The Problem of Detecting Stealth Airborne Vehicles

Under present-day conditions, when the INF Treaty eliminating intermediate and lesser-range missiles has been concluded between the USSR and United States and talks are under way about a 50-percent reduction in strategic offensive arms, Pentagon strategists' plans are placing more and more emphasis on low-signature airborne vehicles. Since 1983 the American Stealth program, aimed at working out the technology of low-signature airborne vehicles, has been covered in the western press to a lesser extent. The Strategic Defense Initiative has moved into first place in popularity. Nevertheless, implementation of the Stealth program continues at rather high rates. In the opinion of foreign military specialists, results obtained in the course of its realization will strongly influence the appearance of future airborne vehicles. It is believed that a reduction in signature will become the leading trend in military aircraft construction of the 1990's. Programs for developing the highest priority airborne vehicles of various classes having the property of a low signature serve as confirmation of this. They include the B-2 bomber, the ATF advanced tactical fighter, and the ACM cruise missile.

The signature of airborne vehicles is being reduced in various sectors of the electromagnetic spectrum: radar, optical, infrared and acoustic. Greatest emphasis is being placed on reducing radar signature inasmuch as radar presently is the basic equipment in air defense systems for detecting airborne vehicles. Technical ways of reducing the radar signature of airborne vehicles also are known: improving aerodynamic shape, using new structural materials and radar-absorbing coatings, reducing the number of antennas and so on. Judging from foreign press announcements, modern technologies created under the Stealth program permit almost a 70 percent reduction in the radar cross-section of airborne vehicles compared with that of aircraft with traditional configurations. The detection range of such a low-signature aircraft will be reduced by a third, since detection range is proportionate to the 4th root of radar cross-section values.

In forecasting the massive introduction of low-signature airborne vehicles to the inventory in the 1990's, foreign military departments are unfolding a broad complex of work to study problems of countering them. Specialists devote primary attention here to problems of increasing the radar detection range of low-signature aircraft, assuming that realization of results largely will determine the appearance of radar equipment of the 1990's.

Present R&D is arbitrarily divided into two groups. The first group of studies is being conducted within the scope of a traditional approach to solving the problem of increasing the radar detection range of targets. In particular, possibilities are being studied for increasing the energy potential of radars and increasing the sensitivity of radar receivers. A typical feature of this work is that it essentially does not consider the specifics of stealth aircraft as radar targets. Results of the work are to be used basically in modernizing exiting radars.

The second R&D group is distinguished by a great diversity of research ideas and directions and represents both completely new approaches as well as familiar ideas in theoretical radar which were not previously realized for various reasons. What is common is the researchers' attempt to take advantage of signs that are specific for low-signature aircraft (such as characteristic shapes) for increasing detection range. The need for creating fundamentally new systems and equipment as a rule is substantiated as a result of this R&D.

The problem of detecting low-signature airborne vehicles is connected with radar cross-section, the magnitude of which depends on many factors: dimensions, configurations, spatial attitude of the airborne vehicle, the material from which it is made, and the illuminating signal's frequency, polarization and shape. Even a slight change in any of these factors can lead to a substantial change (by an order of magnitude or more) in the radar cross-section value. Therefore in indicating the radar cross-section values of specific airborne vehicles the conditions under which they were obtained must be precisely specified. Foreign publications devoted to low-signature airborne vehicles, however, often ignore this rule. For example, in speaking of the radar cross-section value of a low-signature airborne vehicle, its value with the vehicle illuminated in the forward hemisphere usually is given, although the generally accepted indicator is the mean value of aircraft radar cross-section when illuminated from all directions. Because of such "little ploys," a radar cross-section value equal to 10' m^2 appears in western publications devoted to low-signature airborne vehicles.

Foreign military specialists note that the majority of authors of publications on low-signature aircraft are directly involved in their development. Therefore these articles as a rule emphasize the advantages of low-signature airborne vehicles and are silent about shortcomings or disputes. What is common in calculations of the detection range of low-signature airborne vehicles is the use of characteristics of existing air defense radars. The possibilities of improving the radars as well as changing the parameters affecting target radar cross-section usually are not examined, although specialists in the field of radar already have determined future ways of improving the detection range of this type of target based on an objective analysis of the features of low-signature airborne vehicles and the dependence of their radar cross-sections on radar characteristics.

Traditional methods of improving detection range are based on an increase in radar energy potential and an improvement in the quality of signal processing. The former can be increased by increasing transmitter output and the radar antenna's directive gain. The appearance of generator devices which will permit increasing radar transmitter output by 2-3 times is expected in the future.

An increase in directive gain as a rule is connected with an increase in antennas' geometric dimensions. The possibility of creating conformal antennas based on phased arrays for radar early warning aircraft is being studied. This type of antenna will be part of the aircraft skin, which will permit accommodating them, for example, along the entire fuselage or leading edge of the wing. Thus there is an opportunity to increase an antenna's geometrical dimensions to limits determined by the dimensions of the platform aircraft. Calculations show, however, that even increasing antenna dimensions to maximum values will increase detection range only by 60-70 percent, which will permit compensating for a decrease in target radar cross-section by 10 db. In this connection foreign specialists are directing attention to the fact that the role of ground radar systems with antennas which essentially have no limitations on geometrical dimensions is again growing.

It is planned to improve the operating quality of radar receivers above all by an analysis of the fine structure of signals based on realization of digital filtration algorithms on computers. In this connection great hopes are being placed on introducing ultrafast integrated circuits and monolithic integrated circuits in the SHF and EHF bands. Charge-coupled instruments as well as those using surface acoustic waves are being created to perform individual signal processing operations.

To increase the detection range of low-signature targets, the U.S. Air Force plans to modernize the radars of AWACS system E-3 early warning and control aircraft (see color insert [insert not reproduced]), i.e., improve digital signal processing quality using computers, in the first half of the 1990's. It is believed that the detection range of targets will increase significantly after modernization because of a 10-13 db increase in signal level, and radar operating reliability and antijam capability also will improve. Other electronics of the E-3 aircraft also will be upgraded. In particular it is planned to install direct ELINT systems for passive detection of enemy aircraft, NAVSTAR satellite navigation system gear, and 2d class terminals of the JTIDS joint tactical information distribution system.

A known method for increasing detection range is to increase the time of coherent accumulation of echo signals. An inverse aperture synthesis method has been developed based on this principle. It uses algorithms which are the inverse of those used in radar aperture synthesis modes and permits obtaining detailed ground target images based on an analysis of Doppler shifts in the signal frequency. A distinctive feature of this method is that signal accumulation occurs because of target motion and not radar antenna motion as in ordinary aperture synthesis.

The inverse aperture synthesis method was tested in ground measurement systems (radar signals of space objects were received on Kwajalein Island using radars), and in the early 1980's it was also realized in an onboard radar which underwent flight testing. The AN/APS-137 radar, intended for identifying and classifying naval targets, became the first series-produced onboard radar in which this method was used. It is installed in S-3B

Viking deck-based ASW aircraft and P-3 Orion land-based patrol aircraft. The requirement to know the distance to a target and its speed is considered to be a shortcoming of this method. Errors in determining these parameters lead to deterioration of the radar's accuracy characteristics in the inverse aperture synthesis method mode of operation.

Methods based on selecting the optimum band of radar operating frequencies are conditionally categorized among traditional methods of increasing the detection range of low-signature airborne vehicles. Presently known means of reducing signature are effective only in a limited frequency band. It is believed that the lower limit of this band is 1 GHz and the upper limit is 20 GHz. Signature reduction throughout this band can be achieved only by integrated use of different methods and equipment. Individual equipment is even more narrow-band. The 1-20 GHz band was not chosen by chance. First of all, the bulk of existing air defense radars operate in it, and so designers strive to reduce the signature of airborne vehicles specifically in this band. Secondly, there are a number of fundamental physical limitations in the path of reducing the signature of airborne vehicles outside this band.

The basis for choosing the optimum band of radar operating frequencies is the dependence of an airborne vehicle's radar cross-section on the frequency of the illuminating signal. For example, the radar cross-section of fighters with traditional configurations increases according to a law near that of linear law with a decrease in frequency (or an increase in wavelength) of the sounding signal. A similar dependence is even more strongly expressed for low-signature airborne vehicles—radar cross-section is proportionate to the square of the sounding signal's wavelength. Calculations show that the detection range of a low-signature aircraft in free space in the 1-2 GHz band is 1.75 times more than in the 2-4 GHz band, and it is 2.2 times more than in the 4-8 GHz band. In this regard foreign specialists note the increased interest in radars of the metric and decimetric bands. For several decades one of the leading radar trends was the development of bands of higher and higher frequencies, dictated by the possibility of obtaining higher resolution. The appearance of low-signature airborne vehicles again drew specialists' attention to the metric and decimetric bands.

The use of radar-absorbing coatings is an important direction in reducing the signature of airborne vehicles. It is assumed that if radars of different bands are used in air defense systems, it will be practically impossible to create an effective radar-absorbing coating for an aircraft. Ferritic radar-absorbing materials are relatively narrow-band. For example, materials known as echosorb with a thickness of 5-8 mm absorb 99 percent of the energy of an incident wave in a band of approximately 300 MHz. It is noted that it is necessary to apply multilayer coatings to reduce the signature of airborne vehicles in a broader band, but this is hardly realizable considering the fact that the specific mass of a modern ferritic coating is almost twice that of an aluminum coating. Coatings based on dielectrics have less mass, but their thickness is directly dependent on the frequency of waves absorbed. For example, to counter sounding signals of a radar operating at a frequency of 1 GHz the coating thickness must be approximately 300 mm, which naturally is unacceptable for aviation.

If the sounding signal wavelength is commensurate with the target's dimensions, the reflection will bear a resonant character dictated by the interaction of the direct reflected wave and waves bending around the target. This phenomenon contributes to the formation of strong echo signals. The resonance phenomenon also can arise on the target's structural elements. For example, stabilizers and wingtips fall in the resonance area of the E-2C Hawkeye early warning aircraft radar operating at frequencies around 400 MHz (wavelength 0.75 m). The U.S. Navy command plans to keep the Hawkeye in the inventory after the next equipment modernization.

The possibility of using two bands and changing the sounding signal frequency in accordance with target configuration is the basic idea in creating the ASTARA (Atmospheric Surveillance Technology Airborne Radar Aircraft) advanced early warning aircraft, which is intended specifically for detecting low-signature airborne vehicles. It is assumed that the ASTARA will supplement AWACS system E-3 aircraft. Flight tests of the new aircraft are planned for 1991.

Creation of over-the-horizon [OTH] radars in the United States began long before work was organized to counter low-signature aircraft, but the fact that such radars operate in the metric wave band now gives American specialists the basis to view them as an important means of detecting low-signature airborne vehicles. Therefore further development and tests of OTH radars are being conducted with consideration of their performance of the new function. U.S. Air Force specialists have been working on development of oblique incidence-backscatter sounding OTH radars since 1975. It is planned to build four radars for detecting targets approaching the North American continent from any direction except north. The latter cannot be covered because of the unstable character of propagation of shortwave band signals in high geographic latitudes.

In 1988 the U.S. Air Force conducted the first tests of an OTH radar for detecting small targets simulating cruise missiles. Its capability for detecting targets in air space between Puerto Rico and the Bermuda Islands was evaluated. The radar operates in the 5-28 MHz band. Higher frequencies in this band were used in the daytime and lower frequencies at night because of the ionosphere's influence. Cruise missiles were simulated by AQM-34M drones launched from an NC-130 platform aircraft. They flew at various altitudes (150, 4,500 and 7,500 m) at a speed of 650-750 km/hr. A U.S. Air Force representative declared that the tests confirmed the possibility of an OTH radar detecting small targets at a distance up to 2,800 km. Based on their results, the decision was made to increase the size of the receiving antenna of the radar being built on the U.S. west coast from 1,500 to 2,400 m, which will permit doubling radar receiver sensitivity. It is planned to conclude development of a system of four OTH radars in the 1990's.

The U.S. Navy is developing the ROTHR transportable OTH radar, the basic advantage of which is considered to be its capability of being moved to previously prepared positions in a relatively short time period. This radar supports the detection of aircraft at distances of 925-2,700 km in a 60° sector. Its electronics are accommodated in 30 vans. Antenna fields are being created in potential areas of combat operations, to which vans with equipment will be transported in case crisis situations arise. According to a statement by a Raytheon representative, a prototype of the radar already has been positioned in the state of Virginia and subsequently it is planned to rebase it to the Aleutian Islands. Other positions have not yet been selected for the radar, but it is proposed to deploy at least nine radars, above all in sea or ocean theaters of operations, where they will be used together with E-2C Hawkeye and E-3 Sentry early warning aircraft.

U.S. Air Force specialists are studying the possibility of creating an artificial ionospheric mirror to improve the functioning quality of OTH radars. In their opinion, it will facilitate a more focused reflection of sounding signals, which will increase resolution and will permit detecting targets at distances of less than 500 km.

Even the most ardent supporters of OTH radars admit their serious inherent shortcomings: poor resolution and weak antijam capability. Nevertheless, in the opinion foreign experts, OTH radars are the only type of system which can be placed in service with a number of western countries in the future and support detection of low-signature airborne vehicles. All other types of systems, no matter what advantages they may have, are in earlier stages of development.

The above approach to optimum band selection was oriented toward increasing the wavelength of sounding signals compared with those being used in modern air defense radars. The foreign press also is discussing an alternative path consisting of shifting to the millimeter wave band. Inasmuch as it is believed that radar-absorbing materials which are most effective in the millimeter band presently are lacking, therefore radars operating in the millimeter wave band can become an important component of future air defense systems. Millimeter band development is going on at fast tempos. An element base and principles for constructing systems operating at frequencies of 30-40 and 85-95 GHz already have been worked out, and models with operating frequencies near 140 GHz also are being created.

Nontraditional methods for increasing the detection range of airborne vehicles with low radar **cross-sections** are based on new approaches (time-and-frequency and spatial) to solving the problem. Methods of forming and processing new spread spectrum radar signals are being studied within the scope of the time-and-frequency approach.

The use of sounding signals matching target shape permits considerable amplification of echo signals. This method is similar to the method of matched filtration being used in modern radars. Sounding signals are formed on the basis of the target's pulse characteristic, which depends on its configuration, spatial attitude and movement dynamics. In practice, matching signals with a target requires pulses of nanosecond length. Nonsinusoidal signals are a particular occurrence of such pulses. Their important features include a super-wideband nature. As an example, the foreign literature examines signals occupying the 0.5-10 GHz band and having a duration of 0.1-1 millisecond. Their use provides a range resolution within limits of 0.15-0.015 m. Reflections from a target represent a set of echo signals from several point reflectors distributed over the target surface, which permits constructing a model of reflections from a specific airborne vehicle, with which the shape of sounding signals is matched. Calculations show that ferromagnetic materials weakly absorb the energy of nonsinusoidal radar signals.

Inasmuch as information on the configuration of an airborne vehicle can be used to increase detection range of airborne vehicles with low radar cross-sections, foreign military specialists are considering possible measures to conceal it. They include the following among such measures: accommodating airborne vehicles in shelters; selecting locations rationally and limiting training flights in daylight to reduce the probability of various reconnaissance assets obtaining photographs of airborne vehicles; improving simulator systems and shifting the center of gravity of flight personnel training to simulators; outfitting low-signature airborne vehicles with devices that increase and distort the aircraft's radar cross-section, since the probable enemy may obtain information on actual radar cross-sections when training flights are conducted within the coverage of radars of civil aviation air traffic control systems.

The time-and-frequency methods of detecting low-signature airborne vehicles also include using radars with multifrequency signals. In this case the target is illuminated by several continuous wave signals simultaneously on different frequencies. Echo signals are received and processed using a multichannel receiver. Signal pairs are formed in each channel at close frequencies, then they are multiplied and integrated or undergo Doppler filtration. The advantage of multifrequency radar consists of the possibility of selecting a set of frequencies providing maximum detection range. As in the previous method, target configuration is the determining parameter.

Possibilities of using the "nonlinear radar" effect also are being studied to improve detection range of airborne vehicles with low radar cross-sections. The effect consists of the fact that on being irradiated, equipment objects not only reflect incident waves, but also generate re-emission on harmonics. Sometimes this phenomenon is called the "rusty bolt" effect, since connections of metal components are in part a source of harmonic oscillation. But semiconductors also have a similar property. The latter circumstance sparks researchers' interest in connection with airborne vehicles being outfitted with multifunction active phased arrays in which it is planned to use gallium arsenide components. Emission level drops sharply with an increase in the harmonic number. This is why only emissions on second and third harmonics are of practical interest.

Judging from western press announcements, all methods of the time-and-frequency group still are in early stages of theoretical and experimental research and development and so their realization will become possible only in the distant future.

Methods and means based on airborne vehicle radar cross-section as a function of the direction of illumination are being developed within the framework of the spatial approach to increasing detection range of low-signature airborne vehicles. As a rule, designers of such vehicles are succeeding in decreasing the radar cross-section value chiefly when illumination is in the forward hemisphere.

Specialists' interest has grown in recent years in so-called multiposition radars, which represent a set of several interworking transmitters and receivers separated in space. The simplest multiposition radar, consisting of one transmitter and one receiver, is called a bistatic radar. Principles of constructing multiposition radars were known back at the dawn of radar, but certain technical problems such as supporting data transmission for synchronizing transmitters and receivers did not find a satisfactory solution in those years. Therefore further development of radar followed the pith of improving single-position systems.

An important parameter of bistatic radars is the angle between directions from the target to the transmitting and receiving positions—the so-called bistatic angle. Special attention is given to research on radars with a bistatic angle equal to 180 °, i.e., when the detected airborne vehicle is on a straight line connecting the transmitter and receiver. In this case the airborne vehicle's radar cross-section increases greatly (by tens of decibels) as a result of an effect known as "forward scatter." In the first approximation the "forward scatter" radar cross-section equals the ratio of the square of the illuminated area of an airborne vehicle to the square of radar transmitter wavelength multiplied by a factor of 12. Inasmuch as "forward scatter" radar cross-section is independent of the material from which the airborne vehicle is made, the effect of using composite materials and radar-absorbing coatings in low-signature airborne vehicles will be neutralized. The magnitude of the "forward scatter" radar cross-section decreases with a decrease in bistatic angle, but even, at an angle of 165° it is still considerably more than for a single position radar.

The foreign press proposes different variants for building multiposition radars differing chiefly in the method of organizing target illumination. Radars of early warning systems and of integrated reconnaissance and strike systems, space-based radars, or even television broadcasting stations can be used as transmitting stations. The possibility also is being considered of introducing a multiposition mode to existing radars and creating radar nets on their basis.

The use of space-based radars will permit illuminating airborne vehicles from above. Here the airborne vehicle's radar cross-section will increase because of an increase in illuminated area. At the present time specialists of the United States, Great Britain and Canada are fulfilling a joint program for creating a space-based radar intended for detection and early warning of a raid by bombers and cruise missiles. At the same time, demands being placed on the space system by each of the countries have their own features.

UK specialists believe that a space-based radar also has to support the tracking of ground and naval objects, including on the battlefield. In their assessments, tracking naval targets presents no serious technical difficulties, but realizing the capability of tracking targets on the battlefield will require a large volume of research. A synthetic aperture radar is considered to be the most suitable type of radar for accommodation on a space platform.

Canada is participating in a number of projects together with the United States in support of air defense of the North American continent, including modernizing the ground radar network, creating OTH radars, and expanding zones monitored by E-3 aircraft. But representatives of the Canadian Ministry of National Defense consider space-based radars the sole means which can support surveillance of the country's entire territory including adjacent air space and sea areas. In addition to solving the basic problem, in their opinion such a station must perform the functions of search and rescue, navigation, and air traffic control systems. Initial plans provide for inserting 4-10 radar-equipped satellites into low polar orbits. To improve system survivability U.S. Air Force specialists are considering the possibility of creating a space-based distributed radar. Joint functioning of the "galaxy" of satellites will permit realizing an extraordinarily large overall system aperture. Proposals to accommodate radars on dirigibles or balloons which support the ascent of a payload weighing up to one ton to a height up to 25 km also are being advanced as intermediate solutions.

In parallel with development of radars, the United States is preparing an experiment to place an infrared telescope in orbit as a means of detection with a passive operating mode and higher resolution. It was planned to place the telescope in orbit in March 1986 using the Shuttle spacecraft, but the disaster of the Challenger craft delayed the experiment for several years.

In assessing the problem of improving detection range of low-signature airborne vehicles as a whole, foreign specialists note that intensive theoretical and experimental work has been going on in all possible directions. Individual results may be realized in the near future after reliable information is obtained about what methods and means of reducing the signature will find practical embodiment in aircraft of the 1990's. Radar specialists are optimistic, since the history of equipment development shows that radars always had advantages over countermeasures, and this situation apparently will be preserved even in the foreseeable future.

The problem of combating Stealth aircraft troubles foreign military specialists to a lesser extent. It is believed that with reliable detection and tracking they can be destroyed with a given probability both by existing and by future surface-to-air missile weapons.