Threat of Terrorism Using Unmanned Aerial Vehicles:

Technical Aspects

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Abbreviations

GPS – Global Positioning System
GPRS – General Packet Radio Service
MTCR – Missile Technology Control Regime
PCM – Pulse Code Modulation
PPM – Pulse Phase Modulation
RC – Radio Control
RPAV – Remotely Piloted Aerial Vehicle
SAM – Surface-to-Air Missile
UAV – Unmanned Aerial Vehicle
UAAV – Unmanned Automatic Aerial Vehicle

Introduction

There is growing interest in unmanned aircraft at the beginning of the 21st century in almost all developed countries. Due to the revolutionary development of a set of technologies, unmanned aerial vehicles (UAVs) may prove an efficient application for a wide spectrum of military missions, many of which can be categorized as "the dull, the dirty, and the dangerous."[1] Because they carry no pilot, UAVs may be smaller in size and more cost effective in operation than manned aircraft.

The most intensive development of pilotless aircraft has been in the U.S., which accounts for 73% of worldwide research and production spending on UAVs.[2] There are plans to increase funding for U.S. military UAV programs by an order of magnitude, so that almost $3 billion could be spent annually by 2010.[3] As a result, dual-use means and technologies will also emerge. The U.S. aviation industry, suffering a crisis because of shrinking the market of civilian airliners, is already actively studying potential demand for unmanned aircraft in the civilian sector and attempting to change legislation in order to remove bureaucratic barriers on the way to wide commercial application of UAVs.[4] The most promising areas include transport and agriculture, communications, surveillance, traffic control in cities, etc. Thus, new technologies and means will soon appear in the civilian market. They may, at the same time, become potentially usable by terrorists.

Experts and media have been discussing the potential use of UAVs for terrorism for some time. Until recently, this threat was considered to lie primarily in the conversion of anti-ship cruise missiles or small manned airplanes to land attack missiles.[5] Previous studies fo-

[1] UAVs seem more promising than manned aircraft for a variety of missions, such as
- a) for long and monotonous functions (in particular, search and surveillance)
- b) for monitoring areas with a risk to human life (e.g., areas of radiation accidents)
- c) for combat missions to highly defended areas, where there is a high risk of loss of the aircraft

[2] Steven J. Zaloga, "UAVs Increase in Importance," *Aviation Week & Space Technology*, January 19, 2004, p. 105.

[3] "Unmanned Aerial Vehicles Roadmap 2002–2027," Office of the Secretary of Defense, December 2002.

[4] Robert Little, "FAA's OK sought for drones," *Baltimore Sun*, July 16, 2003.

[5] See, for example, Dennis M. Gormley, "Hedging Against the Cruise Missile Threat," *Survival*, International Institute for Strategic Studies, Spring 1998, pp. 92–111; Christopher Bolkcom, Statement before the Senate Governmental Affairs Committee, Subcommittee on International Security, Proliferation, and Federal Services, June 11, 2002.

cused on threats from so-called “states of concern” rather than non-state actors. A broader spectrum of possible terrorist uses has been addressed since September 11, 2001.[6]

Experts point to a set of advantages that may make UAVs seem attractive to terrorists:

- Possibility to attack targets that are difficult to reach by land (cars loaded with explosives or suicide terrorists)
- Possibility of carrying out a wide-scale (area) attack, aimed at inflicting a maximum death rate on a population (particularly, through the use of chemical or biological weapons in cities)
- Covertness of attack preparation and flexibility in choice of a UAV launch site
- Possibility of achieving a long range and acceptable accuracy with relatively inexpensive and increasingly available technology
- Poor effectiveness of existing air defenses against targets such as low-flying UAVs
- Relative cost effectiveness of UAVs compared with ballistic missiles and manned airplanes
- Possibility of achieving a strong psychological effect by scaring people and putting pressure on politicians

No incident of UAV employment in a terrorist attack has yet been reported. However, media reports reveal that terrorists are actively studying this means of delivery (see appendix).[7]

Certainly, preparing and conducting a terrorist UAV attack is much more difficult than such frequently used methods as mining buildings and cars or using suicide bombers. Nevertheless, the 9/11 events, when terrorists captured airliners with passengers and used them as huge cruise missiles to attack buildings in New York City and Washington, D.C., have demonstrated that it is necessary to be prepared to repel “high-tech” threats as well. For this reason, it seems expedient to examine the technical capabilities of UAVs to deliver terrorist weapons.

Threats from terrorist UAVs first became an issue of concern for the U.S. government after September 11, 2001. The growth of this concern is underlined in statements by official representatives of intelligence community. In particular, former CIA Director George J. Tenet stressed in his testimony before the Senate Select Committee on Intelligence in February, 2004: ”Many countries remain interested in developing or acquiring land-attack cruise mis-

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[6] See, for example, Dennis M. Gormley, “UAVs and Cruise Missiles as Possible Terrorist Weapons,” in “New Challenges in Missile Proliferation, Missile Defences, and Space Security,” ed. by James Clay Moltz, Occasional Paper No. 12, Center for Nonproliferation Studies and Mauntbatten Centre for International Studies, July 2003; Dennis Gormley, “New Developments in Unmanned Air Vehicles and Land Attack Cruise Missiles,” SIPRI Yearbook 2003: Armaments, Disarmament and International Security; 2003.

[7] In particular, ex-U.S. intelligence officer Louis R. Mizell lists 43 cases involving 14 terrorist groups in which remote-control delivery systems were “either threatened, developed, or actually utilized.” (Michael Gips, “A Remote Threat,” *Security Management Online*, October 2002). Some of the cases are mentioned in the appendix.

siles, which are almost always significantly more accurate than ballistic missiles and complicate missile defense systems. Unmanned aerial vehicles are also of growing concern."[8] The problem of cruise missile and UAV proliferation, and how to face this threat, became the subject of attention in Congress,[9] the departments of defense and homeland security, and other U.S. agencies.

Unfortunately, terrorism became a grave reality in Russia, and UAV use by terrorists may be an even greater threat than in the U.S. To many readers, UAVs may seem too exotic, demanding substantial efforts and costs compared with the methods terrorists frequently use. But science and technology is developing so fast that we often fail to recognize how much the world has changed. Moreover, the appearance of new public services such as Internet, cellular communications, Global Positioning System (GPS) makes society more vulnerable. Therefore, we often miss a chance to react to emerging threats in a timely fashion.

Does the Russian government understand the threat from terrorist UAVs? Has it assessed this threat? Does it have a strategy for prevention? This issue is not discussed in the domestic media, so neither the public nor the author can answer those questions.

This report assesses the technical possibility of UAV use as a delivery means for terrorists. The analysis shows that such a threat does exist and that it will grow. The author also considers areas that require higher attention from government agencies. This report is also targeted at the Russian public. Terrorist activity can be prevented only through the coordinated efforts of the government and civil society. The government cannot efficiently fight terrorists without the active involvement of the population. The first step toward creating such an alliance is to recognize the threat and its potential consequences.

Terms and Definitions

In the domestic literature, "unmanned aerial vehicle" has a variety of definitions. Most frequently, UAVs include a wide class of aircraft guided by other means than by a pilot on board that aircraft.[10] Sometimes the same abbreviation designates a narrower category,

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[8] See, for instance, "The Worldwide Threat 2004: Challenges in a Changing Global Context," Testimony of Director of Central Intelligence George Tenet, Senate Select Committee on Intelligence, February 24, 2004. A compendium of statements of U.S. intelligence officials can be found at http://www.ceip.org/files/nonprolif/resources/intelligence.asp.

[9] In particular, hearings on the nonproliferation of cruise missiles were held by the U.S. Congress in June 2002 and March 2004. See also "Nonproliferation: Improvements Needed to Better Control Technology Exports for Cruise Missiles and Unmanned Aerial Vehicles," Report to the Chairman, Subcommittee on National Security, Emerging Threats, and International Relations, Committee on Government Reform, House of Representatives, GAO-04-175, January 2004.

[10] See, in particular, *Voyenno-Enciclopedicheskii Slovar'* (*Military Encyclopedic Dictionary)*, Vol. 1, ed. by A.P.Gorkin, V.A.Zolotarev, V.M.Karev et al., Moscow, Bol'shaya Rossiyskaya Encyclopedia, RIPOL CLASSIK, 2001, p. 175.

namely an aircraft that accomplishes its missions automatically using onboard systems. Secondary tasks, such as takeoff and landing may be accomplished via remote control. Unmanned reconnaissance airplanes are an example.[11] Sometimes, other abbreviations (e.g., UAAV, Unmanned Automatic Aerial Vehicle) are used to underscore the distinctive features of the aircraft.[12] Aircraft that are guided remotely via communication channels are referred to as remotely piloted aerial vehicles (RPAVs).[13]

Differing opinions also exist about whether to include cruise missiles in the UAV category. Notably, cruise missiles are defined as a subcategory of UAVs in some international agreements such as the Missile Technology Control Regime (MTCR), of which Russia is a member. However, cruise missiles are frequently considered a separate category from UAVs because they can be used only once. But this distinction is insufficient: both unmanned combat aerial vehicles (UCAVs)[14] and electronic attack UAVs[15] are designed for a single use.

For the purpose of this report, **UAV is** defined as **an aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, and can carry a lethal or nonlethal payload**. This definition thus covers a wide category of aerial vehicles. It includes cruise missiles and assumes that UAVs can be expendable or recoverable. However, the analysis in this report focuses on a narrower category: small propeller-driven model airplanes. These can be easily assembled. At the same time, they have important capabilities: covertness, speed, and accuracy.

Potential Terrorist Targets and Possible Damage

As evidence suggests, the objects of terrorist attack and the most vulnerable targets are often places crowded by people: mass gatherings, highly populated city areas, public transportation at rush hour, etc. Terrorists usually pursue two goals: maximizing the number of victims and creating chaos and panic.

The greatest damage by UAV attacks may be achieved if terrorists use weapons of mass destruction. Experts frequently note that an aerial vehicle is an ideal tool for delivering a

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[11] See, for example, N.V. Chistyakov, "Chto takoye DPLA (rassuzhdeniya) (How to define remotely piloted aerial vehicle)." This article is available at http://www.dpla.ru in Russian.

[12] V.V. Rastopchin, S.S. Rumyantsev, "Bespilotnyye Aviatsionnyye Systemy (Unmanned aerial systems)," *Vestnik Vozdushnogo Flota*, N 2, 2001.

[13] Experts have differing views on how to define RPAVs as well. See, for example, N.V. Chistyakov, ibid.

[14] For future UCAVs see, for instance, A. Kirillov, "Perspectivnyye Zarubezhnyye Boyevye Bespilotnyye Apparaty (Future foreign combat unmanned aerial vehicles)," *Zarubezhnoye Voyennoye Obozreniye*, N 3, pp. 35—40, 2002.

[15] In particular, the "Novik – XXI Century" design "Moshkarets" RPA is an example of such a system, http://www.dpla.ru/Moshkarec/index.htm.

biological or chemical weapon.[16] Using a UAV would permit the terrorist to disperse aerosol over a wide area more efficiently than through other means of delivery. For example, the payload of a ballistic missile undergoes high temperature and dynamic pressure, so that, according to some experts, the efficiency of a biological weapon carried by the missile would degrade by an order of magnitude.[17]

The results from computer simulations of various air attack scenarios can be found in the open literature. For example, dispersal by a Chinese "Silkworm" variant cruise missile of 120 kg of *Tularensis* bacteria[18] from an altitude of 100 m along a flight path of 10 km could infect 90% of the population within a 400-km^2 area in two hours.[19] The results from simulating an attack with anthrax are even more impressive. If 900 grams (!) of weapons-grade anthrax was dropped from a height of 100 m just upwind of a large U.S. city, 1.5 million people would become infected. Even with the most aggressive medical measures that can realistically be taken during an epidemic, the model estimates that 123,000 people would die.[20]

Nor is it possible to exclude a scenario in which terrorists use radiological ("dirty") weapons that mix radioactive materials with explosives. One study analyzes the consequences of dispersing 2 kg of plutonium (Pu-239) and 50 g of cesium (Cs-137) over San Diego.[21] Computer simulations indicate that 12,000 people would be exposed to various doses of radiation, 500 of them lethal. The area within a radius of about 7 to 8 km would be contaminated.

Many analysts are skeptical about the ability of a "dirty" bomb to cause mass fatalities. A relatively efficient bomb that posed a danger to people over a large territory would also endanger the terrorists themselves, during assembly or transportation. Moreover, the dispersal of the "dirty" bomb's radiological stuffing over a large area is also a challenge. Most radioactive materials exist in a solid form, which may split into relatively large fragments after the bomb explodes, so that the impact on people would be negligible.[22] The more likely

[16] Gormley, "UAVs and Cruise Missiles as Possible Terrorist Weapons," in Moltz, 2003.

[17] Gormley, "UAVs and Cruise Missiles as Possible Terrorist Weapons," in Moltz, 2003.

[18] *Tularensis* bacteria are incapacitating, and they cause the disease Tularemia. The disease's onset emerges in about three to seven days (Dennis Gormley and Richard Speier, "Cruise Missile Proliferation: Threat, Policy, and Defense," Carnegie Endowment for International Peace, Proliferation Roundtable, October 9, 1998).

[19] Gormley and Speier, 1998.

[20] Lawrence M. Wein, D. L. Craft and E. H. Kaplan, "Emergency Response to Anthrax Attack," *Proceedings of the National Academy of Sciences,* Vol. 100, No. 7, pp. 4346–4351, April 1, 2003.

[21] M. Bakanov, "O provodimykh v SshA meropriyatiyakh, povyshayuschih vozmozhnosti bor'by s krylatymi raketami (On measures, taken in the USA, to improve defense capabilities against cruise missiles)," *Zarubezhnoye Voyennoye Obozreniye*, N 10, pp. 30—35, 2002.

[22] Cesium-chloride a powder form is, perhaps, the only exception. Many analysts believe that use of this material by terrorists has the highest probability (Charles D. Ferguson, Tahseen Kazi, and Judith Perera,

dangers are the chaos and panic in the area of "dirty" bomb attack and the substantial economic losses.[23]

Appreciable damage, though not so massive, could be caused by the most frequently used weapon of terrorists: a mix of explosives with small metal parts. Even a small explosive device, delivered by a UAV to a place crowded by people, could inflict much more damage than the same device on the belt of a suicide terrorist.

The details of one terrorist attack are worth attention. Fifteen people were killed and over fifty injured as a result of two bombs on July 5, 2003, near the Tushino airfield in Moscow, where a rock concert was going on. The bombs, which were carried by suicide women (so called "shaheed belts"), consisted of 0.5–1 kg explosives mixed with 2 kg of small fragments (metal balls, screws, etc.)[24] This composition was not optimal to ensure maximum efficiency, since both terrorists evenly distributed the mix of plastic explosives and metal fragments around their waists in order to hide the deadly load. As a result, one bomb did not work as expected. Only its detonator exploded, killing only the terrorist. The expert who investigated the case suggested that the electric detonator of the bomb was coupled with a small fragment of the explosive, weighing about 30 to 50 grams, and the rest of explosives were separated from that fragment with a layer of metal balls. Thus, only the detonator and a small part of explosives worked, and the whole device did not explode.[25]

The second explosion occurred among a crowd of people who were standing in line at the ticket office. Most of those who suffered were standing close by the terrorist. They acted as a "live shield" for people who stood behind them at a distance of few meters. Had the same bomb been set off from a UAV at an altitude of few meters, the geometry of dispersal of the metal parts would differ, and the number of victims would have been higher. Fragments of the UAV and remaining fuel might have caused additional damage.

As investigation of the case showed, the terrorists intended to enter the airfield, where many people had gathered for the concert. Perhaps they expected that the explosions would create panic among the spectators, and a crush would occur.[26] History demonstrates many cases in which a high death rate from explosions, fires, or other accidents can be explained by panic among the victims. However, police cordoned off the entrance to the concert and inspected the audience thoroughly. In addition, mobile communications were shut down immediately after the terrorist act in order to prevent panic among the audience. Thus the

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"Commercial Radioactive Sources: Surveying the Security Risks," Occasional Paper No. 11, Center for Nonproliferation Studies, January 2003).

[23] See, for instance, Andrei Vaganov, "«Gryaznaya bomba» vzryvayetsya v umakh lyudei ('Dirty bomb' explodes in minds of people)," *Nezavisimaya Gazeta*, March 26, 2003; Michael A. Levi and Henry C. Kelly, "Weapons of Mass Disruption," *Scientific American*, November 2002, pp. 77-81.

[24] Kirill Vishnepol'ski, "Ya ubit u zabora (I was killed near a fence)," *Kommersant-Vlast'*, July 14, 2003.

[25] Sergei Dyupin, "Terror protiv roka (Terror against the rock)," *Kommersant*, July 7, 2003.

[26] Natalia Kozlova, "Moskva prikhodit v sebya posle teraktov (Moscow recovers after terrorist acts)," *Rossiiskaya Gazeta*, July 12, 2003.

audience had no idea what was going on beyond the cordon. If a UAV had been used, such measures would have been useless.

Terrorist targets may be not only crowded places, but also key facilities, destruction of which can result in victims, environmental or economic disaster, chaos and panic. From a technical point of view, this task is more complex because substantial efforts are usually implemented to protect such facilities from terrorist attacks. Not only do the terrorists need critical information on the "Achilles' heels" of the target facilities that is not available to wide public, but UAVs employed for this purpose must meet higher requirements such as covertness and accuracy of weapon delivery.

These examples illustrate the spectrum of possible consequences from UAV use in terrorist attacks, but certainly this list is not comprehensive. The following discussion does not specify terrorist's targets or payloads. UAVs are considered only as a delivery means having certain specifications: mass of payload, range, accuracy, etc.

How May Terrorists Acquire UAVs and What Types of UAVs Represent the Highest Danger?

The analysis below refers primarily to the case of Russia, although many aspects may be universal.

Terrorists may acquire UAVs by various means. Areas of potential concern include

- UAVs for military application (both produced and experimental)
- UAVs for civil use (both produced and experimental)
- Conversion of private airplanes into UAVs
- Assembly of UAVs on the basis of commercially available technologies and components
- Modification of commercially available radio-controlled model airplanes

One important conclusion of the previous section is that even a small payload—of just a few kilograms—is capable to cause substantial damage. This suggests the need for careful consideration of **mini-UAVs:** aerial vehicles with a mass below 100 kg, which are capable of carrying payloads weighing from one to dozens of kilograms. As the following analysis shows, prospects for terrorist use of larger UAVs seem less likely, although this possibility cannot be dismissed entirely.

Military UAVs

Land attack cruise missiles usually weigh hundreds to thousands kilograms. In theory, terrorists could gain access to these missiles and use them. However, to do so, they would have to solve a complex set of problems that includes capturing a missile and its launcher, equipping the missile with a desirable payload, launching it, and delivering the payload to the target with the required accuracy. All these tasks would need to be solved under conditions of severe time pressure. Thus, covert capture of a combat cruise missile and its launcher seems nearly impossible.

Similar arguments apply to the use of military UAVs. Almost all types of Russian military UAVs in service are vehicles with a take-off weight over 100 kg;[27] thus, they require support equipment.[28] Moreover, preventing unauthorized use of a military UAV is not a new challenge. The military routinely guards equipment at military and production facilities and protects sensitive information about such facilities and equipment.

In theory, a hostile country that supports terrorists could provide them with domestic UAVs or military UAVs exported from a third country. But such activity would no doubt lead to grave consequences for the country supporting the terrorists.

International regimes such as the Missile Technology Control Regime (MTCR) and the Wassenaar Agreement aim at preventing such threats.[29] In particular, the MTCR prohibits export of any UAV capable of delivering a payload weighing more than 500 kg, and it restricts exports of all UAVs capable of flying further 300 km. In addition, it restricts a list of technologies and accessories, which is regularly revised at MTCR sessions.

UAVs for Civilian Applications

Terrorist acquisition of a civilian UAV in Russia may appear unlikely because the Russian market for civilian UAVs is currently rudimentary. In spite of plenty of offers from domestic and foreign manufacturers[30] and affordable prices,[31] UAVs are applied to civilian tasks

[27] In particular, the status of military UAVs implementation in Russia is considered in S.M. Ganin, A.V. Karpenko, V.V. Kolnogorov, and G.F. Petrov, "Bespilotnyye letatel'nyye apparaty, (Unmanned aerial vehicles)," St. Petersburg, 1999; S. Kobrusev and A. Drobyshevskii, "Razvedka bez razvedchikov (Scoutless reconnaissance)," *Nezavisimoye Voyennoye Obozreniye,* May 16, 2003; N. Khorunzhii, "Vzletel skat i zavis nad protivnikom, (A skate took off and hovered over the adversary)," *Izvestiya*, April 5, 2004, p. 6.

[28] The state of affairs may differ in such countries as the U.S. or Israel, where mini-UAVs (including those for individual application such as "Pointer" or "Dragon Fly") are widely used by the military. There have already been press reports on a fact of theft of a military UAV in Israel ("Ukraden izrail'skii samolyot-razvedchik [An Israeli reconnaissance plane was stolen]," *Vremya Novostei*, November 11, 2003). In this connection, a concern was expressed that the stolen UAV could be used by terrorists. However, the covert implementation of military mini-UAV could be a challenge for terrorists, if they are not familiar with its design and the security measures to prevent unauthorized use.

[29] These regimes are discussed in more detail at http://www.mtcr.info/ and http://www.wassenaar.org/ .

[30] The state of affairs in implementation of civilian UAVs is considered in Ganin et al., 1999; Vladimir Il'in, "Rossiiskiye bespilotnyye letatel'nyye apparaty (Russian unmanned aerial vehicles)," *Vestnik aviatsii I kosmonavtiki*, N 5, pp. 20—24, 2003; see also the web site of the Scientific Production Design Center «Novik-XXI Century»: http://www.dpla.ru.

[31] In particular, the Scientific Production Design Center «Novik-XXI Century» offers the "GRANT" and "Otshel'nik" UAVs, which are capable of carrying a payload of 3 and 15 kg, respectively, for a price of 1–1.2 Million Rubles ($34,000–$41,000). The details can be found at the official web site of «Novik-XXI Century»: http://www.dpla.ru/Ceny.htm)

only in isolated cases.[32] However, the capabilities of UAVs will continue to improve and their costs will decrease, so that eventually unmanned aircraft will be applied widely in the civil sector. The Russian state will need to fill the legislative vacuum that exists in the sector of civilian UAV application. Currently, no standard procedures or regulations govern UAV flights in Russia,[33] and UAV manufacturers advise buyers that they use the products at their own risk, because they may be unable to get official approval.[34] No agency in Russia currently fills a role for civilian UAVs similar to that which the Federation of Amateur Aviators of Russia provides to private aviation, the Federation of Ultralight Aviation provides to ultralight aerial vehicles, and the Federation of Aeronautics provides to aerostatic aerial vehicles. Protection against terrorist use of civilian UAVs cannot be effective, until legislative measures are settled.

Another important aspect of prospective UAV application in the civilian sector is the necessity of putting restrictions on the technical capabilities of the planes. Internal sales of civilian UAVs in Russia are currently not subject to restrictions. Since the volume of sales is relatively small and can be controlled, it is not difficult to track both sellers and customers. If the volume of sales increases dramatically in the future, state control over proliferation and use of UAVs will become significantly more complicated, especially in case of a lack of adequate mechanisms.

In this respect, the MTCR, which restricts imports from external markets and covers both military and civilian unmanned aircraft, might be helpful. Restrictions on the range and mass of payload were already mentioned above. Decisions to tighten control over UAVs were made at the MTCR session in Warsaw in September 2002. The equipment, software, and technology annex revised in the spring of 2003 includes UAVs designed or modified to dispense an aerosol of a volume greater than 20 liters, as well as those having autonomous flight control and navigation or the capability for controlled flight beyond the direct visual range of the human operator.[35] Note that this category includes UAVs with a maximum range less than 300 km.

The question of restrictions on technical capabilities of UAVs for internal market is undoubtedly debatable. Perhaps the way to solve it is to differentiate among various catego-

[32] Civilian UAVs have found their niche in some countries. In particular, unmanned helicopters are successfully used in agriculture in Japan and South Korea. In 2002, the number of registered users of unmanned helicopters produced by Japan's "Yamaha Motors" was nearly 1,700. See http://www.yamaha-motor.co.jp/eng/sky/agricultural/index.html.

[33] According to Article 2 of Section I of "Federal Aviation Regulations for Flights in the Air of the Russian Federation," approved by a joint order of the Ministry of Defense, Ministry of Transport, and Russian Aviation-Space Agency on March 31, 2002 "Flights of automatic balloons, remotely piloted aerial vehicles and unpiloted aerial vehicles are conducted according to regulations, established by a specially authorised agency in the defense sector." However, according to competent sources, such regulations do not exist yet.

[34] An interview of Nikolai Chistyakov, Chief Engineer of Scientific Production Design Center «Novik-XXI Century» and the designer of several UAV types.

[35] Missile Technology Control Regime, Equipment, Software and Technology Annex, May 15, 2003, p. 56.

ries of customers. In such case, both the scope and the control methods would differ by category.

Conversion of Private Airplanes into UAVs

Analysts frequently raise the potential problem of the conversion of private airplanes into UAVs.[36] This category covers light aerial vehicles capable of delivering a payload of several hundred kilograms at a distance of hundreds kilometres. Although private airplanes are not widely used in Russia compared with, for example, the U.S.,[37] the growth of private air business in Russia outstrips that of mobile communications, the Internet, or satellite TV.[38] According to expert estimates, 1,200 light airplanes belonged to members of the Federation of Amateur Aviators of Russia by mid-2003,[39] and each year the number of plane owners increases by several hundreds.[40]

A wide variety of private airplanes is on the Russian market,[41] and they can be purchased without restriction. Most light airplanes cost from $10,000 to $100,000, so they are affordable even for small terrorist groups. The problem of potential conversion of private airplanes into UAVs by terrorists is aggravated by the fact that such planes are frequently equipped with on-board automatic navigation and control systems. Moreover, plenty of manufacturers offer fully integrated flight management systems for private airplanes that cost about $35,000.[42]

However, light airplanes must be registered and certified by governmental organizations. Flights are conducted according to preliminary applications submitted at least 24 hours in advance. Restrictions also exist on flight routes.[43]

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[36] See, for instance, Gormley, "UAVs and Cruise Missiles as Possible Terrorist Weapons," in Moltz, 2003.

[37] The number of private airplanes exceeds 300,000 in the U.S., and over 600,000 people have pilot licenses (Robert Tilles, "Tyazhyolyy vzlyot maloi aviatsii, (Hard take-off of private aviation)," *Aviatsiya Obschego Naznacheniya*, N 7, 2003)

[38] Yekaterina Blinova and Dmitry Simakin, "Nebesnyye besprizorniki (Sky strays)," *Nezavisimaya Gazeta*, July 14, 2003.

[39] Tilles, 2003.

[40] Blinova and Simakin, 2003.

[41] According to expert assessments, over 500 well-tested designs are currently commercially available. Most of these airplanes can fly a distance of over 1,000 km and carry a payload over 180 kg. These airplanes can take off from a flat playground the size of a football field, and their stall speed does not exceed 150 km/h (Testimony of Dennis M. Gormley, Senior Fellow, Monterey Institute's Center for Nonproliferation Studies, before the Subcommittee on National Security, Emerging Threats, and International Affairs of the U.S. House of Representatives Committee on Government Reform, March 9, 2004).

[42] Gormley, "UAVs and Cruise Missiles as Possible Terrorist Weapons," in Moltz, 2003.

[43] The air defense system's existing technical capabilities do not permit reliably control the flight routes of private airplanes. This aspect is discussed in a greater detail in the section "Existing Air Defenses Against Terrorist Mini-UAVs".

Clearly, private light airplanes are one potential tool for terrorists. They could, for example, be used in an attack by a "kamikaze" pilot in the same way as the attack of September 11, 2001, in the U.S. An onboard automatic flight management system broadens options for such an attack. For example, a take-off and climb could be conducted manually by a pilot, then the flight control could be transferred to the automatic onboard system, and the pilot could leave the airplane using a parachute. However, a commercial flight management system on board an airplane would not allow the whole flight to be conducted in automatic mode. Therefore, conversion of a private airplane to a UAV will require substantial effort, which is unlikely to be accomplished covertly.[44] For this reason, the creation and use of UAVs for terrorist acts within the Russian Federation seems unlikely.

Self-made and Commercial Model Airplanes

The gravest concern may be caused by amateur aircraft modeling, where great success has been achieved due to recent progress in modern electronics and information science, as well as the appearance of new services that had not been available to consumers in the past. Such services include information provided by radio navigation space systems (GPS, GLONASS), commercial high resolution imaging satellites, and mobile communication.

Model aircraft built by amateurs demonstrate surprisingly sophisticated capabilities. Especially remarkable was the recent flight of a 5-kg TAM-5 aircraft model across the Atlantic. The TAM-5 model started from Canada, conducted the flight in automatic mode, and landed 39 hours later 3,000 km away in Ireland.[45]

Bruce Simpson, an engineer from New Zealand, started a project to design of a small cruise missile powered by a pulsejet engine specifically to illustrate opportunities available to terrorists.[46] The author estimated that such a model would cost US $5,000 and would be able to fly nearly 100 miles within 12 minutes.[47] In spite of obstacles created by the New Zealand authorities, which Simpson assumed was the result of pressure from the U.S., he intended to conduct a test of his missile in early 2004.[48]

What is the current status of aircraft modeling in Russia? The Soviet Union actively promoted aircraft modeling as a sport through such organizations as the Voluntary Union of Support for the Army, Aviation, and Navy (DOSAAF), the Federation of Aircraft Modeling

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[44] In particular, testing private airplanes in a fully automatic mode may become a challenge.

[45] Emily Sohn, "Model Plane Flies the Atlantic," *Science News for Kids*, December 17, 2003

[46] A DIY Cruise Missile Project,: http://www.interestingprojects.com/cruisemissile/

[47] The Low Cost Cruise Missile,: http://aardvark.co.nz/pjet/cruise.shtml.

[48] Author's announcement at the web discussion http://pub92.ezboard.com/fhomemadejetenginesandotherinterestingprojectsfrm9

Sport, and palaces of pioneers. As a result, this sport had millions of fans.[49] After the collapse of the Soviet Union, state support virtually ceased and today aircraft modeling is a hobby of enthusiasts. Most of aircraft modelers belong to clubs that provide classes and help from experts. The clubs also offer materials, instruments, machining facilities, and room for assembly. In some large cities such as St. Petersburg or Novosibirsk, these clubs have tens of thousands of members. The Moscow aircraft-modeling club unites 45 teams from various parts of the city that educate nearly 1,300 children.[50]

Compared with the situation prior to the 1990s, the major difference in conditions for aircraft modeling is that modelers are currently able to assemble vehicles with capabilities that used to be achievable only by professional teams. Not only are production-run accessories and separate parts such as engines, radio controls, servos, flight stabilization systems, and GPS receivers currently available commercially, but a wide spectrum of ready-to-fly aircraft kit models are on the market. Some models require experience in piloting, but other aircraft that are simple and stable in flight are produced specifically for beginners. The former may cost over US $1,000, the latter start at US $500. According to expert estimates, the model aircraft market in Moscow[51] was nearly US $1 million per year by mid-2003, and it was growing.[52] While most products sold in Russia are manufactured abroad, some domestically produced items, such as engines and construction materials, are quite competitive.[53]

As the following analysis shows, the aerodynamic properties of an airplane model chosen for use in a potential terrorist attack (delivery of a payload of a certain mass to a desired target) do not need to meet very strong requirements. Most likely the attack cannot be prevented during the launch of the terrorist UAV, or in flight, even if incidental spectators detected the vehicle at launch. Such a vehicle will not suffer the high g-load factor that is characteristic of the maneuvers of aerobatic models. Therefore, relatively simple designs that are stable in flight may be used. UAV control and delivery to a target becomes a more complex task, but as shown below, this task is not beyond power of nonprofessionals. The most important element—preparation of an aerial vehicle for a terrorist attack, including assembly and tests—can be done legally, because such activity is not regulated or controlled.

Assessment of Technical Characteristics of a Mini-UAV

To deliver a terrorist weapon, the major criteria a mini-UAV must meet are range, mass of payload, and accuracy of delivery.

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[49] "Ruchnaya aviatsiya (Handmade aviation)," *Kommersant-Den'gi*, August 25, 2003.

[50] "Ruchnaya aviatsiya," 2003.

[51] There were nearly 30 model aircraft stores in Russia by mid-2003, 8 of which were located in Moscow ("Ruchnaya aviatsiya," 2003).

[52] "Ruchnaya aviatsiya," 2003.

[53] "Ruchnaya aviatsiya," 2003.

Maximum payload can be roughly estimated on the basis of the capabilities of modern UAVs with the take-off weight in the range of a few to dozens of kilograms. Such mini-UAVs can be transported, tested, and launched without inviting much attention. A disassembled mini-UAV can easily fit in the trunk of a car and the process of assembly and preparation for launch may last from minutes to an hour. Take-off conditions for mini-UAVs are also undemanding. Models weighing less than 4 kg can be launched by hand.[54] Larger mini-UAVs can take off from an asphalted road, a flat open area, a simple catapult, or even the roof of an accelerating car.[55]

The take-off weight of a mini-UAV is the sum of the weights of its constituents. A simple propeller-driven UAV consists of an airframe (wing, fuselage, keel, ailerons, rudders, etc.), gas or electric engine and propeller, fuel tank (or battery), receiver with servos, autopilot (gyros, GPS receiver, accelerometers, speed-measuring devices, altimeter, onboard computer, etc.), onboard electric generator,[56] and payload.

As analysis of the weight proportions of light aircraft (from 500 kg to 4,500 kg) shows, the airframe usually accounts for 25% to 40% of the take-off weight of the airplane.[57] The relative weight of the airframe is not likely to be higher for the class of aerial vehicles under consideration, as can be seen from the examples of mini-UAVs advertised for civilian applications. In particular, the weight of the airframe of the "Otshel'nik" remotely piloted aerial vehicle is about 15 kg or 25% of its take-off weight.[58] The relative weight of the airframe for the "TeAM-micro" RPAV is even smaller: about 1 kg, which is 20% of its take-off weight.[59] The structural strength required for terrorist mini-UAVs could be substantially less. Since terrorist mini-UAVs are intended for a single use, they can be composed of lighter materials that lose strength over time.

The relative weight of piston engines for reconnaissance mini-UAVs is estimated to be less than 10%.[60] Published data on the weights of the "KhAI-112" and "Otshel'nik" mini-UAVs

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[54] E.P. Lukasheva and N.V. Chistyakov, "Novyye» ili mini-DPLA ('New' or mini-UAVs)," March 2003, online at http://www.dpla.ru.

[55] In particular, the take-off of the "Poisk-2" RPAV designed by NIIPFM of KhAI is conducted from the roof of a car, as can be seen from photographs online at http://www.khai.edu/niipfm/russian/sapsan-ru.htm.

[56] Various schemes of electric energy supply are used in mini-UAVs. In particular, an electric generator is sometimes applied for a vehicle with an internal combustion engine. The onboard electronics of an electrically driven UAV may use the same battery as the engine. However, a separate battery is often used to power onboard devices in order to reduce the noise of the electric engine.

[57] A.N. Arep'yev, "Voprosy proyektirovaniya lyogkih samolyotov (Problems of light aircraft design)," Moscow, MGTUGA, 2000, p. 10.

[58] Information from the manufacturer at http://www.dpla.ru.

[59] A. Smolyakov, "Pervym delom, samolyoty bez pilota (The first thing is unmanned airplanes)," *Aviatsiya obschego naznacheniya*, N 7, August 1995.

[60] Unmanned Aerial Vehicles Roadmap 2002–2027, Office of the Secretary of Defense, December 2002.

(see Table 1) agree with the above conclusion. When the mini-UAV is intended for tasks requiring fast speed and maneuverability (e.g., as a target for training air-defense units), the relative weight of the engine may achieve 15%.

Table 1. Specifications of mini-UAVs designed by Russian and Ukrainian manufacturers[61]

Type	Manufacturer	$M_{take\text{-}off}$ (kg)	M_{eng} (kg)	P_{eng} (h.p.)	M_{payl} (kg)	T_{fl} (hour)	D_{max} (km)[62]	V_{cruis} (km/h)
Aist	NIIPFM KhAI (Ukraine)	2		0.2	0.3	1	10	
BRAT	Novik – XXI Century (Russia)	2.8					90	
TeAM-micro	NTTs KhAI (Ukraine)	5			1	20	500	50
Bekas	NIIPFM KhAI (Ukraine)	20		3	5	4	> 60	120
GrANT	Novik – XXI Century (Russia)	20			3	3...4	> 70	120
Fazan[63]	NIIPFM KhAI (Ukraine)	60	9	20	10	2	> 60	450[64]
KhAI-112	NIIPFM KhAI (Ukraine)	60	5	12	15	5	> 120	120
Otshel'nik	NIIPFM-Novik	60	5	10	15	6	> 600	110

Due to dramatic progress in the miniaturization of onboard electronics of mini-UAVs over the last 10–15 years, the onboard control system of modern vehicles weighs from tens to hundreds of grams.[65] Taking into account the weight of the power source for the onboard control system, the specific weight of the on-board equipment does not exceed 5–10%.

These estimates suggest that, depending on the design, the specific weight of a payload plus fuel may reach almost 60% of the aircraft's take-off weight.[66]

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[61] The table is composed of information published at official sites of UAV manufacturers http://www.dpla.ru; http://www.khai.edu/niipfm/index.htm, and in Smolyakov, 1995.

[62] The maximum range indicated for some types of UAVs is restricted not by the amount of onboard fuel, but by the distance at which the UAV is capable to communicate with the ground control station. This distance usually depends on the power of the ground transmitter.

[63] The "Fazan" mini-UAV is intended for training air-defense units.

[64] Maximum speed is indicated.

[65] In particular, the automatic control system of the "Otshel'nik" RPAV, designed jointly by NPKTs "Novik-XXI Century" and NIIPFM, weighs only 0.3 kg, while the take-off weight of the vehicle is 60 kg. NIIPFM KhAI (Ukraine). See http://www.dpla.ru/Otshelnik/Otshelnik.pdf.

[66] For a comparison, statistical analysis of the capabilities of light airplanes (from 500 to 4,500 kg) shows that the weight of fuel and payload is about 40% of the take-off weight (A.N. Arep'yev, "Voprosy proyektirovaniya lyogkih samolyotov (Problems of light aircraft design)", Moscow, MGTUGA, 2000, p. 25).

For a given weight and aerodynamic characteristics of mini-UAV and the energetic specifications of its propulsion system, the weight of fuel will be defined by the required range (endurance) and the specified flight and weather conditions. The specific weight of fuel may be less than 3–4% per hour for a propeller-driven reconnaissance UAV powered by a piston engine.[67] Thus, the lowest weight of fuel for a UAV with a range of 300 km and cruising speed of 100 km/h is nearly 10–15% of the take-off weight. Therefore, the specific weight of a payload could be almost 50%. However, a high payload weight will inevitably worsen the vehicle's aerodynamic characteristics and maneuverability, thereby restricting its application.

As analysis of the data in the Table 1 shows, the specific weight of a payload is usually in the range of 15–25% for existing types of reconnaissance UAVs. This may be explained by the relatively long flight durability, as claimed by manufacturers, which leads to an increase in the amount of onboard fuel and the fairly high empty weight of an aircraft designed for repeat use.

Mini-UAV Control and Desired Accuracy of Payload Delivery

Control of UAV flight assumes solution of two related tasks: providing a given orientation of the aircraft in space relative to its center of gravity and a given transition of the center of gravity of the UAV from a launch point to a target. Control of a UAV can be conducted remotely or autonomously. Major peculiarities of these regimes and corresponding methods of their implementation are considered below.

Manual Remote Control at a Distance of Direct Vision

As a rule, aerobatic radio-controlled (RC) aircraft models are controlled completely in a manual mode via radio. The operator on the ground watches the orientation of the model and the character of its flight. With the help of a manual joystick connected to a radio transmitter,[68] he sends commands to the servos that turn the rudders or control the output power of the engine, changing the model's orientation and its direction of flight as desired.

Two VHF bands are officially allowed for use by aircraft modelers in Russia: near 27 MHz and 40.66–40.70 MHz. However, in practice modeling enthusiasts also use the frequency bands allowed in Europe (35, 40 MHz) and the U.S. (72 MHz), because a wide variety of transmitters and receivers working on these frequencies is manufactured and commercially available.[69]

[67] "Unmanned Aerial Vehicles Roadmap 2002–2027," 2002.

[68] Review of equipment for control of RC model airplanes can be found, in particular, in: Vladimir Vasil'kov and Vitali Puzrin, "Apparatura radioupravleniya. Chast' 1. Peredatchiki (Radio control equipment. Part 1. Transmitters)"; Vladimir Vasil'kov and Vitali Puzrin, "Apparatura radioupravleniya. Chast' 2. Priyomniki (Radio control equipment. Part 2. Receivers)." Both are online at http://www.rcdesign.ru/.

[69] Vasil'kov and Puzrin, Part 2.

The distance at which an airplane model can be remotely controlled is usually restricted by one of two factors: the range of model visibility by its operator or the power limitations of the transmitter. As a rule, the second limitation prevails in areas with intense radio interference such as near industrial centers.

Generally, transmitters produced for aircraft modelers and available commercially have an output power of 0.5–1.5 Wt. This is usually enough for remote control of an airplane model at a distance of direct visibility in an open area far from industrial centers. According to the legislature of the Russian Federation, transmitters for remote control of a model aircraft must be amplitude modulated and their output power cannot exceed 1 Wt. Assembly and use of such a transmitter requires a corresponding license. However, aircraft modelers often ignore these requirements.

Automatic Control Regime

As a rule, automatic control is implemented when a UAV flies beyond the visual range of the ground operator. It is also applied when the vehicle flies out of the zone in which it can communicate with a ground station. For this reason, the UAV is equipped with an autopilot, which includes sensors for assessing the orientation, location, and speed of the vehicle; an onboard computer; interfaces connecting the sensors and the computer with the servos; and an onboard receiver.

The capabilities of modern commercially available electronic equipment for mini-UAVs can be illustrated through the example of the AP50 autopilot and flight control system produced by UAV Flight Systems Inc.[70] This system includes a GPS antenna for finding the location. The orientation of the aircraft (roll, pitch, and yaw angles) is supported through information obtained from a three-axis sensor module, two-axis accelerometer, barometric altimeter, and pilot airspeed sensor. The AP50 system also includes two onboard computers, one of which provides stability control. The other provides navigation control for course, airspeed, and altitude settings and executes mission-related tasks required upon the UAV's arrival at a waypoint.

The AP50 system may be installed on almost any mini-UAV and is compatible with a standard onboard PPM or PCM 5-channel receiver. The control law parameters required to stabilize the flying aircraft is set up on the ground and during test flights. During test flights, the radio can continuously downlink telemetry information to a standard laptop computer on the ground. The flight scenario is entered into the system's onboard computer from a laptop computer on the ground. The user may enter up to 24 waypoints, setting a specific speed and altitude for each leg of the journey.

An important advantage of the AP50 is that it allows UAV control not only in an automatic mode but also in a manual mode (with the autopilot turned off) or a remotely piloted mode. The latter allows the user to correct the flight path or its regime even though the UAV is

[70] The manual and technical capabilities of AP-50 autopilot can be found at the official web site of the manufacturer: http://www.uavflight.com/UAV_AP50_DataSheet.htm.

beyond direct visual range. Flight regimes may also be combined. For example, take-off and landing can be performed in a manual or automatic mode, and flight along the programmed path in an automatic or remotely piloted mode.

According to the manufacturer's data, the AP50 onboard system weighs only 50 g (the power source is not accounted for). Its size is 144 x 47 x 28 mm. Power consumption is about 1 Wt (150 mA, 5–8 V). The cost of the system, including equipment and software, is $2,700. At the same time, the AP50 system provides 15-m position accuracy, 3-m altitude accuracy, and 10% of indicated airspeed accuracy.[71]

The AP50 is a relatively expensive system capable of controlling UAVs that are unstable and manually difficult to fly. The manufacturer also sells less sophisticated variants, the AP30 and AP40, which are half the cost of the AP50 system.

High aerodynamic quality UAVs may be controlled by even simpler and less expensive systems. In particular, a wide variety of so-called airplane model "trainers" intended for beginners is commercially available. The orientation of a trainer can be maintained in an autopilot mode by an infrared flight stabilization system that costs about $120.[72] The cost of the onboard GPS receiver and antenna can be as low as $120.[73]

Principle Schemes of Mini-UAV Flight Control Systems

The mode of UAV flight and the design of its flight control system depend largely on the task. As the analysis above shows, each method of flight control has advantages and disadvantages. The manual mode is simpler to implement, but limited by the range of visibility (less than 1–2 km). The automatic mode is more noise-immune, but it requires high reliability from all elements of the on-board flight control system. Therefore, its implementation demands more care during preparation from a technical standpoint. Moreover, take-off and approach to the target may require additional efforts that make the flight-control system more complex. In addition, using a remote control regime beyond the range of visibility gives an invaluable advantage for in-flight retargeting. However, it also complicates the flight control system.

For these reasons, the most efficient system may be one that combines manual control at the beginning and end phases of the flight and automatic (remotely piloted) control in the middle phase. If terrorists choose to attack an area target (e.g., disperse a chemical or biological weapon over a crowded stadium), a single operator suffices to control the plane's take-off. The rest of the mission may be conducted in an automatic mode. If a point or a

[71] See answers to frequently asked questions: http://www.uavflight.com/UAV_Faqs.htm.

[72] A DIY Cruise Missile Project, Phase 2: The Flight Control System, http://www.interestingprojects.com/cruisemissile/flightcontrol.shtml.

[73] A DIY Cruise Missile Project, Phase 1: Procurement, http://www.interestingprojects.com/cruisemissile/procurement.shtml.

moving target is attacked, the terminal phase of the mission must be performed manually by a second operator located near the target.

The distance from the launch point to the target also influences the choice of flight control method. If the range to the target is less than several dozen kilometers, terrorists need not worry about possible countermeasures resulting from interception of their radio broadcasts during flight in the remotely piloted mode. Even if the speed of the UAV is as low as 80 km/h, the range of 20 km can be passed within 15 minutes. It is practically impossible to react within such a short time. If, however, the distance to a target is several hundred kilometers and the UAV's cruising speed is 100–200 km/h, the radio exchange in remotely piloted mode could pose a serious threat of discovery. This is a strong argument in favor of autonomous flight.

Nevertheless, there are other means of diminishing possible countermeasures in a remotely piloted regime. The most radical way is to increase the speed of the mini-UAV, for example, by using a pulsejet engine,[74] so that the flight time is significantly reduced. A second way involves "masking" the radio exchange. In particular, the information exchange between a UAV and its ground control station can be conducted via a cell phone line (currently, cell phone communication services are provided by many companies in Russia, such as "Beeline," MTS, etc.) For this purpose, standard cell phones with infrared ports could be installed nearby on-board and ground-based computers. The baud rate achievable for modern cellular communication (over 15 kB/s), not to speak of opportunities offered by General Packet Radio Service (GPRS), allows transfer not only of telemetry information, but even, perhaps, of simple images of the earth surface below the UAV, if a small video camcorder is available on board.

Finally, if a terrorist's target is located within a large industrial city, artificial sources of powerful radio transmissions may become additional (or even primary) points of reference. Usually a city holds many stationary radio transmitters whose properties may be studied in advance. Moreover, terrorists themselves may install radio beacons near the target and turn them on just before the planned attack.

Existing Air Defenses Against Terrorist Mini-UAVs

The problem of possible terrorist UAV attacks is aggravated by the fact that there is virtually no defense from such a threat. The air defense systems of many countries, including Russia, were designed to counter a completely different type of threat. They were intended to repel a wide scale attack of aviation and missiles by an external adversary.[75]

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[74] Bruce Simpson, an engineer from New Zealand is going to implement exactly this type of engine (The Low Cost Cruise Missile, http://aardvark.co.nz/pjet/cruise.shtml). According to his estimates, the aerial vehicle is capable of flying with a speed of nearly 800 km/h.

[75] Capabilities of existing air defenses to oppose modern threats are discussed in Sergei Ptichkin, "Prikryt li Kreml' ot ataki s vozduha? (Is the Kremlin protected from an attack from the air?)" *Rossiiskaya Gazeta*, September 14, 2001.

In Russia, the task of defending a relatively large area (such as large industrial cities) from an air attack is laid on a layered air defense system that includes fighter aviation and anti-aircraft missiles of the S-300 type with a range of 150 km. The most valuable targets are protected with another line of air defense: short-range antiaircraft missiles or guns.[76] Defending all installations in a large industrial city from UAVs would be extremely complicated, from both a technical and an economic point of view. In addition, another problem could occur: the air defense systems could themselves fall into terrorist hands. Wide-scale measures are currently implemented to restrict proliferation of shoulder-fired antiaircraft missiles that terrorists frequently use against military and civilian airplanes.[77]

According to expert estimates, the Soviet air defense system was, even at the best of times, unable to protect every installation in its territory. Moreover, it had limited capability to defend industrial centers against stealth cruise missiles flying at low altitudes.[78] The air defense potential has by no means increased after the collapse of the Soviet Union, prolonged economic difficulties, several reorganizations of the air defense forces, and scaled cutbacks of equipment and personnel.[79] Publications in open sources frequently suggest a gloomy picture even for such relatively successful military districts as Moscow. These sources indicate that, as a result of recent cutbacks, not a single regiment in the air defense system of the Russian capital (S-50) remained on alert, and “Moscow and the Central Industrial region are practically not protected from possible attacks of not only prospective but even modern means of air attack existing in developed countries.”[80] According to expert estimates, the S-50 system is only capable of intercepting 12—to 15 out of 100 cruise missiles, and this figure may at best reach 28 of 100 “after a long period of mobilization and coordination of regiments of the S-50 systems that are currently understaffed.”[81]

Not only is interception of targets in the air a problem, but their detection as well. In an ordinary day-to-day alert (not on the highest level possible), the coverage of radar searching

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[76] Principles of formation of the Air Defense system in Russia are presented in “Proyektirovaniye zenitnykh upravlyayemykh raket (Design of antiaircraft guided missiles),” ed. by I.S. Golubev and V.G. Svetlov, Moscow, MAI, 1999, pp. 79–88.

[77] See, for example, Oleg Yelenskii, “Razvedka Ischet “Igly”, i, Glavnoye, Nahodit (Intelligence Looks For ‘Igla’ missiles and, above all, finds them),” *Nezavisimoye Voyennoye Obozreniye,* November 28, 2003; Pavel Bruntal’skii, “Kak Ostanovit’ “Strely” i “Igly”, (How to stop ‘Strela’ and ‘Igla’ missiles),” *Voyenno-Promyshlennyi Kurier,* November 12–18, 2003.

[78] John W. R. Lepingwell, “Soviet Strategic Air Defense and the Stealth Challenge,” *International Security*, Fall 1989, Vol. 14, No. 2, pp. 64—100.

[79] On modern Russian air defenses see, for example, Mikhail Khodaryonok and Yuri Tikhomirov, “Programma Perevooruzheniya po Biznes Planu, (Rearmament program according to a business plan),” *Nezavisimoye Voyennoye Obozreniye*, August 22, 2003; O. O. Gapotchenko, “V Ozhidanii Novogo Rusta (Waiting for new rust),” *Voyenno-Promyshlennyi Kurier,* December 24, 2003; Grigorii Dubrov, “Rossii Grozit Slepota, (Russia is going to be blind),” *Nezavisimoye Voyennoye Obozreniye*, April 28, 2000.

[80] Khodaryonok and Tikhomirov, 2003.

[81] Khodaryonok and Tikhomirov, 2003.

for air targets is not continuous even over high priority territories. According to Lieutenant-General Mikhail Kizilov, the Chief of the Directorate for Use of Airspace and Air Traffic Regulation of the Russian Ministry of Defense, the military currently do not control almost 70% of the airspace in certain directions and at certain altitudes.[82] Lieutenant-General G. K. Dubov, Ret., former Commander of the Radio Engineering Service of the Air Defense Forces, claims that the zone under control has been reduced from 100% to 55% at an altitude of 10 km, and from 84% to 23% at altitudes below 1000 m. Normally, even the airspace over Moscow is not covered by radar.[83] Illegal flights of private airplanes in Moscow region support this claim.[84]

Thus, if a terrorist attack from the air occurs at a range of dozens kilometers from the target (in fact, inside the zone of layered air defense), and the flight time of the terrorist UAV lasts no more than 15–30 minutes, the existing air defense system is useless against it.

Furthermore, the existing means of monitoring airspace are designed primarily to find and defeat targets that differ from mini-UAVs in operating speed and altitude. For example, the radars of the AWACS and JSTARS early warning airplanes intentionally eliminate slow-flying targets in order to filter out false targets such as birds.[85] Domestic military radars likely implement similar data-processing algorithms. A mini-UAV flying at an altitude of 100 m with a speed less than 100 km/hr looks more like a bird on the radar screen than the cruise missile of a potential adversary. Moreover, the radar of the air defense system will become practically useless against a mini-UAV flying at a low altitude just above buildings in a city because of the scattering effects of the radar signal from background objects that have much larger cross sections compared with that of the mini-UAV.

Even if an air space monitoring system were built to detect mini-UAVs with high reliability, many factors make the use of existing surface-to-air missiles problematic. As a rule, civilian and private airplane traffic is busy near industrial cities. Using surface-to-air missiles (SAM) against a small UAV could lead to a mistaken attack against an airliner, because the latter is a "brighter" target compared with the former. Such an accident happened in October 2001, when an anti-aircraft missile of the Ukrainian S-200 (SA-5) air defense system hit a Russian Tu-154 airliner over the Black Sea.[86] U.S. "Patriot" surface-to-air mis-

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[82] Ol'ga Bozh'yeva, Nebo Rossii Popolam ne Delitsya, (The sky cannot be split in half)," *Krasnaya Zvezda*, April 10, 2003.

[83] Dubrov, 2000.

[84] "Interfax" agency reported that two hijacked airplanes (An-2 and PZL-35) had been found in the Ruza district of the Moscow Region. The planes were illegally used for commercial flights for fun ("Obnaruzheny Dva Ugnannykh Vozdushnykh Sudna [Two hijacked airplanes have been found]," *Gazeta,* January 28, 2004).

[85] Dennis M. Gormley, "Dealing with the Threat of Cruise Missiles," Adelphi Paper 339 (Oxford: Oxford University Press for the IISS, 2001).

[86] See, in particular, Yuri Butusov, "Tu-154 – sekretnaya khronica pozora (Tu-154 – A secret chronicle of shame)," *Zerkalo Nedeli*, Issue 40, October 7, 2003.

siles downed two airplanes of the coalition forces during the "Enduring Freedom" operation in Iraq in 2003 after mistakenly identifying these planes as hostile cruise missiles.[87]

The cost of air defense interceptors is also a significant factor. One "Patriot PAC-3" surface-to-air missile costs about $3.5 million[88] and the cost of a SAM of the 48N6E type for the S-300 air-defense system is likely comparable. These figures are higher by orders of magnitude than potential expenditures by terrorists. And more than a single missile may be needed to hit a mini-UAV with a high probability.

All this suggests that once a terrorist mini-UAV has been launched, it will be practically impossible to defend against. Thus, the main accent of dealing with this threat needs to be on measures to prevent the attack during its preparation stages.

Conclusions

1. The analysis in this report demonstrates that, from a technical standpoint, the use of UAVs for weapon delivery purposes is an achievable task for terrorists. Further technical development and wide application of unmanned aerial vehicles for military and civilian purposes will contribute to the growth of this threat.

2. The use of UAVs to deliver weapons of mass destruction poses the greatest danger. However, terrorist UAVs may cause considerable damage even if they carry conventional payloads.

3. In Russia, the most likely threat may occur from self-made mini-UAVs. The most worrisome situation stems from model aircraft, where uncontrolled access to the knowledge, skills, and equipment required for mini-UAV assembly exists. On the other hand, prohibitive measures in this area alone cannot produce positive results, especially if they are taken in a single country. Moreover, model aircraft have always played an important role in the development of domestic aviation and have an educational significance. For this reason, model airplaning should become an area of priority attention from the state.

4. One of the tasks that the state needs to address is filling the legal vacuum in the area of UAV applications for civilian purposes. At the same time, it is important that any restrictions or rules not become an obstacle to UAV use where it is cost efficient.

5. Existing air defense systems have little use against terrorist mini-UAVs, since they were developed to face different kinds of threats. For this reason, the main accent of dealing with the threat of terrorist UAVs needs to be on preventive measures. Police and security forces are unlikely to be able to resolve this task in isolation from the pub-

[87] Dennis M. Gormley, "Missile Defence Myopia: Lessons from the Iraq War," *Survival*, Vol.45, No. 4, Winter 2003–04, pp. 61—86.

[88] Gormley, Testimony, 2004.

lic. At least the public should be made aware of the threat and its potential consequences.

Appendix. Media Reports of Terrorist Attempts to Employ UAVs

- In 1995 Aum Shinrikyo, the Japanese terrorist group that attacked the Tokyo subway with sarin gas, planned to use remote-control helicopters to spray dangerous chemicals from the air.[89] The helicopters crashed during testing.

- In 2001 Osama bin Laden considered using remote-control airplanes packed with explosives to kill President George W. Bush and other heads of state at the G-8 summit in Genoa, Italy.[90]

- In June 2002, quoting a German intelligence official, the *Reuters* news agency reported that al Qaeda might be planning to attack passenger aircraft using model airplanes.[91]

- One terrorist group, the Revolutionary Armed Forces of Colombia, or FARC, was discovered in possession of nine remote-controlled unmanned aircraft when a Colombian army unit overran one their remote camps in August 2002.[92] However, such radio-controlled craft can only be effectively flown for a few miles.[93]

- According to *Debka.com*, in December 2002, Palestinian toy importers in Jerusalem and Ramallah were told to order hundreds of model airplanes for distribution to Palestinian children in hospitals. Subsidies from European Union member-governments could legitimately be allocated to this humanitarian purpose. The model airplanes were purchased in Europe and shipped openly to Palestinian shopkeepers. The model planes were sent to Palestinian workshops for conversion into miniature air bombers with explosive payloads. Tanzim militiamen from Arafat's Fatah, sent out to open areas near Jericho to test the new weapons, discovered they could fly to a distance of 1 kilometer and an altitude of 300 meters. The only problem was how to guide the plane to a target inside a built-up Israeli area where it would no longer be visible to the remote control holder. A small adjustment was made in the engine enabling the operator to cut it out from a distance, so that it dropped to the ground and blew up. Contrary to reports that Arafat had withdrawn from the day-to-day management of Palestinian terrorist operations, *DEBKAfile's* counter-terror sources emphasize that the results of the model plane conversion tests were brought before him. Delighted with its performance, he ordered the new weapon to be used in the coming days in Jerusalem. He chose Jerusalem, calculating that it would be some time before Israeli security and intelligence authorities caught on to and learned how to intercept the new miniweapon whizzing around the city

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[89] Michael Gips, "A Remote Threat," *Security Management Online*, October 2002.

[90] Gips, 2002.

[91] Gips, 2002.

[92] "Colombia – FARC Drones Discovered," *EFE News Service*, August 28, 2002.

[93] Gormley, "UAVs and Cruise Missiles as Possible Terrorist Weapons," in Moltz, 2003.

before it blew up. The deadly toy is easily launched from Arab Jerusalem. Its flying time is estimated at no more than 2–3 minutes.[94]

- The *Vremya Novostei* newspaper reported in November 2003 the theft of a copy of the newest developmental reconnaissance UAV model from a building plant in Israel. The UAV weighs 14 kg and has a wingspan of 1.5 m. The thief was not caught, and there were fears about the possible use of the model by terrorists.[95]

- According to the London *Independent* newspaper, a British national held at Camp Delta, Guantanamo Bay, Cuba, has confessed to being part of an al Qaeda plot to acquire a drone to attack the House of Commons with anthrax.[96]

- According to *Reuters*, in early March 2004, Israeli intelligence prevented a terrorist act with use of a UAV loaded with explosives. Representatives of the administration of Prime Minister Ariel Sharon claimed that a Palestinian extremist group planned to attack a Jewish settlement in Gaza sector.[97]

[94] "Arafat's New Terror Weapon: Exploding Toy Planes," *DEBKAfile* Special Counter-Terror Report, January 14, 2003.

[95] "Ukraden izrail'skii samolyot-razvedchik, (An Israeli reconnaissance airplane has been stolen)," *Vremya Novostei*, November 11, 2003.

[96] Gormley, Testimony, 2004.

[97] "V Izraile predotvraschyon terakt s ispol'zovaniyem BLA (Terrorist act with UAV employment has been prevented in Israel)," *Polit. Ru*, March 10, 2004.