

Annex 3

Report of JSC Air and Space Defense Corporation "Almaz-Antey" on a flight test of the air-route radar complex "Utes-T" located at the air-route radar position "Ust-Donetsk" at the Rostov Regional Centre of the Russian Federation Unified Air Traffic Management System, 2019

(translation)

REPORT

on a flight test of the air-route radar complex "Utes-T"
located at the air-route radar position "Ust-Donetsk" at the Rostov Regional Centre
of the Russian Federation Unified Air Traffic Management System

Moscow, 2019

Designations and Abbreviations

AC	- aircraft
UATMS	- Unified Air Traffic Management System
PSR	- primary surveillance radar
PJ	- passive jamming
RI	- radar information
RC	- radar complex
RS	- radar station / radar
RF	- Russian Federation
MTS	- moving target selection
TRS	- technical requirement specification
ARRC	- air-route radar complex
MOR	- military operational requirement
RCS	- radar cross-section

Terms and Definitions

The following terms with their respective definitions were used in preparing this report:

False-alarm probability: The probability that noise or other interfering signals will erroneously cause a target detection decision. *See also:* detection probability (according to IEEE Std 686).

Detection probability: 1) (detection probability): the probability that a signal, when actually present at the input of the receiver, will be correctly declared a target signal based on observation of the receiver output. *See also:* false alarm probability;

2) (acquisition probability): the probability of establishing a stable track on a designated target (according to IEEE Std 686).

Secondary RI processing: The processing of primary RI that provides target trajectory detection, filtering and extrapolation of detected trajectory parameters and target tracking, as well as recognition of radar target classes based on signal and trajectory characteristics. The result of secondary processing is trajectory radar information on the target (trajectory parameters).

Range: Distance between a radar and a target (according to IEEE Std 686).

Minimum detectable velocity (MDV): In a Doppler processing radar for detection of moving targets, the minimum target velocity that can be detected (according to IEEE Std 686).

Minimum detectable signal (MDS): The minimum signal level that gives reliable detection in the presence of white Gaussian noise (according to IEEE Std 686).

Note: MDS must be described in terms of probability of detection and probability of false alarm, due to its statistical nature.

Slant range: The slant distance between a radar and a target (according to IEEE Std 686).

Slant distance: The distance between two points which are not at the same elevation. Used in contrast to ground distance (according to IEEE Std 686).

Radar coverage area: The area of space within which RI can be obtained and which is characterised by the coordinates of the area boundaries in terms of range, azimuth, elevation and scan period (rate).

Radar detection area: The part of the coverage area where detection of a specific type of target with predetermined characteristics of correct detection and

false alarm is provided. The detection area is characterised by RCS and flight speed of the target and the boundary values of range, altitude, elevation angles and azimuth.

Detection: Isolation of an object from the background and classifying it as an object of potential interest.

Detection of a radar target: establishing the presence of a target as a result of RI processing and determining the position of the target in space and identifying the nature of actions.

RI processing: the process of transforming RI, including by combining RI received from several radars, in order to improve its completeness, accuracy and reliability.

Radar signal processing: The process of converting radar signals to reduce interference and isolate useful RI.

Backscatter: Energy reflected or scattered in a direction opposite to that of the incident wave (IEEE Std 686).

Signal-to-noise ratio: In radar, the ratio of the power corresponding to a specified target measured at some point in the receiver to the noise power at the same point in the absence of the received signal (according to IEEE Std 686).

Primary RI processing: The processing (conversion) of radar signals received from the output of a receiving radar over a certain time interval or in a single space scanning session, which provides detection of a signal reflected from or emitted by a target, stabilization of false alarm level, obtaining primary measurement information about radar target coordinates. The result of the primary processing is RI on coordinates of the target (coordinate points).

Radar position: An area of the earth's surface on which a radar is located or which is prepared for the deployment of a radar or parts thereof.

Threshold: A value of voltage or other measure that a signal must exceed in order to be detected or retained for further processing (according to IEEE Std 686).

Potential (from Latin potentia: power): 1) energy characteristic of a system or a device; 2) an available resource that can ensure the implementation of a particular process.

Radar potential: A generalised characteristic of a radar which depends on the ratio of its transmitter power to the receiver sensitivity.

Radar information (RI): The totality of information about radar targets that is obtained by radar methods in the process of radar observations.

Radar station (RS, radar): (1) radar equipment that comprises structurally and functionally related components and is designed for radar observation; (2) an

electromagnetic system for the detection and location of objects that operates by transmitting electromagnetic signals, receiving echoes from objects (targets) within its volume of coverage, and extracting location and other information from the echo signal (according to IEEE Std 686).

Notes:

1. Radar is an acronym for radar detection and ranging.
2. Radar equipment can be operated with the transmitter turned off, as a passive direction finder on sources radiating within the band of the receiving system.

Radar target: A radar observation object in the form of an object or environment that is capable of emitting or altering the parameters of radio waves.

Radar observation: The process of obtaining information about objects and environment using radioelectric methods based on the phenomena of emission, propagation and scattering of radio waves. Radar observation of airborne objects includes: surveillance of a defined area of space, searching for and detecting various objects, determining their coordinates and radial velocity, and obtaining non-coordinate information about them.

Radar complex (RC): Radar equipment comprising one or more radars and communication and RI processing facilities which are functionally linked and shared for radar observation.

Radar scanning: The process of radar observation of targets in a defined coverage area, which is characterised by the distribution of emitted and received energy. The nature of the energy distribution is determined by the shape of the antenna directivity pattern, as well as the law of motion of antenna.

Radar signal: A signal in the form of radio waves used in the radar observation process to obtain information about radar targets.

Tracking: The process of following a moving object or a variable input quantity. In radar, target tracking in angle, range, or Doppler frequency is accomplished by keeping a beam or angle cursor on the target angle, a range mark or gate on the delayed echo, or a narrowband filter on the signal frequency, respectively (according to IEEE Std 686).

Note - This process may be carried out manually or automatically for one or more of the above input quantities. The beam, range gate, or filter can be either centered on the input quantity or can be coarsely placed, with interpolation measurements providing accurate data to a computer that does the fine tracking. *See also:* automatic tracking; tracking radar; track-while-scan.

Elevation angle: In radar, the angle between the line-of-sight in the direction of interest and a horizontal reference plane, measured upwards (according to IEEE Std 686).

Radar equation: a mathematical expression that relates the range of a radar at which specific performance is obtained to the parameters characterizing the radar, target, and environment. Synonym: radar range equation; range equation (according to IEEE Std 686).

Note: The parameters in the radar equation can include the transmitter power, antenna gain and effective area, frequency, radar cross section of the target, range to the target, receiver noise figure, signal-to-noise ratio required for detection, losses in the radar system, and the effects of the propagation path.

1. Purpose and Objectives of the Flight Test of Utes-T ARRC

The DSB's report "Crash of Malaysia Airlines Boeing 777-200, 9M MRD, flight MH17" claims that the crash of Boeing 777 was caused by the impact of "a 9H314M war head carried by a 9M38-series missile"¹ and concludes that the probable location of the missile launch is "eastern Ukraine"², indicating the possible launch area of about 320 km², as calculated by experts of the "Netherlands Aerospace Centre" (NLR)³.

The experts of Almaz-Antey Air-Defence Corporation ("Almaz-Antey") claim that if the 9M38 missile was launched from the area mentioned in DSB's report, there would be a high probability that the missile would have been detected by Utes-T ARRC deployed in the village of Ust-Donetsk in Rostov Region of the Russian Federation. However, a careful review of the documented primary radar information from Utes-T ARRC shows that the missile was not detected by the locator. This fact, along with an analysis of the performance features of: (i) the Buk surface-to-air missile system, (ii) 9M38 surface-to-air guided missiles, (iii) damage to the outer skin, internal equipment and load-bearing structure of the Boeing 777, and (iv) the results of experiments and special research conducted by Almaz-Antey led to the following conclusions:

- If the crash of the Boeing 777 was caused by a 9M38 missile, then this could only have happened in case the missile was on a "collision course" (the most likely angle of the missile's approach to the aircraft in the horizontal plane could be 72^{+2}_{-10} deg.;

- The launch area could be the area shown in yellow in Figure 1 and shown in the presentation⁴ at Almaz-Antey Air-Defence Corporation's press conference held in October 2015 to present the results of the full-scale experiment;

- When a 9M38 missile was launched from the area indicated by the Corporation's experts, Utes-T ARRC was not capable of detecting it;

- If a 9M38-type missile was launched from the area specified in the DSB's report, it would have had a high probability of being detected by Utes-T ARRC.

¹ The name of the weapon from the DSB's Report.

² Final Report. 11. Missile flight parts, p.256.

³ Final Report. Visualisation of NLR fly out simulation result. Figure 62, p.144.

⁴ "Results of a Field Experiment to Evaluate the Causes of the Crash of MH17", October 2015.

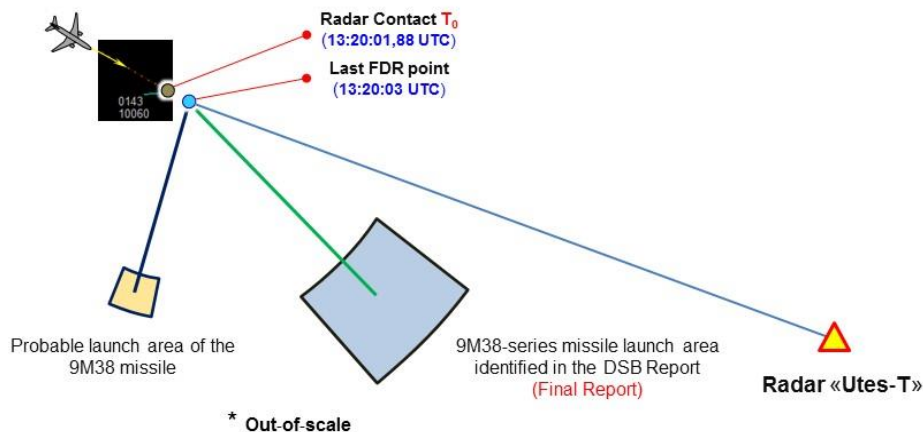


Figure 1 - Presumed missile launch areas

In order to confirm the conclusions drawn by experts of Almaz-Antey, a flight test of Utes-T ARRC was conducted.

The purpose of the flight test of Utes-T ARRC was to assess the spatial characteristics of Utes-T ARRC's primary surveillance radar (PSR) and its ability to detect airborne objects whose flight and reflection characteristics are similar to those of a 9M38-series missile.

The objectives of the flight test were:

1. Defining more precisely the acquisition radar range of Utes-T ARRC's PSR for airborne objects with radar visibility corresponding to a 9M38-type missile.
2. Determining the capability of Utes-T ARRC's PSR to detect and track airborne objects:
 - flying at supersonic speeds, including in the acceleration and deceleration areas;
 - suddenly appearing from below the radio horizon and moving along trajectories consistent with the hypotheses under consideration concerning the 9M38 missile intercept flight.

2. Conditions and procedures for conducting the flight test

The 9M38 missile detection capabilities of Utes-T ARRC's PSR was determined in two phases.

In the first phase, the potential capabilities were determined using known analytical relationships based on the PSR characteristics set forth in Utes-T ARRC operational documentation.

In the second phase, information on detection of real airborne objects manoeuvring under different conditions was gathered, and the PSR detection area diagram for 9M38-type objects was built.

The flight test was conducted in the airspace of the Russian Federation symmetrically in relation to the phase centre of Utes-T ARRC's PSR. The test diagram is shown in Figure 4.

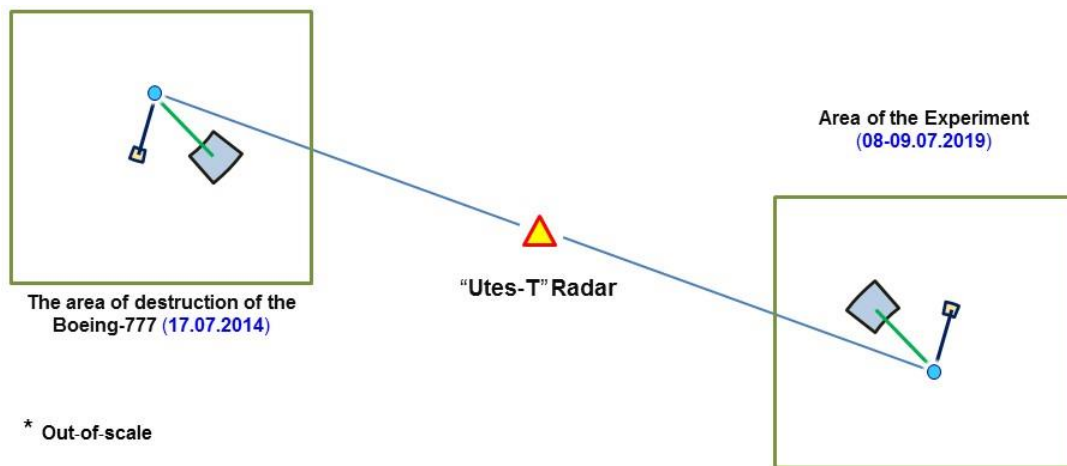


Figure 2 - Flight test diagram

During the test, all events were simulated under maximally similar initial conditions as to relative position of the radar and the reference airborne objects.

Utes-T ARRC operated in a routine automatic mode. The equipment operated in a routine mode and the operators did not interfere with the operation of the ARRC during the tests⁵.

In the test area (reference area), Utes-T ARRC's primary radar, which operated in an automatic mode, was detecting airborne objects in MTS mode. This is evidenced by the forms in respect of the aircraft which were travelling in international air corridors and the reference airborne objects.

⁵ Audio and video recording of the tests was carried out.

The weather conditions at the time of the test were equivalent to the actual weather conditions in the area of the Boeing 777 crash (Figure 4), which is also evidenced by weather radar data at Millerovo position (Figure 5).



Figure 3 - Actual weather conditions at the time of the test



Figure 4 - Weather radar data (Millerovo position)

MiG-29 and MiG-31 aircraft, as well as Orlan-10 UAV took part in the flight test of Utes-T ARRC.

The RCS of MiG-29 aircraft was about 5 m². Orlan-10 UAV RCS data obtained by means of statistical processing of the back reflection diagrams measured by the reference radar are shown in Table 1.

Table 1 - RCS of Orlan-10 UAV

Location angle sector*	$0^{\circ}\pm 45^{\circ}$	$90^{\circ}\pm 45^{\circ}$	$180^{\circ}\pm 45^{\circ}$
RCS value for level 0.5 ($\sigma_{0,5}$), m ²	0.23	0.26	0.13

* - 0° angle corresponds to location from the nose; 90° angle corresponds to location from the side; and 180° angle corresponds to location from the tail of the unit in the course plane (horizontal plane).

The test flight around the radar position was conducted over two days, 08 July 2019 and 09 July 2019, using the single programme and methodology.

At the boundaries of the area of ARRC detection by reference airborne objects (MiG-29), the test flight was performed at ranges of 280 to 380 km and altitudes of 7,000 to 12,600 m, which corresponds to the elevation position range of 0.3 to 1.0 degrees relative to the radar position.

The test flight was performed both by approaching and moving away from the ARRC position. When approaching the ARRC near the far edge of the detection area, the reference airborne objects flew with their transponders turned off.

The test plan included special reference trajectories of two types. The first type was a high-speed supersonic segment with preliminary acceleration, supersonic manoeuvring and subsequent deceleration. During the acceleration and manoeuvring and throughout the reference high-speed segment and deceleration segment, the reference targets (MiG-31) were flying with the transponder off.

The second type of reference trajectories is the simulation of a missile flight according to the versions of the hypothesis in question.

Before the flight along the special trajectories of the second type, the reference targets (MiG-29s) also switched off their transponders and descended below the radio horizon. When below the radio horizon, they manoeuvred and approached the point of origin of the special reference trajectory.

The reference targets then flew a trajectory consistent with the hypotheses under consideration: "in an opposite direction" and "on a collision course".

Test results were recorded using ARRC initial log files, recordings of parametric recorders, GPS sensors, and audio, photo and video equipment mounted on ARRC, reference airborne objects and other objects.

3. Brief Description of the Test Object

The object of the tests was Utes-T ARRC's PSR (serial number 208020) located at the Ust-Donetsk radar position at the Rostov Regional Centre of the UATMS of the Russian Federation (Figure 5).



Figure 5 - Utes-T ARRC in Ust-Donetsk village, Rostov Region, Russian Federation

Utes-T ARRC is used for air traffic control. Certificate of FAVT-RTOP-005 type issued for Utes-T ARRC by the Federal Air Transport Agency of the Russian Federation on 17 July 2018 confirms that Utes-T ARRC is a high-performance radar complex which meets the requirements of ICAO and Eurocontrol.

The operating area of the PSR at zero takeoff angle for aircraft with the RCS equal to 5 m² under probability of correct detection of at least 0.8 and probability of false alarms based on the receiver's own noise of no more than 10⁻⁶ is as follows:

- minimum elevation angle: not more than 0.5 deg.;
- maximum elevation angle: at least 45 deg.;

- maximum detection range: at least 360 km;
- maximum detection altitude: at least 20 km.

The threshold signal-to-noise ratio in terms of power for defined probabilities of correct detection (P_d) and false alarm (P_{fa}) is as follows:

$$q_0 = \frac{\ln P_{\text{ЛТ}}}{\ln P_0} - 1 \approx 60,9 \approx 17,85 \text{ дБ} \tag{1}$$

* $P_{\text{ЛТ}} = P_{fa}$
 $P_0 = P_d$
 дБ = dB (translator's note)

Using the above data, it is possible to determine from the radar equation the RCS potential (P_{RCS}), which must be at least

$$\Pi_{\text{ПОРЛ}} \geq \frac{q_0 \cdot D_{\text{макс}}^4}{\sigma_0} = \frac{60,9 \cdot (360000)^4}{5} = 2 \cdot 10^{23} \tag{2}$$

where $D_{\text{макс}}$ (D_{max}) is the maximum detection range of the PSR which is equal to 360,000 m;

σ_0 - target RCS equal to 5 m².

* $\Pi_{\text{ПОРЛ}} = P_{\text{RCS}}$ (translator's note)

The vertical section of the PSR detection area for a target with the RCS equal to 1 m² under detection probability of at least 0.8 and false-alarm probability of no more than 10⁻⁶ is shown in Figure 3.

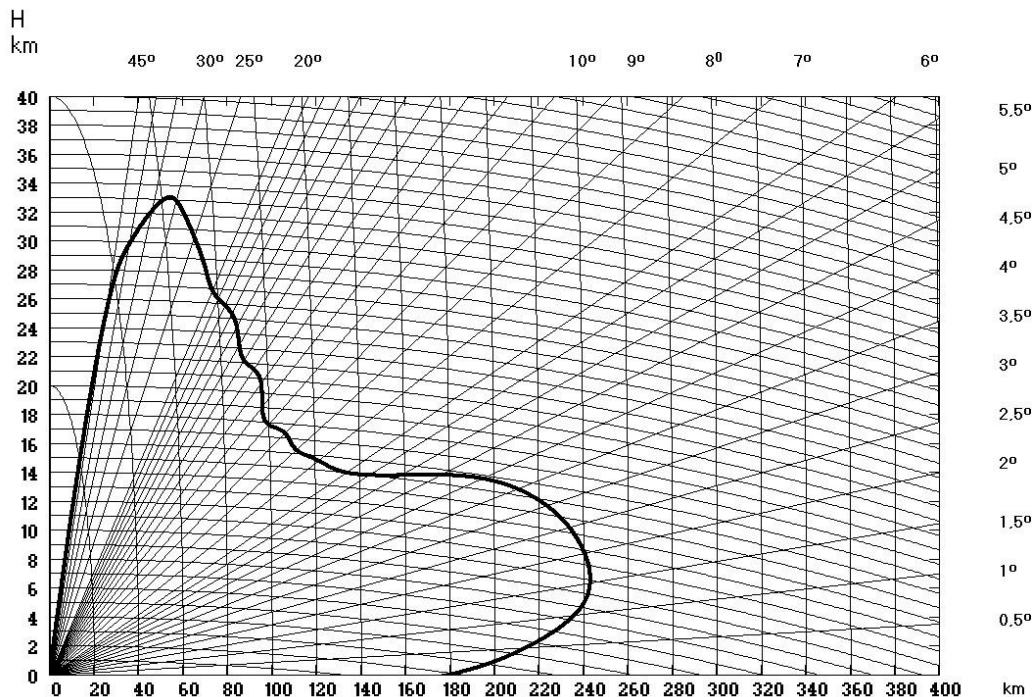


Figure 6 - Vertical section of Utes-T ARRC's PSR detection area for a target with RCS equal to 1 m^2 under detection probability of 0.8 and false-alarm probability of at least 10^{-6}

The PSR operates in the L-band (1215 - 1350 MHz).

The radar complex has high reliability and features automatic back-up, remote control, monitoring and diagnostics, and unattended operation, and is built on solid-state technology featuring state-of-the-art signal and information processing methods.

The signal and information processing system provides a dynamic range of digitally processed signals of at least 70 dB and primary and secondary processing of radar information. The complex ensures documentation and reproduction of all processed radar information.

The MTS algorithm is implemented in a special signal processor and is based on the principle of adaptive grid Doppler filtering. The MTS provides separation of reflected signals from aircraft moving with radial velocities of 40 to 500 m/s against the background of noise created by stationary objects and objects moving at a speed of less than 40 m/s (reflections from ground and water surfaces, moisture targets, etc.). In the area where the radial velocities are from 500 to 1,000 m/s, there are no long-term dips in the transmission ratio of more than 2-5 dB in depth (Figure 7).

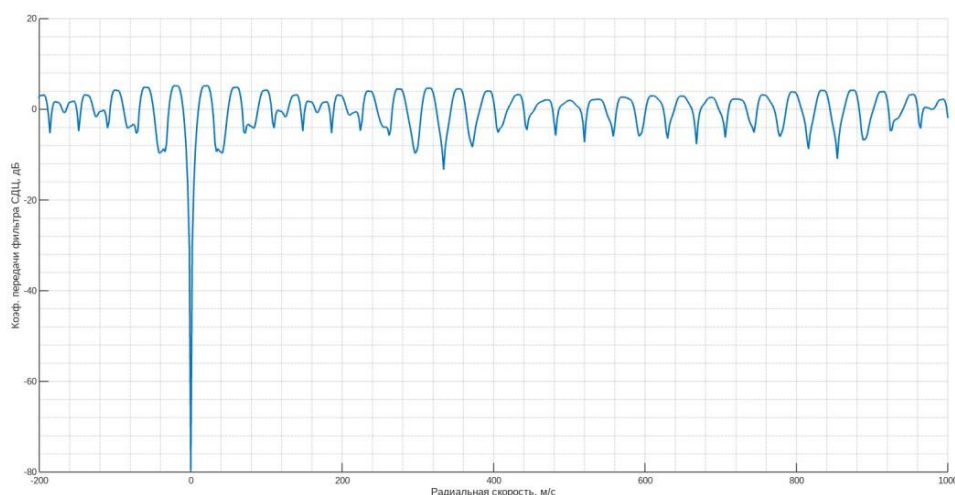


Figure 7 - Velocity performance of Utes-T ARRC's MTS system

- * MTS filter transmission ratio, dB
- Radial velocity, m/s

In order to eliminate "blind" velocities, wobbling of the repetition intervals of sounding signals is used. The use of signals with a non-equidistant pulse sequence makes it possible to create a passive noise rejection zone with no significant dips in the non-zero velocity zone. The passive interference suppression ratio is at least 50 dB.

4. Estimate of missile detection capability

The RCS values for a 9M38-type missile obtained from different observation angles when taking measurements at the reference radar complex in the L-band with horizontal polarization of the signal are shown in Table 2.

The radar performance was determined using a 9M38RM missile equipped with a standard radiotransparent radome and mounted target seeker device. The radar visibility characteristics of the 9M38RM unit were obtained by means of statistical processing of the measured back scattering diagrams.

Table 2 - RCS of 9M38 type-missile

Location angle sector*	$0^{\circ}\pm 10^{\circ}$	$90^{\circ}\pm 10^{\circ}$	$90^{\circ}\pm 30^{\circ}$	$165^{\circ}\pm 15^{\circ}$	$180^{\circ}\pm 10^{\circ}$
RCS value for level of 0.5 ($\sigma_{0,5}$), m^2	0,3	3,3	0,9	0,85	2,3

* - 0° angle corresponds to location from the nose; 90° angle corresponds to location from the side; 180° angle corresponds to location from the tail of the unit in the course plane (horizontal plane).

According to the transcripts of the Boeing 777's parametric recorders, the crash of flight MH17 occurred at 13.20:03 UTC.

The last measurement of Boeing 777's position was taken by Utes-T ARRC's PSR at $T_0 = 13.20:01.88$ UTC (Figure). Thus, about 1.12 seconds elapsed between the last measurement and the crash.

According to the DSB's report, the Boeing 777 airliner did not perform any manoeuvres three minutes before the Last FDR point, and its altitude, course and speed were constant. The experts of Almaz-Antey conducted a simulation of the 9M38-type missile's acquisition of a non-manoeuving aerodynamic target for two hypotheses:

- "in an opposite direction" launch
- "on a collision course" launch

The 9M38 missile flight trajectories for the two hypotheses are shown in Figure 9 (time T_0 corresponds to the time of the last measurement in relation to the Boeing 777, while time T_{-10} and T_{-20} correspond to 10 s and 20 s before the last measurement, respectively). One can see from the figure that given the time of the missile's flight to the Last FDR point, the missile should have entered the ARRC's coverage area at least twice in case of a flight "on a collision course" and should have entered that area three times in case of a flight in "an opposite direction".

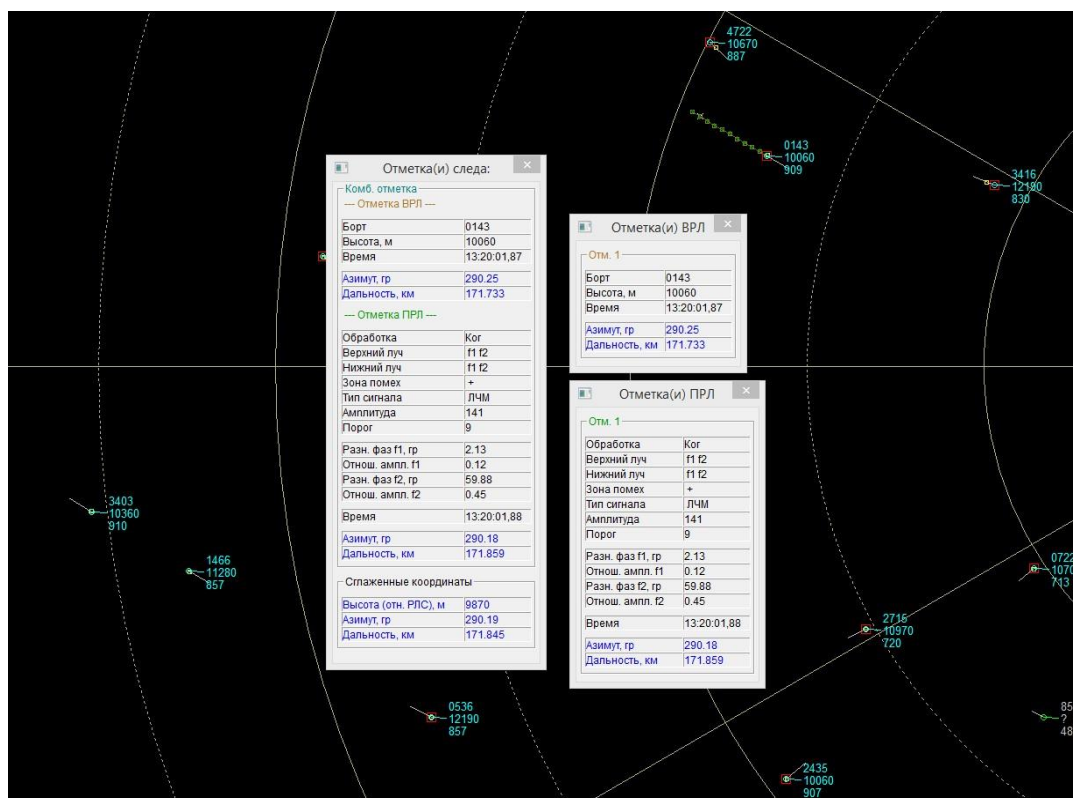


Figure 8 - Last measurement taken
by Utes-T ARRC in relation to Boeing 777 aircraft

*

Trail mark(s)

Combined mark - Secondary radar mark	
Board	0143
Altitude, m	10060
Time	13:20:01,87
Azimuth, deg..	290.25
Distance, km	171.733
- Primary radar mark	
Processing	Coherent
Upper beam	f1 f2

Lower beam	f1 f2
Interference area	+
Signal type	Linear frequency modulation
Amplitude	141
Threshold	9
Phase difference f1, deg..	2.13
Amplitude ratio f1	0.12
Phase difference f2, deg..	59.88
Amplitude ratio f2	0.45
Time	13:20:01,88
Azimuth, deg..	290.18
Distance, km	171.859
Smoothed coordinates	
Altitude (relative to radar), m	9870
Azimuth, deg..	290.19
Distance, km	171.845

Secondary radar mark(s)

Mark 1	
Board	0143
Altitude, m	10060
Time	13:20:01,87
Azimuth, deg..	290.25
Distance, km	171.733

Primary radar mark(s)

Mark 1	
Processing	Coherent
Upper beam	f1 f2
Lower beam	f1 f2
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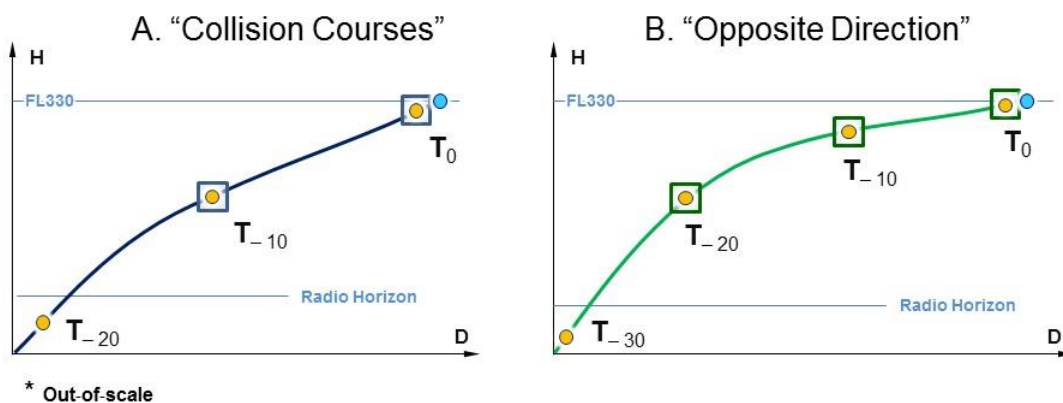


Figure 9 - Possible trajectories of 9M38 missile flight
A - "collision course"; B - "opposite direction"

The maximum distance of the missile from Utes-T ARRC at the time T_0 was about 170 km.

The maximum detection range for a radar target can be determined from the known characteristics of the radar and the RCS of the target (σ_{target}):

$$D_{\text{макс}} = \sqrt[4]{\Pi_{\text{ПОРЛ}} \cdot \frac{\sigma_{\text{ц}}}{q_0}} \quad (3)$$

* $D_{\text{макс}} = D_{\text{max}}$
 $\Pi_{\text{ПОРЛ}} = P_{\text{RCS}}$
 $\sigma_{\text{ц}} = \sigma_{\text{target}}$

The maximum detection range for a 9M38 type missile (depending on the angle of its observation) for correct detection probability of 0.8 and false alarm probability of 10^{-6} is shown in Table 3.

Table 3 - Maximum detection range for 9M38 type missile

Location angle sector*	$0^\circ \pm 10^\circ$	$90^\circ \pm 10^\circ$	$90^\circ \pm 30^\circ$	$165^\circ \pm 15^\circ$	$180^\circ \pm 10^\circ$

Detection range, km	177	323	233	230	295
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* - 0° angle corresponds to location from the nose; 90° angle corresponds to location from the side; and 180° angle corresponds to location from the tail of the unit in the course plane (horizontal plane).

It can be seen from the table that at any angle of observation, the maximum detection range for a 9M38 missile exceeds its maximum distance from the radar.

It is also possible to determine the signal-to-noise ratio and the probability of detecting the missile at times of its presumed location. The fact that the signal-to-noise ratio exceeds the threshold value also confirms the likelihood of its detection.

Given the known potential of Utes-T ARRC's PSR, the signal-to-noise ratio for the targets can be calculated using the following formula

$$q = \Pi_{\text{ПОРЛ}} \cdot \frac{\sigma_{\text{ц}}}{D_{\text{ц}}^4}, \tag{4}$$

where $\sigma_{\text{ц}}$ is the target's RCS;

$D_{\text{ц}}$ (D_{target}) - slant range equal to the distance from the radar to the target.

With fixed false alarm value, the probability of correct detection will be

$$P_0 = \exp\left(\frac{\ln P_{\text{ЛТ}}}{q + 1}\right) \tag{5}$$

* $P_{\text{ЛТ}} = P_{\text{fa}}$

In addition to the sufficient detection range, it is also important that the conditions for observing the missile correspond to the capabilities of the PSR in terms of elevation angles and radial velocity at the times of the missile location.

The estimated values of trajectory parameters and conditions for observation of a 9M38-type missile by Utes-T ARRC for the launch in an opposite direction and on a collision course at points in time T_{-20} , T_{-10} and T_0 are shown in Table 4.

Table 4 - Conditions for missile observation by Utes-T ARRC

Characteristic	Missile's course					
	Collision course			Opposite direction		
	T_{-20}	T_{-10}	0	T_{-20}	T_{-10}	0

Ground speed, m/s	680-740	975-990	750-770	930-970	770-850	635-670
Radial speed, m/s	- (9-11)	12-15	-(17-19)	790-820	730-810	606-630
Elevation angle, degrees	-(0.45-0.35)	1.2-1.4	2.4-2.6	1.6-2.1	2.4-2.75	2.6-2.75
Slant range (not more than), km	-	170	170	150	160	170
Observation angle, degrees	-	90°±30°	90°±30°	165°±15°	165°±15°	165°±15°
RCS, m ²	-	0.9	0.9	0.85	0.85	0.85
Signal-to-noise ratio	-	215	215	336	275	208
Probability of detection	-	-	-	0.96	0.95	0.94

It is seen from the table that a 9M38-type missile fails to enter Utes-T ARRC's coverage area in terms of elevation angles in one instance only: when it is below the radio horizon line (on a "collision course" at $T-20$).

Utes-T ARRC's PSR has sufficient capability to detect a 9M38-type missile in flight both in an opposite direction and on a collision course. The expected signal-to-noise ratio was significantly above the threshold in all scan periods. However, a 9M38-type missile could not be detected by Utes-T ARRC's PSR in case of a flight on a "collision course" because of excessively low radial velocity. The minimum radial velocity at which the radar can detect moving targets when the MTS equipment is on is 30(50) m/s. In contrast, the probability of detecting a 9M38-type missile flying to intercept a target in an "opposite direction" is high in each of the three scan periods. Further, the probability of detecting the missile in at least one of the three scan periods is close to 1 and is greater than 0.99.

The results of the flight test should confirm or refute the conclusions drawn from the analytical calculations.

5. Main results of the flight test

When flying around Utes-T ARRC's PSR in the far periphery of the detection area, the reference airborne objects both approached the position of the ARRC and moved away from it.

An example of detecting a reference airborne object, which was detected when it was approaching the radar position, is shown in Figure 10.

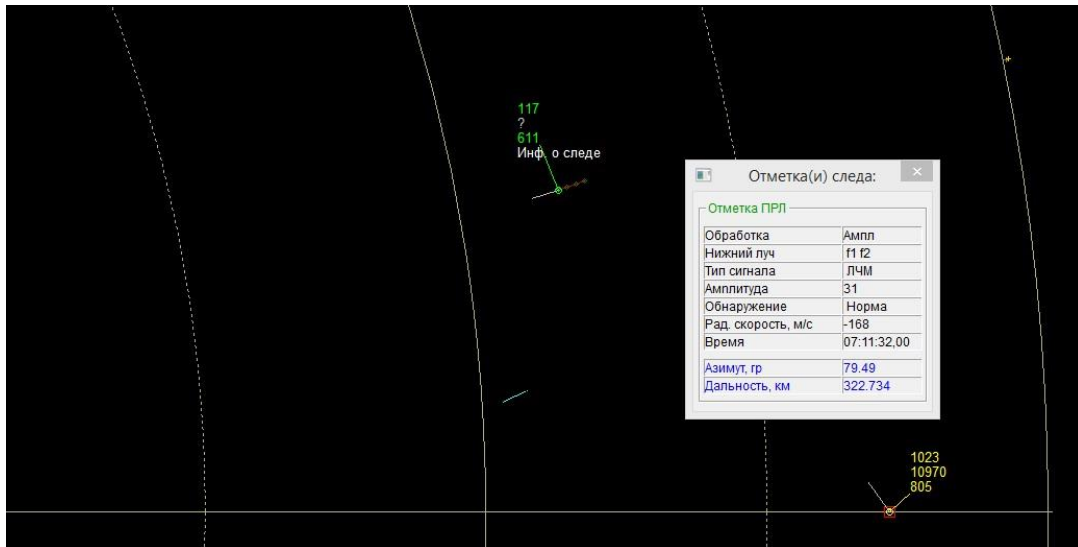


Figure 10 - Detection of reference airborne object No. 117 by the PSR at a distance of 322.7 km

* Trail mark(s)

- Primary radar mark	
Processing	Ampl.
Lower beam	f1 f2
Signal type	Linear frequency modulation
Amplitude	31
Detection	Standard
Radial velocity, m/s	-168
Time	07:11:32,00
Azimuth, deg..	79.49
Distance, km	322.734

The results of the test flight along the far edge of the detection area are shown in Table 5.

Table 5 - Range of reference targets detection

	Range, km	Radial speed, m/s
Approaching the ARRC	309,5...354,4	-245...-168
Moving away from the ARRC	304,3...360,9	172...256

According to the results of the flight around Utes-T ARRC, the detection range for an airborne object the RCS of which corresponds to that of a 9M38 missile (recalculated using the formula for free-space RCS, taking into account equal angular positions) should be at least 200-218 km. The results of confirmation of the far edge of the detection area for the RCS equal to 0.85 m^2 and 1.0 m^2 are shown in Figure 11.

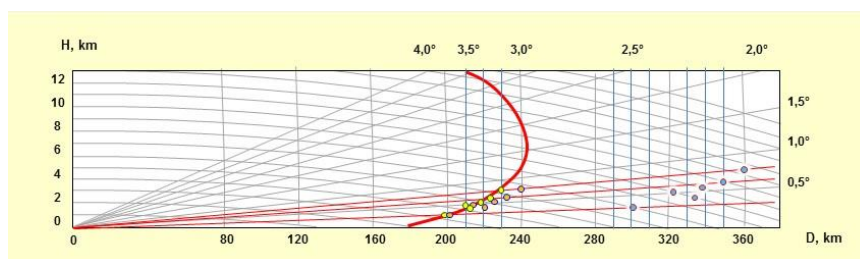


Figure 11 - Confirmation of estimated area of detection of a 9M38-type missile at altitudes above 3,500 m based on the results of reference targets' test flight

The primary radar's capability to detect small targets is additionally confirmed by the fact that at the time of the events that occurred on 17.07.2014 an Orlan-10-type UAV, the RCS of which is 3-5 times smaller than that of a BUK missile, was detected and tracked by the ARRC. The radar mark and the airborne object ("Orlan-10") form are shown in Figure 12.

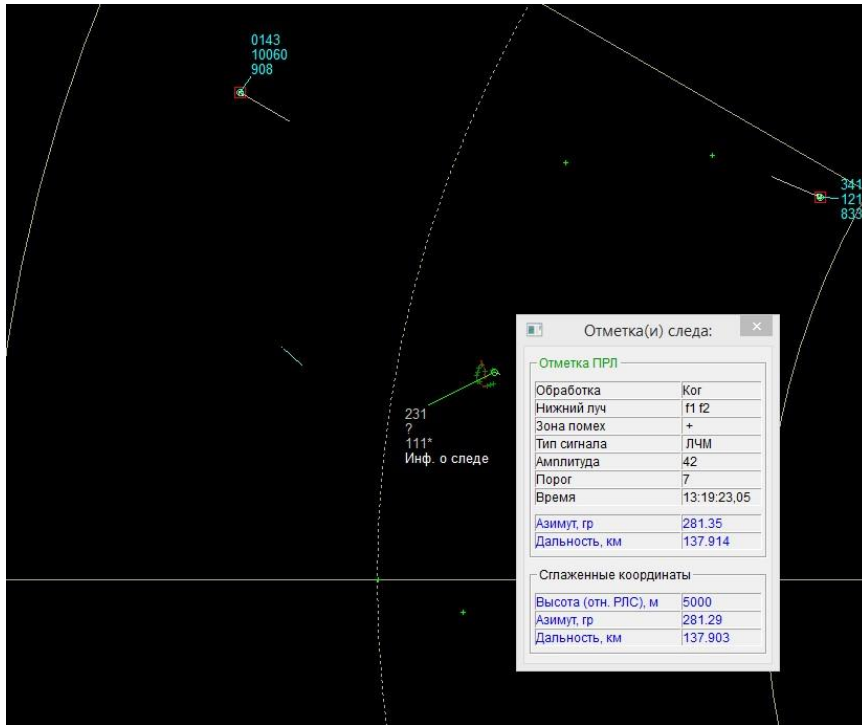


Figure 12 - Radar mark and form in respect of airborne object No. 231 (Orlan-10 UAV) at a distance of 137.9 km from Ute-T transponder. Time: 13:19:23.05 UTC (registration file "14-07-17_fragment.kt")

* Trail mark(s)

- Primary radar mark	
Processing	Coherent
Lower beam	f1 f2
Interference area	+
Signal type	Linear frequency modulation
Amplitude	42
Threshold	7
Time	13:19:23,05
Azimuth, deg...	281.35
Distance, km	137.914
Smoothed coordinates	
Altitude (relative to radar), m	5000
Azimuth, deg.	281.29
Distance, km	137.903

Thus, a missile flying at altitudes above the radio horizon can be detected by the primary radar at distances greater than 200 km.

Confirmation of the speed characteristics of the primary radar.

While circling Utes-T ARRC's primary radar, a reference supersonic airborne object in the area of the high-speed segment was manoeuvring and accelerating to supersonic speed:

true speed, max M= 2.04...2.1
 indicated speed, max M= 1.9...2.0

The airborne object was steadily observed in the entire reference segment of the trajectory. The radial velocity V_R measured by the ARRC ranged from 508 to 567 m/s (Figures 13 and 14).

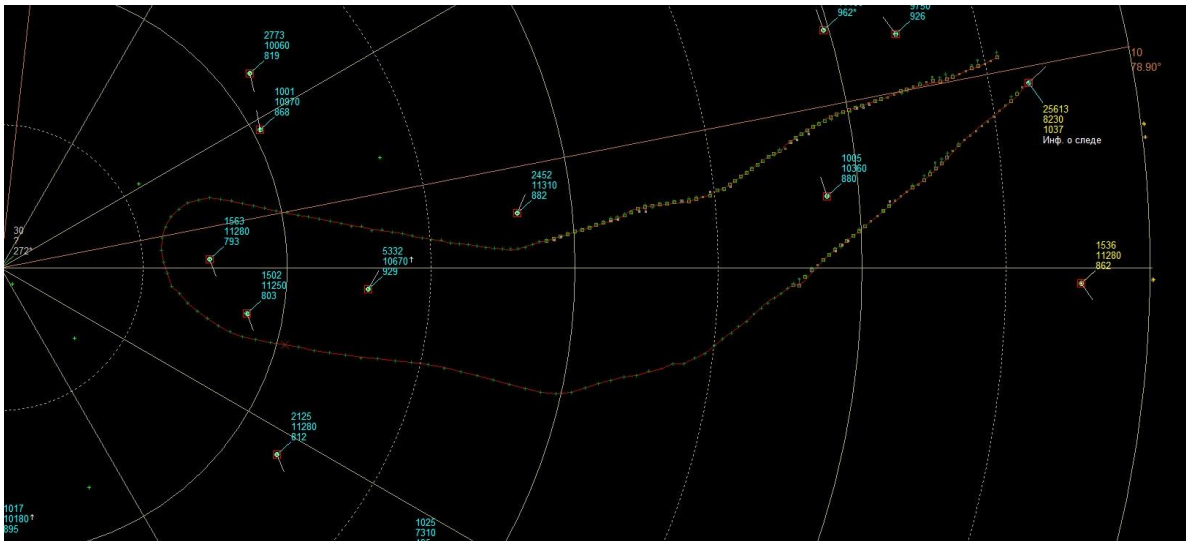


Figure 13 - Supersonic airborne object flight path including the reference segment of the trajectory

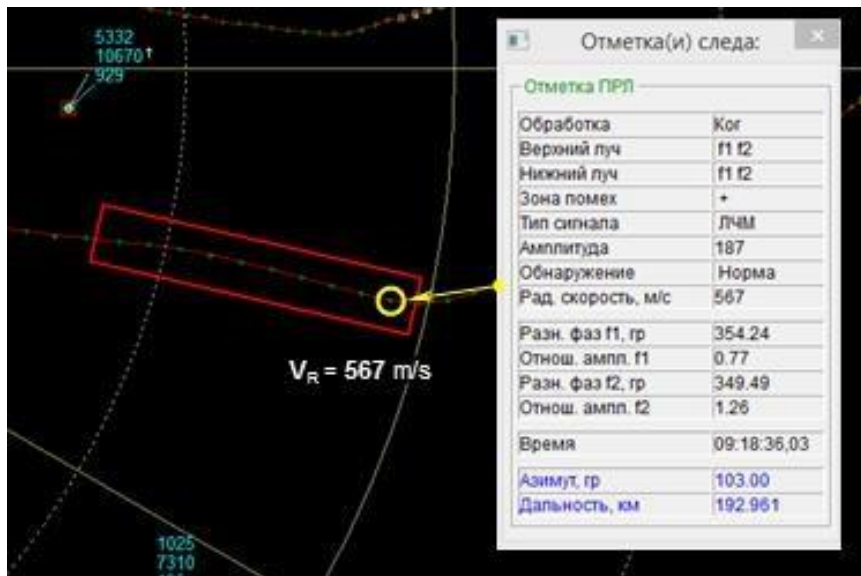


Figure 14 - Reference supersonic segment of the trajectory. True velocity of airborne object M= 2.04...2.1. Radial velocity measured by the ARRC is 567 m/s (time 09:18:36.03 UTC 09.07.2019)

* Trail mark(s)

- Primary radar mark	
Processing	Coherent
Upper beam	f1 f2
Lower beam	f1 f2
Interference area	+
Signal type	Linear frequency modulation
Amplitude	187
Detection	Standard
Radial velocity, m/s	567
Phase difference f1, deg..	354.24
Amplitude ratio f1	0.77
Phase difference f2, deg..	349.49
Amplitude ratio f2	1.26
Time	09:18:36,03
Azimuth, deg..	103.00
Distance, km	192.961

The capability of Utes-T ARRC to detect supersonic airborne objects is also confirmed by air situation data of 2001. This air situation data obtained by Utes radar at Gelendzhik position (earlier generation radar, which is a predecessor to Utes-T ARRC) in October 2001 was used in practice to determine the cause of Tu-154M RA85693 crash over the Black Sea.

At that time, the primary radar detected an unidentified airborne object moving in the direction of the Tu-154M aircraft's flight path at a speed of about 1,000 m/s. Subsequently, the recorded marks were identified as S-200 SAM missile that caused the crash⁶.

Figure 15 shows a fragment of "Findings of Damage Research on Fragments of Tupolev 154M RA85693 Crashed on October 4, 2001 over Black Sea" with the flight path of the Tu-154M in the last segment.

⁶ Final Report ACCID Tu-154 RA-85693 (EN), p.16-17.

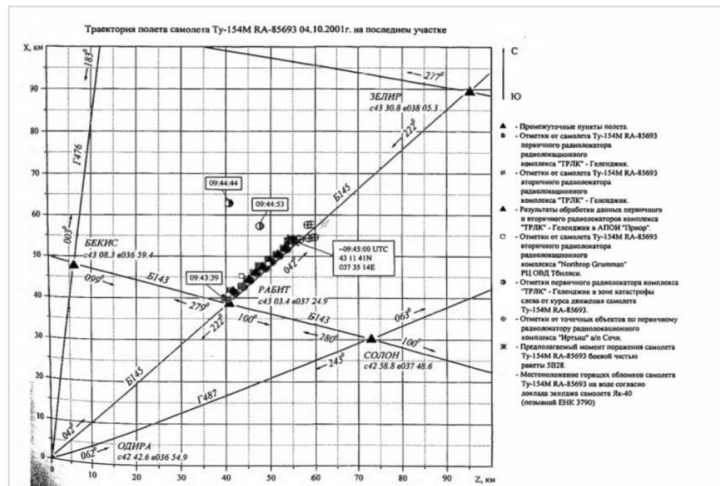


Figure 15 – The last segment of the flight path of Tu-154M RA-85693 on 04.10.2001. There are marks from an airborne object detected by the ARRC at Gelendzhik position to the left of the aircraft's path.

*

- Waypoints
- Marks from Tu-154M RA-85693 by the primary radar of the radar complex in Gelendzhik
- Marks from Tu-154M RA-85693 by the secondary radar of the radar complex in Gelendzhik
- Results of data processing by APOI Prior in relation to data from the primary and the secondary radars of the radar complex in Gelendzhik
- Marks from Tu-154M RA-85693 by the secondary radar of Northrop Grumman radar complex of RTs OVD Tbilisi
- Marks by the primary radar of the radar complex in Gelendzhik in the crash area, to the left of Tu-154M RA-85693 aircraft's course
- Marks from point-like objects according to the primary radar of Irtysh radar complex in Sochi
- Presumed moment when Tu-154M RA-85693 aircraft was hit by the war head of 5B28 missile.
- Location of burning debris of Tu-154M RA-85693 aircraft in water according to the report of Yak-40's crew (call sign EHK 3790)

Thus, a missile flying at a supersonic speed corresponding to the radial speed of up to 1,000 m/s can be detected by the primary radar within the detection area.

When testing the "opposite direction" hypothesis, the marks from the reference target were detected immediately after they crossed the radio horizon. The primary radar's marks with the derived data are shown in Figures 16 and 17.

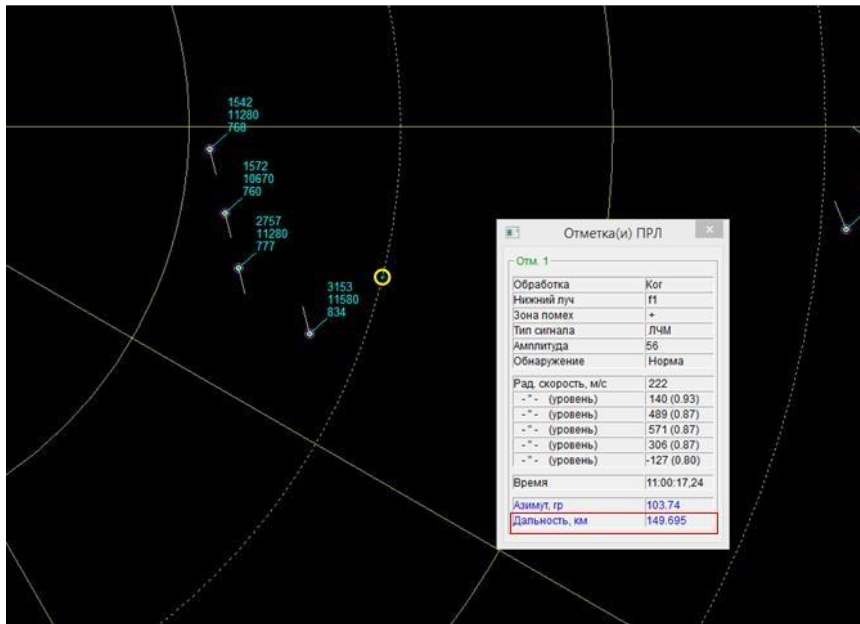


Figure 16 - First mark from the reference airborne object after it went beyond the radio horizon. The distance is 149.7 km

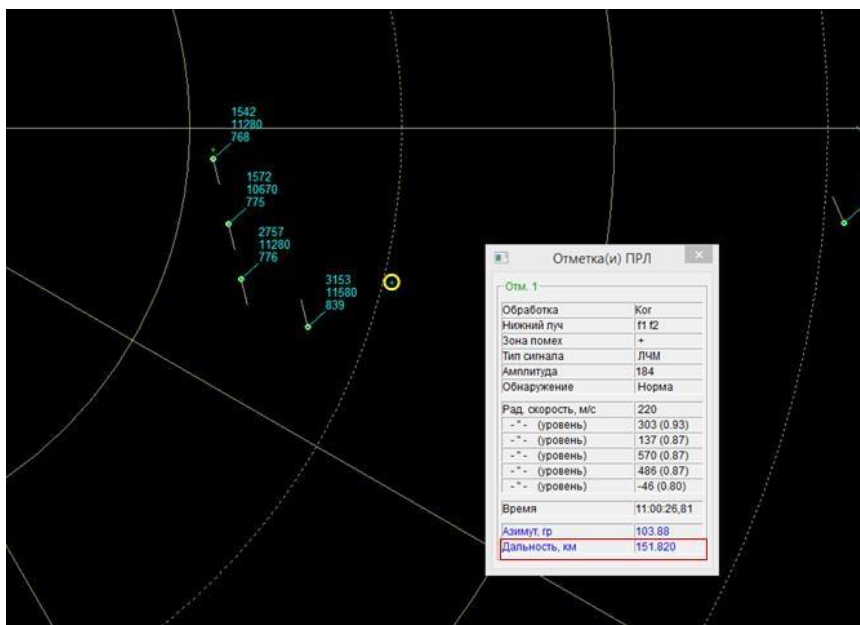


Figure 17 - Second mark from the reference airborne object after it went beyond the radio horizon. The distance is 151.8 km

- Primary radar mark(s)	
Mark 1	
Processing	Coherent
Lower beam	f1
Interference area	+

Signal type	Linear frequency modulation
Amplitude	56
Detection	Standard
Radial speed, m/s	222
- * - (level)	140 (0.93)
- * - (level)	489 (0.87)
- * - (level)	571 (0.87)
- * - (level)	306 (0.87)
- * - (level)	-127 (0.80)
Time	11:00:17,24
Azimuth, deg..	103.74
Distance, km	149.695

- Primary radar mark(s)	
Mark 1	
Processing	Coherent
Lower beam	f1
Interference area	+
Signal type	Linear frequency modulation
Amplitude	184
Detection	Standard
Radial speed, m/s	220
- * - (level)	303 (0.93)
- * - (level)	137 (0.87)
- * - (level)	570 (0.87)
- * - (level)	486 (0.87)
- * - (level)	-46 (0.80)
Time	11:00:26,81
Azimuth, deg..	103.88
Distance, km	151.820

The object simulating the missile flight "in an opposite direction" was detected immediately after it went beyond the radio horizon (during the first scan period). Following that, the reference airborne object was tracked steadily throughout its flight in the reference segment of the trajectory (Figure 18) and until it exited the detection area at a distance of over 320 km.



Figure 18 – Airborne object No. 116 in "an opposite direction" trajectory.
The airborne object in the reference segment of the trajectory was observed steadily

- Trail mark(s)	
- Primary radar mark(s)	
Processing	Coherent
Lower beam	f1
Interference area	+
Signal type	Linear frequency modulation
Amplitude	56
Detection	Standard
Radial velocity, m/s	222
Time	11:00:17,24
Azimuth, deg..	103.74
Distance, km	149.695

- Trail mark(s)	
- Primary radar mark(s)	
Processing	Coherent
Upper beam	f1
Lower beam	f1
Interference area	+
Signal type	Linear frequency modulation
Amplitude	107

Detection	Standard
Radial velocity, m/s	167
Time	11:01:43,37
Azimuth, deg..	106.25
Distance, km	169.906

Information about this object was continuously displayed on the radar operator's screen and saved as air situation data in the primary registration file "19-07-09.kt", which is similar to the one given to the Dutch experts.

Thus, a missile that is in the space observed by the ARRC and is within the area of detection on the basis of the main parameters, such as radar visibility, position above the radio horizon in the antenna directivity pattern, exceeding the MTS threshold for radial speed, etc., can be detected by the primary radar of Utes-T ARRC without any hindrance.

It follows from an analysis of the results obtained⁷ that if a moving object with characteristics corresponding to a BUK missile and travelling at a speed of 500 to 1,000 m/s was in Utes-T ARRC's observation area, it would have been detected with more than 0.9 probability at a distance of 200 to 240 km.

The distance to aircraft #0143 (MH17) recorded by the ARRC at the time of radar contact T_0 (less than 1.2 seconds before the tragedy) was ~ 171.8 km.

The distance to the weapon moving "in an opposite direction" at the time of radar contact T_0 would be about 170 km, and in time periods T_{-10} and T_{-20} the distance would be significantly less than 170 km.

Thus, at the time of radar contacts T_0 , T_{-10} and T_{-20} the main parameters of the missile flight (radial velocity, position above the radio horizon in the lower lobe of the antenna directivity pattern) made it possible, if the launch hypothesis under consideration is true, to record steady marks of echoes from an object moving towards the aircraft at a speed of 620-970 m/s.

At the time of these "hypothetical" radar contacts, the main parameters of the missile flight (radar visibility; radial velocity; position over the radio horizon in the antenna directivity pattern, etc.) made it possible, in the case of the "opposite direction launch" hypothesis by DSB/JIT, to record steady marks of echoes from an object moving towards the aircraft with a probability of ~ 0.9 in each scan period.

⁷ The tests were conducted over two days on 08.07.2019 and 09.07.2019. The results obtained during the two phases are the same.

The probability of recording at least one mark during three consecutive scan periods exceeds 0.99.

Such marks would have been recorded in the primary registration file containing all primary air situation data. They would have been detected when playing back and reviewing the file "14-07-17.kt" which was previously handed over to the Dutch side.

When playing back the registration file "14-07-17.kt" of Utes-T ARRC for the period from 13:02 to 13:32 UTC 17.07.2014, one can see that no marks were recorded, which suggests the absence of an object moving in the observed area in the direction of the Boeing 777 from the side of Pervomaisky (Snezhnoye) settlement in Donetsk region of Ukraine.

5.8. The airborne object simulating the missile flight from the southern direction ("on a collision course") was not observed by the primary radar in any part of the reference segment of the flight path.

The first mark appeared only after the airborne object completed its flight along the reference trajectory (at an altitude of "10,360 m" and with the MTS radial velocity threshold being exceeded ("-36 m/s")).

The first mark by the primary radar with the derived data is shown in Figure 19.

The reference airborne object was then tracked steadily (Figures 20 and 21).

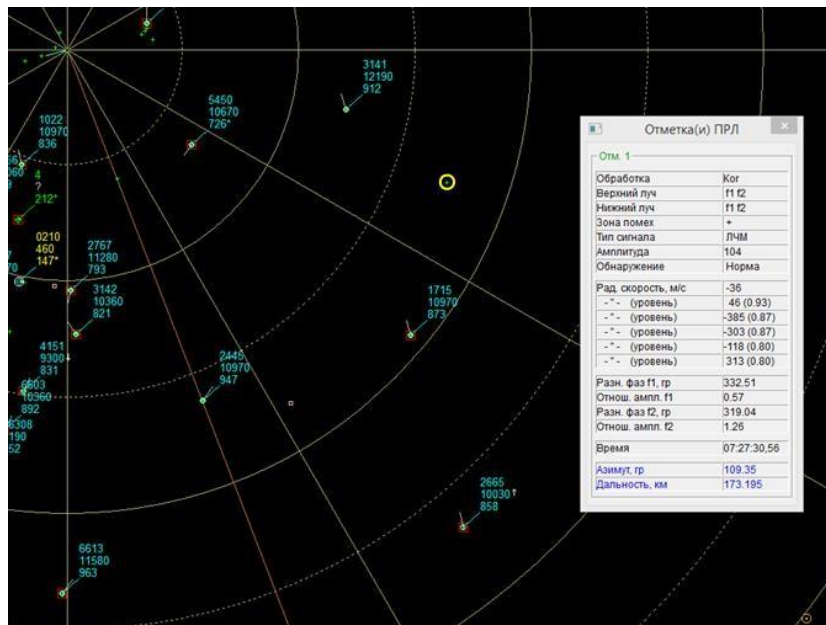


Figure 19 - First mark of the reference airborne object after completion of its flight along the special trajectory simulating the missile flight from the southern direction. The distance is 173.2 km

*

- Primary radar mark(s)	
Mark 1	
Processing	Coherent
Upper beam	f1f2
Lower beam	f1f2
Interference area	+
Signal type	Linear frequency modulation
Amplitude	104
Detection	Standard
Radial speed, m/s	-36
- * - (level)	46 (0.93)
- * - (level)	-385 (0.87)
- * - (level)	-303 (0.87)
- * - (level)	118 (0.80)
- * - (level)	-313 (0.80)
Phase difference f1, deg..	332.51
Amplitude ratio f1	0.57
Phase difference f2, deg..	319.04
Amplitude ratio f2	1.26
Time	07:27:30,56
Time	11:00:17,24
Azimuth, deg..	109.35
Distance, km	173.195

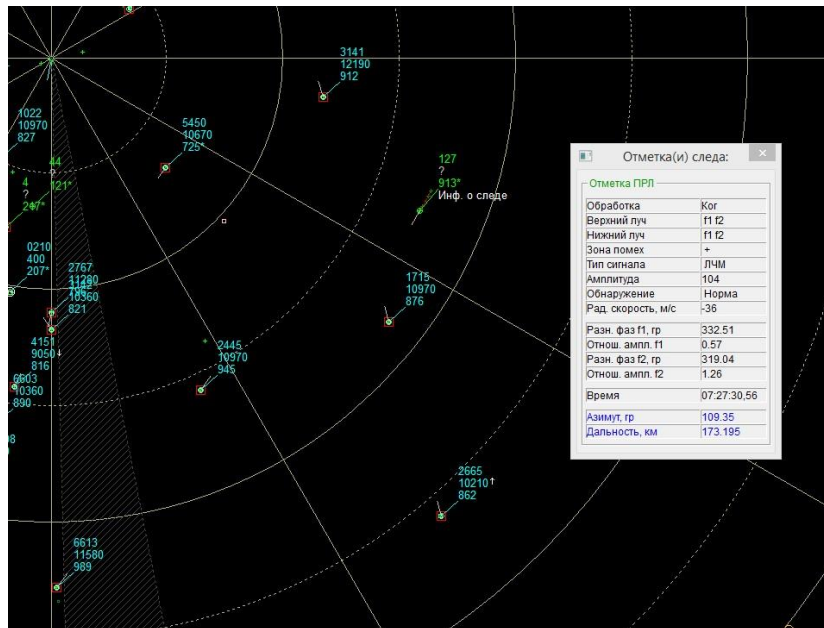


Figure 20 – Tracing of the reference airborne object

*

- Primary radar mark(s)	
Mark 1	
Processing	Coherent
Upper beam	f1 f2
Lower beam	f1 f2
Interference area	+
Signal type	Linear frequency modulation
Amplitude	104
Detection	Standard
Radial speed, m/s	-36
Phase difference f1, deg..	332.51
Amplitude ratio f1	0.57
Phase difference f2, deg..	319.04
Amplitude ratio f2	1.26
Time	07:27:30,56
Time	11:00:17,24
Azimuth, deg..	109.35
Distance, km	173.195

No information about this reference object flying along a special trajectory simulating the missile flight from the southern direction ("on a collision course") was displayed on the radar operator's screen or saved in the primary registration file "19-07-09.kt". The reference object was detected by the primary radar at 07:27:30,56 UTC at an altitude of 10,360 m only after completion of the trajectory flight, when the MTS radial velocity threshold of "-36 m/s" was exceeded.



Figure 21 – Tracking of the reference airborne object after completion of the flight along a special trajectory simulating the missile flight from the southern direction

Thus, a missile in the ARRC's observation area may fly undetected by the primary radar, if its radial velocity is below the MTS threshold (in this case below 30 m/s).

The analysis of primary radar data for 17.07.2014 showed that no objects moving towards the Boeing 777 "from the southern direction" ("on a collision course") were detected, when the registration file "14-0717.kt" was played back. According to the simulation results, the trajectory of the missile approaching the Boeing 777 "from the southern direction" ("on a collision course") has a characteristic feature: a low sign-variable radial velocity. The range of these velocities is -21 to 24 m/s.

In this case, taking into account the missile's trajectory and flight time and the coherent operation mode of Utes-T ARRC in the crash area due to weather conditions, the probability of detecting marks with low radial velocity is low. This was confirmed experimentally: the reference airborne object was only detected after the MTS threshold of -36 m/s for radial velocity was exceeded.

As the test results have shown, the absence of marks in the primary data registration file "14-07-17.kt" of Utes-T ARRC does not mean that there was no object moving towards the Boeing 777 at a high speed "from the southern direction" in the observed space.

6. Conclusions

1. The results of the simulation show that, in the case of the hypothesis suggesting that the Boeing 777 was hit by a BUK missile moving "in an opposite direction", the object would have been within Utes-T ARRC's detection area over three scan periods, while in the case of the hypothesis implying impact from the southern direction ("on a collision course") it would have been there over two scan periods.

2. The flight around of Ust-Donetsk radar position confirmed the main capabilities of Utes-T ARRC to detect small and high-speed airborne objects.

3. The probability of detecting an airborne object with parameters corresponding to a missile flying "in an opposite direction" relative to the Boeing 777 aircraft is about 0.9. At the same time, the probability of recording at least one mark over three consecutive scan periods exceeds 0.99.

4. The fact that the registration file "14-07-17.kt" of Utes-T ARRC for the period from 13:02 to 13:32 UTC 17.07.2014 contains no marks approaching the aircraft at a high speed "from the east of Ukraine" suggests there was no object travelling towards the Boeing 777 from the direction of the village of Pervomaisky in Donetsk Region of Ukraine in the area of observation.

5. According to the results of the completed full-scale experiment the conditions of which were as close as possible to those at the time of the crash, a BUK missile could approach the Boeing 777 without being detected by the radar from the southern direction only, if it was flying on a "collision course".

Thus, if BUK missiles are considered as the probable cause of the destruction of the Boeing 777 aircraft, such missile could approach the aircraft without being detected by Utes-T radar from the southern direction only, if it was flying on "a collision course".

The missile launch from the side of Snezhnoye and Pervomaisky settlements (Donetsk Region of Ukraine), i.e. "in an opposite direction", is not confirmed by air situation data recorded by Utes-T air-route radar complex. The primary data registration file "14-07-17.kt" of Utes-T ARRC for the period from 13:02 to 13:32 UTC 17.07.2014 contains no marks from the weapon, which suggests the absence

of an object moving in the direction of the Boeing 777 "on an opposite course" in the area of observation.
