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THE GROUND BASED AIR DEFENCE SOLUTIONS

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Abstract: The article deals with air defence, focusing on the use of Ground Based Air Defence (GBAD) systems. GABDs are complex systems consists of different types of radars, sensors, launchers, command, control, communication, intelligence information subsystems. GBADs parameters and subsystems features can influence overall GBAD systems characteristics and range of GBADs usage. In this article are described modern GBADs solutions, main advantages, and disadvantages of their composition.

Keywords: Ground based air defence system (GBAD); Air defence; Launcher; Radar; Missile.

1 INTRODUCTION

An air defence (AD) is realized by two category of weapon systems, by aviation systems and by Ground Based Air Defence systems (GBADs).

GBADs are complex systems consists of sensors, radars, command, control, communication, information, and intelligence systems (C2, C3, C4I^2), launchers, missiles, and special power supplies.

GBADs systems are divided into following groups [1]:
- VSHORAD (Very Short Range Air Defence) systems.
- SHORAD (Short Range Air Defence) systems.
- MRAD (Medium Range Air Defence) systems.
- LRAD (Long Range Air Defence) systems.

Engagement ranges of above-mentioned systems are up to 5 km for VSHORAD, up to 15 km for SHORAD, up to 50 km for MRAD and more than 50 km for LRAD systems. Range of GBADs are mainly determined by the missile characteristics.

Different categories of above mentioned GBAD systems can be used against different types of aerial threats. Aerial threats are tactical aviation, bombers, fighters, helicopters, unguided/guided missiles especially cruise missiles, tactical ballistic missiles (TBMs), unmanned aerial vehicles (UAVs), precise guided munition (PGM) and others [2]. Commonly, characteristics of GBADs are divided into the technical, tactical characteristics, maintenance characteristics and economic characteristics [2].

Different categories and types of GBADs create cluster. A cluster creates multi-height and omnidirectional air defence element layered air defence, where the large range GBADs covers GBADs of lower layers (ranges). For example, VSHORAD (SHORAD) GBADs cover LRADs and fill in noncovered zones in an AD. This type of AD is called multi-layered AD.

Each of GBADs can be characterized by its combat features. Combat features are divided into categories of reconnaissance features, firing features a manoeuvring feature [1].

GBADs reconnaissance features define reconnaissance features of sensors (e.g. passive, active radars) which are responsible for aerial reconnaissance and RAP (Recognized Air Picture) creation.

Desired GBADs radar range is defined by the equation [3]:

$$d_{ZP} = d_d + v_C\left(\tau_{PS} + \tau_{rd}\right), \tag{1}$$

where d_{ZP} is desired GBADs radar range, d_d is horizontal maximal range of GBADs engagement zone, v_c is target speed, τ_{PS} is time of GBADs direct preparation of fire and, τ_{rd} is time of missile flight into the maximal engagement zone border.

An engagement zone – is a zone around the GBADs, where surface-to-air missile (SAM) missiles (hereafter just missiles) destroy aerial targets. An engagement zone is described by parameters like ranges in distance or ranges in heights, where aerial targets can be engaged and other parameters mentioned in this article.

Engagement zone is defined in connection with probability of target destruction *P.* Probability *P* is dimensionless number obviously defined according firing results against aerial target in conditions specified by a GBADs producer. Probability P_n is defined when multiple (salvo) missiles are firing against one aerial target [3]:

$$\mathrm{P}_n = 1 - \left(\sum_{n=1}^{n}(1 - P_1^n)\right), \tag{2}$$

where *n* defines number of fired missiles to one target and P_1 is probability of target destruction by one missile. Probability of aerial target destruction is dimensionless value, that is different for different types of targets or for different firing conditions or for conditions created by a jamming.

The target engagement zone with firing characteristics defines range of distances, heights, azimuths, and elevation angles of destroyed aerial targets, their speeds, and types. Firing features define number of simultaneously destroyed targets and number of simultaneously guided missiles.

Manoeuvring features influence the readiness of GBADs for combat operations. These features are defined by the time characteristics, for example time for set up GBADs into firing position, a deployment time GBAD, etc.

2 A CURRENT STATE OF GBADS

The current state in an area of GBADs has been formed by the past development of GBADs, where one-channel GBADs were replaced by the multiple-channel GBADs. Multichannel GBADs can engage multiple targets at the same time.

A development of modern GBADs is still influenced by following facts:

- Spectrum of aerial threats is still increasing (new tactical aviation, UAVs, PGMs, TBMs and hypersonic missiles).
- Technical and tactical characteristics of aerial threats (ranges, their speed, manoeuvrability, operating time etc.) are increasing too.
- A utilization of an integrated inertial navigation systems and global position systems (INS/GPS) leads to increasing the guidance accuracy of threats and guided missile in terminal flight phase.
- Low-cost UAVs can be equipped with 3D full HD cameras, targeting or weapon systems and can be used for reconnaissance or combat operations.
- An operation of low-cost aerial threats is very simple (user-friendly).
- Spectrum of aerial threats fired out of GBADs range (carrying missiles, anti-radiation missiles, cruise missiles) is still increasing.
- Aerial threats use STEALTH technology, that is the fact which leads to decreasing GBADs radar ranges etc.

Thanks to above mentioned facts requirements for GBAD system capabilities are still increasing too.

A lot of armies are so far equipped with legacy GBADs produced by Russia. After start of Russian – Ukraine war conflict, the international security situation and international relationships were changed. It affects the operation of GBADs – it is impossible to service, repair, and supply of spare parts.

Some older GBADs types were developed in 1970’s and produced in 1980’s (SA-6 Gainful) and those systems don’t fulfil current requirements for modern GBADs:

- High effective engagement of wide spectrum of aerial threats.
- Resistance to various types of interference or jamming.
- Operation 24 hours/7 day per week with low level of failures occurrence, in different operational conditions.
- Interoperability of GBADs and their subsystems.
- Economic and logistical aspects of GBADs operation.

3 MODERN GBADS SOLUTION

Modern GBADs in the same way as legacy systems consists of firing units (FUs), sensors – radars, C2, C3, C4I2 systems, launchers, and special power supplies for GBADs subsystems.

An AD effectiveness of the European airspace (or in combat operation) can be increased by centralized commanding. NATINAMDS (NATO Integrated Air and Missile Defence Systems) represents means of Integrated Air and Missile Defense (IAMD) of European airspace.

Firing units (clusters) and their GBADs are commanded and controlled from Joint Force Air Component (JFAC)/Combined Air Operation Centre (CAOC) that represents international commanding level (HQ - Headquarters) as in Fig. 1. CAOCs are superior to national Air Operation Centres (AOC) and Command Reporting Centres (CRC).

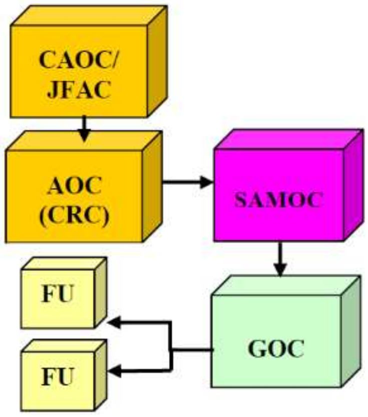

Fig. 1 Structure of commanding levels
Source: authors.

The CRC (at the operational level) commands tactical level units (brigade level), where the Surface to Air Missile Operation Centre (SAMOC) is C4I element. The SAMOC is commanding element for Group Operation Centres (GOC) which control subordinate FUs. Main advantages are:

- Airspace information sharing.
- Early warning and quick reaction.

Main advantages of modern GBADs are:

- GBADs radars uses Active Electronically Scanned Array (AESA), allowing quick reconnaissance and control of operation modes of GBADs radar.
- Radar transmitters can use frequency hopping mode.
- Radar receivers use low noise amplifiers and advantages of high-speed digital signal processing (DSP).
- Radars use set of countermeasures against the current sources of jamming.
- GBADs subsystems use high level of modularity (modules and blocks are backed up).

- FUs can be created according to user (national and NATO) requirements. It means, user can select suitable number of launchers per one FU, suitable numbers of missiles with different guidance systems, suitable levels and types of support devices and maintenance services.
- GBADs subsystems use Built-In-Test-Equipment (BITE) diagnostics which simplify user service operations.
- GBADs use Low Level Air Picture Information (LLAPI) defined in [4], datalinks LINK-11, LINK-16, and Joint Range Application Protocol (JREAP) defined in [5, 6].
- Requirements for operating the of GBADs are lower. It means the range of technical, diagnostic operations and their depth were relatively reduced.

The range of aerial targets speeds are still increasing, therefore ranges of the GBADs radars must be increased too. For example, if the missile speed is v_r = 600 m.s^{-1} and t_{PS} = 20 sec, the computed radar range defined according to (2) for different target speeds is shown in Fig. 2.

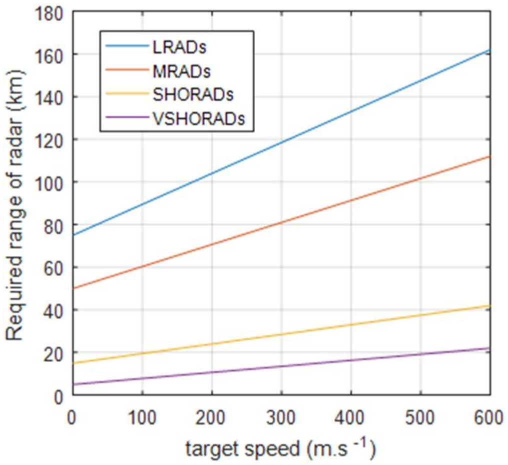

Fig. 2 Required radar ranges vs. target speed.
Source: authors.

3.1 Solutions in the VSHORAD category

The VSHORAD category of GBADs (range up to 5 km) is used for AD of small objects, military bases, land forces units against the enemy aviation, fighters, or helicopters.

Man Portable Air Defence Systems (MANPADS) is category of VSHORAD GBADs. For example, MISTRAL system is according to producer [8] MANPADS.

Modern solutions of VSHORAD systems are for example:
- RBS-70 NG (Saab, Sweden, Fig. 3).
- MISTRAL (MBDA, France, Fig. 4).
- LFK NG (Diehl, Germany, Fig. 5).

The RBS-70 NG is an improved version of the RBS set developed by SAAB (Sweden). The current generation of this set allows to use the original missiles generations as well as the BOLIDE missiles. Basic characteristics of the system are (depending on the missile type) engagement range 250 – 8 000 m, height range 0 – 5 000 m, use of a contact fuse with an adaptive delay, guidance of the missile in a laser beam, and Mach 2 (approx. 600 m/s) missile flight speed.

The RBS-70 NG set consists of:
- RBS-70MK1, MK2 or BOLIDE missiles.
- Aiming system with a tripod.
- IFF and C3I interface.

The system allows to engage air and ground targets, using a system of thermal imaging and automatic target tracking with the option of manual control. It records the combat situation, and it enables its playback.

Fig. 3 RBS-70 NG (Saab, Sweden)
Source: [7].

The advantages are:
- Increased range and probability of target destruction.
- The ability to engage of various target types.
- The ability to engage targets under countermeasures conditions.
- Integrated night reconnaissance system.

The disadvantage of the RBS-70NG is sensitivity of laser guidance in bad weather conditions (smoke, battlefield dust, fog, etc.).

MISTRAL is MANPADS system with following characteristics:
- Range of Mistral Coordination Post (MCP) radar: 30 km distance, 4 km height.
- IFF MODE 4.
- Missile max. range 6 km (M-2 version).
- Missile height range 3 km.

Basic elements (of a platoon) are:
- MCP SHORAR (radar).
- ATLAS launcher 5 pcs.
- MISTRAL-2, and M-3 missile.

Fig. 4 Mistral (MBDA, France)
Source: [8].

LFK NG is a set developed by the company MBDA (Germany) and Diehl BHGT Defence (Germany). The system uses direct guidance method of the missile through the up-link, and it uses vertical launch. Subsequently, it uses a passive homing warhead to terminal guidance. The basic characteristics of the set are:
- Range in the distance 500 – 10 000 meters.
- Height range is 15 – 5 000 m.
- combined fuse (contact and non-contact).

Fig. 5 LFK NG (MBDA, Diehl, Germany)
Source: [8, 10].

LFK NG advantages are increased range, probability of target engagement, the ability to destroy various types of targets on arrival and departure, and the ability to engage targets in the various countermeasures conditions. The disadvantages are longer deployment time, greater number of personnel.

GROM and PIORUN (Poland), STINGER (USA) and Starstreak (UK) are possible solutions in VSHORADs category too.

3.2 Solutions in the SHORADs - MRADs category

SHORAD and MRADs categories of GBADs (range up to 15 km and range up to 50 km) are used for AD of large objects, military bases, land forces, units and terrestrial areas against the enemy aviation, for example fighters, or helicopters.

Nowadays SHORAD-MRADs systems solutions are for example:
- MICA VL (MBDA, France).
- SPYDER-MR (Rafael, Israel).
- NASAM 2 (Norway/USA).
- IRIS-SL (Diehl, Germany).

MICA VL is a system (Fig. 6) using vertical launch missiles in two versions, either MICA RF with active homing or MICA IR with infrared homing in the terminal phase.

For the initial missile flight phase, both versions of the missile are guided to the target using initial information about the target transmitted by radio link. The missiles can capture the target during the flight. Missiles use the advantages of a vertical launch from the container placed on the launcher. It means, there is a possibility to guide a missile in full circle from firing position (launcher). There is not limited firing sector.

MICA VL is composed of:
- ICMP (Improved Command Missile Post).
- Launchers (from 3 to 6 launchers, each equipped with 4 missiles).
- Tactical Operations Center (TOC).
- Integrated logistic support.

MICA VL is characterized by the following characteristics:
- Engagement range of 1500 – 20 000 m.
- Height range 10 – 10 000 m.
- Contact and contactless fuse.
- Deployment time up to 10 minutes.

The advantages of the system are the possibility of simultaneous shooting of several targets. The distance between the launcher and the TOC can be from 0.5 km up to 10 km. The disadvantage is significantly dropping of missile's manoeuvrability, for increasing target distance.

Fig. 6 MICA VL (MBDA, France)
Source: [8].

SPYDER MR is a system (Fig. 7) developed by Israeli companies Rafael Advanced Defense Systems and Israel Aerospace Industries. It uses PYTHON-5 and DERBY missiles. A typical FUs consist of:
- Unit for command and control.
- Usually 6 launchers (each equipped with 4 missiles).
- Loading vehicle.
- EL/M-2106 ATAR radar.

Fig. 7 SPYDER (IAI, Rafael, Israel)
Source: [12, 14].

The EL/M-2106 ATAR radar can track and engage several targets at the same time and control fire units at distance up to 10 km. The system is characterized:

- Engagement ranges from 1 000 m to 35 000 m (PYTHON-5 to 20 km, DERBY 35 km).
- Height ranges from 20 m to 16 000 m.
- Combined fuse.
- Active homing system (DERBY missile) and infrared homing system (PYTHON-5 missile).

The GBADs advantages have possibility of simultaneous shooting of several targets and high rate of fire. GBADs is not intended to destroy the TBM, and missiles are launched at a non-vertical angle.

NASAMS 2 is a system developed by Norwegian Kongsberg companies (Norway) and Raytheon (USA) based on the original NASAM system. System is equipped with AIM-120C AMRAAM missiles (Fig. 8). The NASAMS 2 system has the following typical structure:

- Fire Distribution Centre (FDC).
- 3-D radar type MPQ-64F1 Sentinel.
- Passive electro-optical and infrared sensor.
- Towed launchers with AIM 120A (120C) AMRAAM missiles in containers.

One FUs platoon consists of 3 launchers with 18 missiles, and the battery contains 3 platoons. Radars are connected to the FDC as sources of a radar information.

The NASAMS 2 system is characterized by the following characteristics:

- Engagement range of 2 500 – 40 000 m.
- Height range 30 – 14 000 m.
- Maximum target speed 1000 $m.s^{-1}$.
- Contact and contactless fuse.
- Radio command guidance with active guidance in the terminal phase.

The launchers are located within 25 km radius from FDC, and they can communicate using cable, optical, or radio communication channels.

Fig. 8 NASAMS II missiles
Source: [9].

The multifunctional radar AN/TPQ-64 is pulsed Doppler radar with AESA and IFF Mark XII. It ensures all-round scanning of area with a range of 75 km. The NASAM 2 system obviously uses launchers with a missile launch angle approximately 30°. The advantages of the system are the possibility of simultaneous shooting of several targets, a high rate of fire. Missile uses an optical guidance method.

The disadvantages are follows: missiles are not placed into the containers and missiles have to be manually loaded.

IRIS-SL is a system developed by Diehl BGT Defense (Germany). Missiles IRIS-T SL were developed from the IRIS-T air missile. The system is designed for two variants of the IRIS-T SLS (short range) and IRIS-T SLM (medium range) missiles. The missiles use up-link for the initial guidance phase and an infrared homing in the terminal flight phase.

The system consists of:

- CEAFAR Active Phased Array Radar.
- IRIS-T SL launchers (Fig. 9).
- BMD-FLEX C3 system.
- Oerlikon Skymaster battlefield C2 system.

Fig. 9 IRIS SL subsystems
Source: [10].

The system has the following characteristics:

- Engagement range 1 000 m – 40 000 m.
- Height range 20 m – 20 000 m.

The advantages of the system are the possibility of simultaneous shooting of several targets, high rate of fire, vertical launch of missiles, modularity of the system. The disadvantage is impossibility to engage the TBMs.

3.3 Solutions in the LRADS category

LRADs category of GBADs (range more than 50 km) is used for AD of strategic objects, military bases, land forces, units and large terrestrial areas against the enemy aviation, fighters, helicopters, guided and unguided missiles, cruise missiles and TBMs.

Modern LRADs systems solutions are follows:
- MEADS (France, USA, Italy).
- BARAK 8 (Israel, India).
- SAMP-T (France, Italy).

MEADS is a system in Fig. 10 that gradually replace the PATRIOT and NIKE-Hercules systems.

The MEADS system includes:
- Multifunctional Fire Control Radar (MFCR) using an AESA for precise search, tracking and identification of targets. It uses an AESA to creation Missile Control Fire Radio (MCFR) link.
- Reconnaissance radar is a radar operating in the UHF band with an AESA.
- TOC is the system performing BMC4I (Battle Management, Command, Control, Communication, Computational and Intelligence) tasks.
- Launchers (up to 6 pieces) equipped with ASTER 30 missiles located in containers or PAC-3 MSE missiles.

The MEADS system is characterized by:
- Engagement range 3 000 – 120 000 m,
- Ability to destroy TBM.
- Using several types of missiles.
- Command guidance method and active self-guidance method in the terminal missile flight phase.

The advantages of the system are the possibility of simultaneous shooting of several targets with several missiles, the possibility of firing at the same time in different azimuths, high rate of fire, high resistance to countermeasures, the possibility of using several types of missiles with different ranges and Hit-To-Kill technology. The system is compatible according to NATO requirements. System is not combat proved or a lot of information about its characteristics and next development are missing.

Fig. 10 MEADS subsystems
Source: [8, 11].

BARAK 8 system is the LRAD system defending against aircrafts, helicopters, and guided missiles (Fig. 11). The system was developed in cooperation with the Israeli company Israel Aerospace Industries (IAI) and the Indian Defense Research and Development Organisation.

Fig. 11 BARAK 8 elements
Source: [12, 13].

The missile is guided by a radar EL/M-2248 [7] during the initial flight phase. In the terminal phase of the missile's flight, the main engine is jettisoned (first stage), and the missile it is guided by using an on-board radar.

BARAK 8 consists of:
- Command and control unit (CP).
- Radar EL/M-2248 [7].
- Launchers (4 pieces) each equipped with 8 missiles.
- Loading vehicles.
- Multifunctional (support) vehicle MV.
- Power supply generators.
- The main advantages of BARAK 8 system are:
- Resistance to all kinds of interference.
- Possibility of combination with SPYDER MR elements.
- Compatibility with the EL/M-2084 radar.
- Containerized missiles - long storage period.

The main disadvantages are:
- The problematic interoperability according to NATO standards.
- Deployment time is approx. 45 minutes.

SAMP-T system developed by the companies MBDA, THALES, EUROSAM (France, Italy). The system (in the Fig. 12) is intended for the destruction of a wide range of targets, missiles, UAVs and TBMs.

SAMP-T unit is composed of:
- Multifunctional radar (ARABEL).
- Command module (C2).
- Launchers (up to 6, each equipped with 8 missiles).
- Missile ASTER 30 or ASTER 15.
- Integrated logistic support.

The multifunctional radar ARABEL is intended for the detection and tracking of aerial targets with a range up to 150 km. The X-band radar uses AESA, which allows it to track and identify (IFF) up to 100 air targets simultaneously and guide up to 16 missiles to targets. Missiles are guided over the radio link. Missile launchers can be up to 10 km away from the multifunctional radar.

Fig. 12 SAMPT with ASTER-30 missile
Source: [8].

The system is further characterized by:
- Engagement range 3 000 m – 120 000 m (ASTER-30) or 1 700 – 30 000 m (ASTER-15).
- Engagement of TBMs up to 30 000 m.
- Height range is 0 – 20 000 meters.
- Deployment time within 10 minutes.
- Missile uses active non-contact radio fuse.

Both types of ASTER missiles use an inertial navigation system with control via a radio link from the ARABEL radar. In the terminal flight phase, the missiles use an active homing system.

The advantages of the GBADs are the possibility of simultaneous shooting of several targets with several missiles, high rate of fire, high resistance to countermeasures (jamming), the possibility of using several types of missiles with different ranges. A lot of information about its characteristics and combat operation are missing.

4 CONCLUSION

Legacy or older types GBADs are characterized by their original conception and composition. Those systems are still used in several Armed forces of NATO countries. Their characteristics and capabilities in this time are not enough for creation of the modern IAMD. Service and operation of those systems are not long-term sustainable and cost effective. From this reason is necessary to create IAMD based on current GBADs.

The aim of this paper was to show basic characteristics of current GBADs in all range categories (VSHORAD, SHORAD, MRAD, and LRAD), which can be used for the replacement of legacy systems.

In each category are summarized the composition of GBADs, their basic characteristics (radars, missiles, launchers, etc.), advantages and some disadvantages. Article provides a comprehensive overview in GBADs area focusing on GBADs which can be used in Integrated Air Missile Defense (IAMD) for NATO environment.

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