the development of a medium-range rotary-wing UAV (unmanned helicopter): aerodynamic test data, ready full-size transmission and main rotor system, verified main components and systems, established cooperation lines. The main system components have been verified on the Ka-37 flying test bed and Ka-137 mock up (fig. 13).

Fig. 13 Verification of a medium-range rotary-wing UAV elements on the Ka-37 flying test bed and the Ka-137 mock up

3.3. Short-range rotary-wing UAV system. Fig. 14 presents a short-range rotary-wing UAV with its equipment.

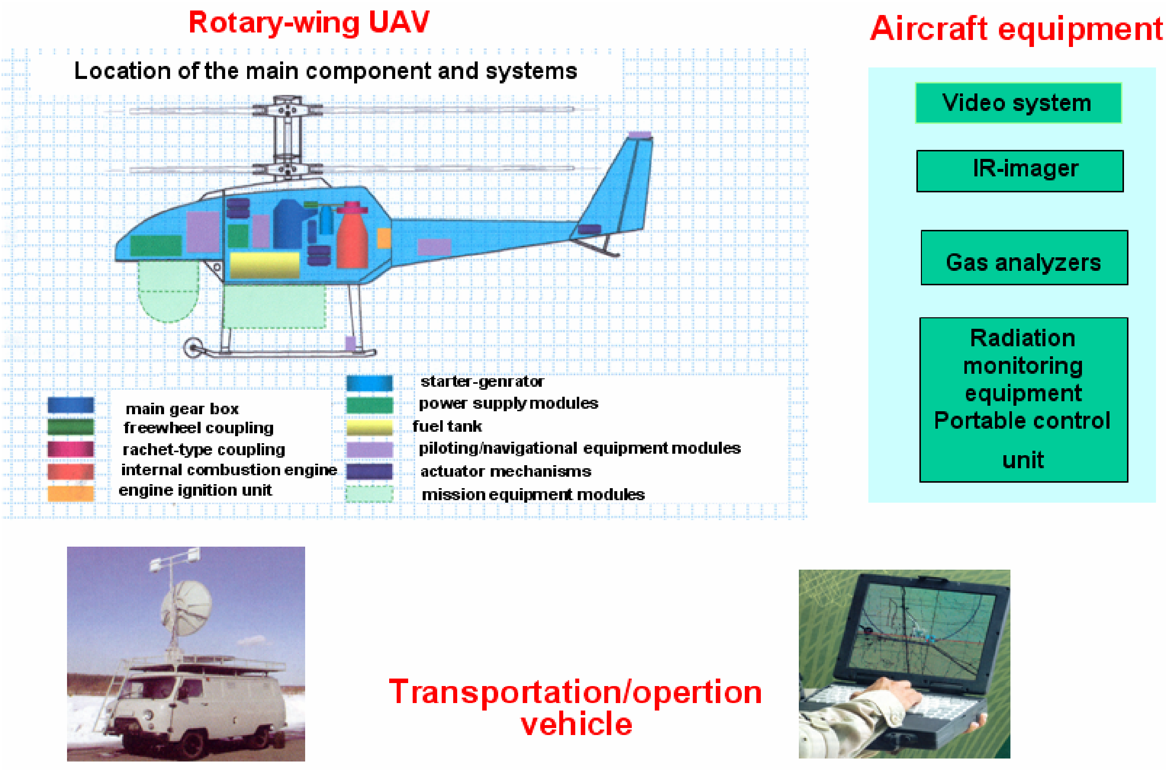


Fig. 14 Short- range rotary-wing UAV system

Development of a rotary-wing UAV system envisages use of common basic elements and software, of the same operation principle of airborne and ground systems, of the same interface, data processing and transmission equipment, and ground support facilities. Unification of the main technical approaches will allow to operate independently each of the three rotary-wing UAV systems in accordance with one of the Patterns discussed above or to employ several different-type systems.

4. DEVELOPMENT STAGES

It is convenient to divide a rotary-wing UAV-based complex development program into several stages. At the first stage the aircraft and its systems are designed and developed while mission and monitoring technology are developed at the second stage. The third stage is used to finalize operation issues of the system and its optimization in the interests of the Customer based on typical elements and unification principles. Such approach would allow to reduce time and resources and obtain additional capabilities of the system adjustment in the process of its development and test operation. The main principles of aerial monitoring system development are presented in fig. 15.

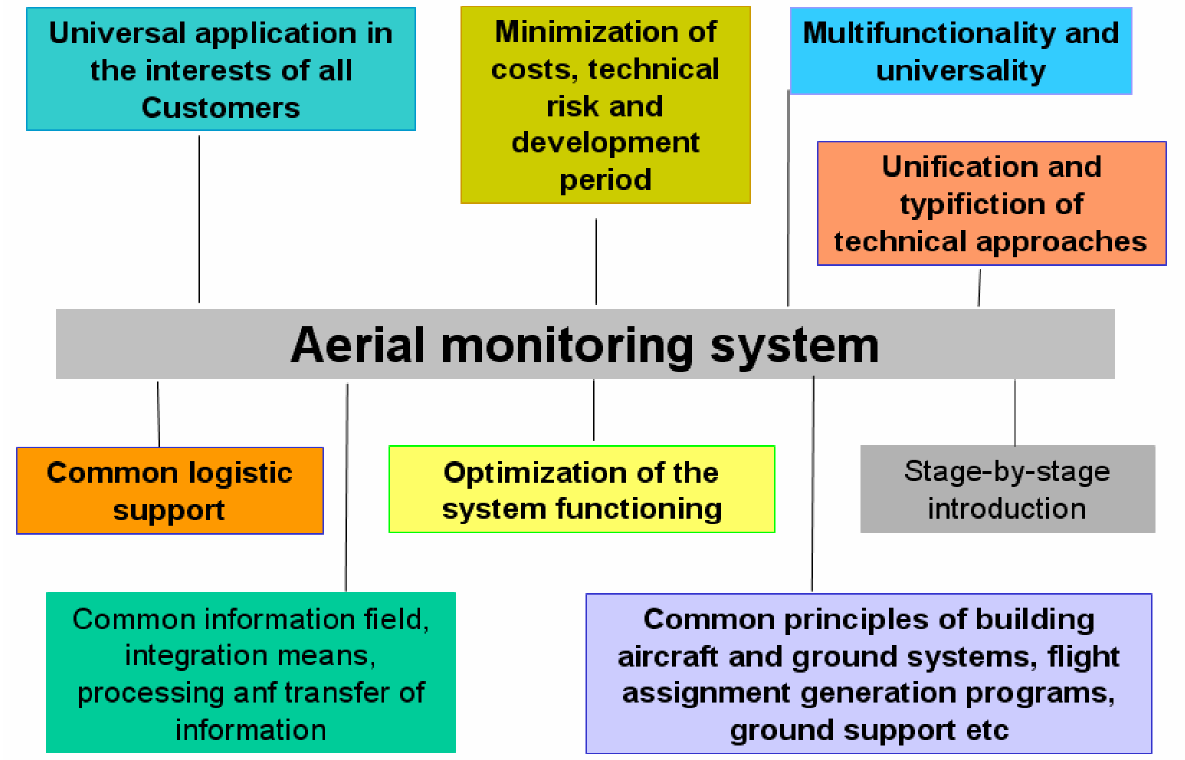


Fig. 15 Main principles of the aerial monitoring system development

5. CONCLUSION

Qualitative evaluations of the integrated system type and parameters, its constituent parameters, their interaction and functioning were obtained through large system optimization with the use of a mathematical tool of the arrangement analysis based on the distribution theory and numerical methods of nonlinear programming. Characteristics of the fuel and energy complex objects are used to determine the aerial monitoring system structure and to generate it in the first approximation. Presented materials are not final frozen statements and are open for discussion.