TransNav
http://www.transnav.eu
the International Journal on Marine Navigation and Safety of Sea Transportation
Volume 9
Number 1
March 2015

DOI: 10.12716/1001.09.01.16

Safety of Navigation on the Approaches to the Ports of the Republic of Poland on the Basis of the Radar System on the Aerostat Platform

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ABSTRACT: The report depicts technical and organizational possibilities with an aim to increase situational awareness and sea travel safety on the entry to Polish seaports on the base of the dedicated radar system on the aerostat platform. The radar system based on the aerostat can work at the altitude of 3,000 meters, which allows detecting sea vessels and low level flying aircrafts in the range of 150 nm and more. The aerostat based in Siemirowice gives opportunities to monitor movements of sea vessels all over the South Baltic Sea, starting with the Lithuanian seaside with Klaipeda seaport in the east where the sea enters Zatoka Gdańska and Trójmiasto seaports, movements along the whole Polish seaside up to Sund Straid near Copenhagen and sea routes all along south Swedish coast. On those bases, it is possible to observe movements of sea transports of special interest including Maersk's big container vessels and gas delivering vessels to Lithuania and to Świnoujście. The proposed radar system is using solutions of towed aerostats tested in working conditions which are exploited by the United States of America to monitor its border with Mexico and to observe movements of sea vessels and low flying aircrafts around Florida Peninsula and Puerto Rico islands on the Caribbean. The radar systems used by the USA are depicted with organizational rules of their exploitation. Advantages and these advantages of such a radar system were depicted and some information about dangers related to aerostat's exploitation is also provided. Additional possibilities of using the radar system based on the aerostat are depicted in the role of a new and important part of the country's defense system.

1 INTRODUCTION

Safety of navigation on the approaches to the seaports of the Republic of Poland can be endangered by increased movement of big ships, including Maersk's container vessels and especially liquid natural gas (LNG) delivering vessels. Gdańsk and Gdynia, Poland's main seaports are located in Zatoka Gdańska in the east of Polish seaside. In the west is located seaport in Szczecin and new build gas port in Świnoujście. Gdańsk and Gdynia take most of the Polish sea trade, having reasonable part in containers transportation on the line to and from China.

In 2014 deliveries of LNG to Lithuania started through seaport of Klaipeda. So movement on South Baltic Sea has tendency to increase in the class of big transport vessels. We especially have to confront new requirements and dangers tied with LNG transportation ships destined to Polish or Lithuania seaports. Any collision or act of terror can be devastating for seaport's infrastructure and population of nearest cities. So there is strong need for close monitoring of ships' movement on the approaches to Polish main seaports and on the main sea routes in South Baltic Sea near of Polish seaside. Generally, system has to be based on regulations from states and organizations. Domestic and international laws have to be complied. We need to base on solid geo data with known all water and underwater obstacles as well as water deep and its change in the time. We need to know actual weather and sea state and forecasts for next hours and days. On such environment we can put data of port's traffic, track of approaching vessels and their identities and alerts of detected suspicious vessels or future suspected illegal activities. We get those data from national or European agencies, organizations and service providers and fuse all the data to obtain clear picture of actual situation and awareness of possible dangers.

In ideal world we have to cope with natural disasters and technical dangers only. But in real world we have to cope with people's lack of knowledge and experiences, tiredness and sickness, which end up with misinterpretation of facts or overload. But we also have to cope with illegal activities, including trafficking of people, weapon and drags and even including acts of terrorism against high value vessels, passengers, seaport's infrastructure and citizens of seaports. There are a lot of evidences of use small boats for attacking vessels on the open sea and in seaports, including suicide attacks to cause many casualties and destroy port's infrastructure.

On the base on experiences in some countries we are proposing aerostat radar system to monitor activity on approaches to seaports and by this means to increase awareness and safety of sea travel and transportation.

2 TETHERED AEROSTAT RADAR SYSTEM

The most widely used aerostat radar system is Tethered Aerostat Radar System (TARS) which is operated by US Homeland Security Department on USA south land and sea borders [6].

TARS was developed in the 1980s to protect US southern border against drag and people trafficking. System is composed of tethered aerostat with airborne radar subsystem and ground base with power to analyze radar data and send them to command posts. Security system of US southern border is shown in Figure 1. Aerostats can hover at altitude up to 4.500 meters but typical working altitude is 3.000 meter. Most of TARS aerostats are operating on land in Texas, New Mexico and Arizona states but there are also aerostats used to monitor Straits of Florida (base on Cudjoe Key island in Key West archipelago) and of Puerto Rico (base is on south west side of island). United Arab Emirates have build base for aerostat radar system to monitor movement of vessels in Straits of Ormuz which is the only way to enter to and depart from Persian Gulf. Republic of Singapore has just announced purchase of aerostat radar system for monitoring of Straits of Malacca, one of the most important sea ways in the world.

In the same time Kingdom of Malaysia has decided to purchase aerostat radar system to monitor situation on the north part of Borneo Island.

Scarce information are only available about aerostat radar systems operated in Israel with view on approaches to Haifa seaport on the Mediterranean and Gulf of Aqaba on Red Sea and about aerostats stationed on the both sides of Strait of Taiwan and operated by Republic of China (Taiwan) and China People Republic. The reason for such secrecy is desire to protect information about performances of radars used in those aerostat radar systems. Those aerostat radar systems primarily are connect to national defense systems to provide better awareness and protect own military and economy assets against any adversary. The secondary role is the monitoring of movement of civil vessels and work for safety of navigation of approaching foreigner ships. Sample of sea mobile radar system for aerostat is shown in Figure 2.

Figure 1. TARS aerostat radar system locations on southern border of United States of America (US Customs and Border Protection - http://www.cbp.gov/frontline/2014/10/frontline-november-aerostats).

Figure 2. Sea Based Aerostat moored to deck of Abshire Tide vessel (http://www.tcomlp.com/gallery/sea-based-aerostats/)

Aerostat radar systems add new possibilities to observe sea waters; seasides and seaports from the air. Using of radars aerostat radar systems can provide wide range surveillance in ranges up to hundreds of nautical miles and by using in combination of electro-optical sensors (EO) can recognize approaching vessels and monitor theirs behavior on short distances. Such bird view can be maintained by utilizing fixed wing and rotary aircrafts. But those assets are typically more costly and cannot provide persistent surveillance because of restricted time of flight (fuel consumption and crew tiredness). Unmanned air systems (UAS) are entering market of persistent surveillance but they are at their infancy yet and have to confront requirements of regulations and mental obstacles. From the cost side of view, UAS are not as cheap as expected in comparison with manned and land observation systems. Least report of US Homeland Security Office of Inspector General put some light on real costs of exploitation of UAS on south border with Mexico. UASs using sophisticated EO systems in stabilized gimbals and 3D radars have only small part in apprehensions of traffickers smuggling drags and people. Because of restrictions of use in civil air space UAS can be used only in some small and strictly designated parts of air space. So theirs view is narrow and restricted and should to be threaten as complementary to other capabilities.

In 2010 was started project called I2C - Integrated System for Interoperable Sensors & Information Sources for Common Abnormal Vessel Behavior Detection & Collaborative Identification of Threat. This international European project was implemented to enable automatic identification and tracking of vessels suspected of involvement in irregular migration, illegal fishing, and drug trafficking and looting of cultural heritage and reporting on EUROSUR (European Border Surveillance System). With the financial help of European Commission companies from some European countries have designed and tested in simulated conditions integrated I2C system. The I2C system acquires information from multiple sources, including coastal radars, aircraft, and airship and observation satellites. This data is analyzed using high-performance algorithmic software to correlate and exploit all the information to assess vessel trajectories and activities dynamically, interrogate databases and automatically raise alerts according to established rules in consultation with the operational authorities. Airborne part of this European early warning system is shown in Figure 3.

Figure 3. Airship during I2C trials on south shore of France (www.i2c.eu).

To improve system possibilities airship was involved in the tests. Airship was equipped with radar and electro-optical observation system in stabilized gimbals. Data from airship's sensors was analyzed on board and send to command center on land. There are plans to continue development of I2C systems in the next years.

But disadvantage of manned and unmanned air systems is theirs dependency on weather conditions. They cannot be exploited in bad weather conditions, so cannot help in emergency situations. Aerostats moored to ground station have proved their capabilities in harsh weather conditions with wind speeds up to 60 kts.

3 AEROSTAT RADAR SYSTEM DESCRIPTION

Aerostat radar system consists of:

1 Aerostat with tether,
2 Airborne radar subsystem with electro-optical sensors in gimbals (optional),
3 Ground car with mooring tower and winch system for tether,
4 Ground station for processing, analyze and distributing of signals from radar system,
5 Ground auxiliary equipment.

Aerostat has non rigid structure without inner skeleton. Aerodynamic shape is provided by overpressure of filling gas - typically helium. Airship canopy is made from high strength Nylon fabric with polyurethane and Tedlar layers to obtain tightness and sturdiness for weather conditions. Canopy has two air pressured ballonets, in front and aft of aerostat, to provide stability in the air stream and to compensate helium volume changes depending on temperature changes inside canopy. Stabilizers on aft of aerostat are filled by pressured air to maintain proper aerodynamic shape. The radar system's antenna on tethered aerostat is shown in Figure 4.

In bottom aft part of aerostat's canopy radar compartment are usually mounted. Radar antenna is under shield witch aerodynamic shape is maintained by air pressure. Under shield are also mounted diesel electric power generator, air blowers for ballonets, air blowers for stabilizers and communication pack for sending crude radar signals to ground base station. To lower mass of airborne radar subsystem on aerostat are mounted only antenna and communication pack. Crude radar signals are sending to ground station and processed by speedy computers (a lot of electric power is needed for this work). When all fuel is burn by diesel electric power generator aerostat have to be pull from altitude and moored to ground base for fuel filling and for maintenance works on airborne subsystems. In newest aerostat radar systems like JLENS special tether was introduced. Inside tether are electric cables as well as optical fibers for control and communication. So, there is no need for every few day fuel filling and communication between antenna and ground processing station are secured and immune of interferences. But such integrated tether is heavier, more costly and has unknown durability (during work on altitude aerostat is exposed on harsh wind blows which generate high loads on tether).

Figure 4. Aerostat radar system on Cudjoe Key Island on Straits of Florida (base for two aerostats) (http://en.wikipedia.org/wiki/Tethered_Aerostat_Radar_System

Airborne radar subsystem is composed of rotational antenna and communication pack. Depending on wind direction and resulted from this direction of aerostat in air, rotational radar antenna provides full coverage of surrounding space. All processing of crude radar signals are done in ground processing station to lower mass of airborne radar subsystem.

Range of radar detection is directly tied with curvature of Earth and operational altitude of aerostat. Even smallest altitude can provide much wider radar view in comparison with land radar systems. According to specification TARS aerostat system can detect naval activity and low flying small aircrafts from distance up to 200 nm (operational altitude is 3.000 meters) and JLENS with more sophisticated radar can detect objects from up to 300 nm. Ground station has round place with car with mooring tower for aerostat. Tower is mounted on the top of rotational car with winch for tether. Car with tower and winch can rotate to allow take any direction depending on wind direction in the sequence of mooring aerostat.

Figure 5. Rotational radar antenna under maintenance

Ground station takes crude data from airborne radar antenna and processes it by using station's computer systems. By this way processing of radar signals is done on the ground, not on the board of aerostat. Computer systems for signals' processing are on the ground and they use electric energy from land sources. So radar system on the aerostat can have lower weight and by this mean aerostat can be smaller (it's also mean cheaper) or can work on higher altitude (greater range).

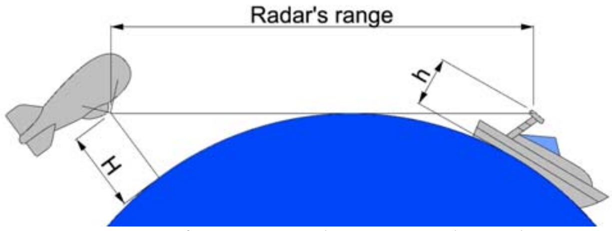

Figure 6. Range of aerostat radar system depending on its altitude and height of observed vessel (Ireneusz KRAMARSKI)

Processed data can be distributed to monitoring system on higher level of command (navigation, emergency, defense, scientific purposes etc.).

Table 1. Calculation of radar's visibility (based on calculator on http://members.home.nl/7seas/radcalc.htm)

Radar's altitude - H [m]	Height of vessel-h[m]	Visual Horizon [nm]	Radar Horizon [nm]
25	3	13	15
300	3	36	42
600	3	50	58
1000	3	64	74
3000	3	108	125

4 POLAND AEROSTAT RADAR PROGRAM

In 1990 years in Poland aerostat radar program was started in cooperation of Institute of Aviation and PIT Company. Working jointly, specialists from the Institute of Aviation and Przemysłowy Instytut Telekomunikacji (now PIT-RADWAR SA) finally came to the idea of designing the observational system, including aerodynamically shaped, unmanned, tethered aerostat carrying the airborne radar with stationary omnidirectional (non directional and non rotational) antenna, and being controlled from ground situated control centre. Such system shows a lot of advantages over widely known airplane installed AWACS facilities: longer endurance, relatively smaller horizontal speed between antenna and object (an important factor of the radar return measurement process), operational safety and low cost of exploitation. [2, 3].

On large aerostats radar antenna is mounted under special gondola under aerostat belly. On small aerostats radar antenna is mounted under belly, typically with addition of EO system (smaller operational altitude and lower range of observation).

Because of medium size of designed SK-1 system, designers choose to mount radar antenna inside aerostat belly. Radar antenna with such dimensions would require gondola of reasonable size and with high front area which can severely affect performances of the aerostat.

Table 2. Comparison of ground and airborne radar systems

Parameters of radar observation system	Ground radar system (mobile)	Airborne radar system on aircraft	Airborne system on aerostat
Range of observation	low (25 -50 nm)	very high (150 - 300 nm)	high (50-150 nm)
Time of nonstop operation	long (week – months)	short (up to 10 hours)	long (week - months)
Mobility of system	high	very high	low
Number of system	low	very high	low
Resistance of weather conditions	very high	high	very high
Cost of purchase	low	very high	high
Costs of medium operations	low	very high	low –

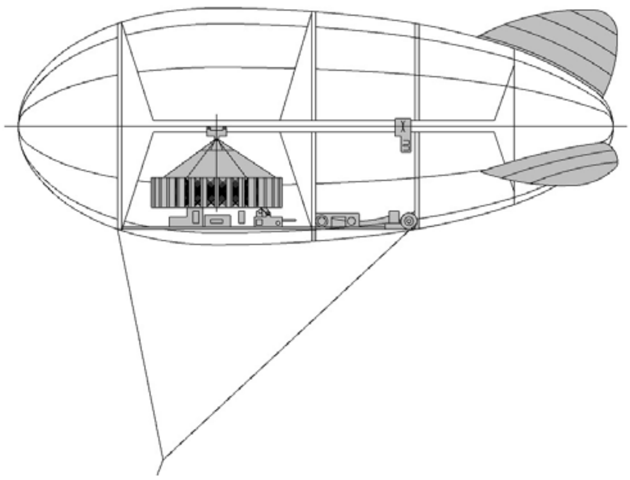

Figure 7. SK-1 aerostat radar system project with omnidirectional (non rotational) antenna (Krzysztof SZAFRAN) [4].

Aerodynamically shaped, SK-1 tethered aerostat radar system was destined to use for observation of objects moving on the ground and water surfaces and objects flying not higher than 300 meters inside the circled area with 75 nm radius. Rough estimations show that it is possible to observe such area effectively from the system working at the altitude of 500 m over the ground/water level.

Table 3. Specific parameters of SK-1 aerostat radar system (ILot 2000) [5].

Length	38 m
Diameter	10 m
Volume	2500 m3
Weight of radar antenna	200 kg
Dimensions of antenna (D x L)	6.6 x 1.5 m
Max weight of payload (airborne equipment including tether line)	1000 kg
Operational altitude	300 - 500 m
Operational range of radar system	up to 75 nm
Operational temperatures	-40 - +45 ^{0}C
Weather conditions	wind, rain, snow

Tether would more aerostat to the ground, provide electrical power to airborne subsystems on board of aerostat and provide communication and control of airborne subsystems by use of optical fibers.

5 BOS-2 SPATIAL OBSERVATION AEROSTAT

To learn some experiences with handling and operating of aerostat in real conditions and to check some technical solutions a smaller demonstrator of aerostat was designed, developed and produced. Named BOS-2, it has had length of 10 m, diameter of 3 m and volume of 50 cubic meters. It can take payload of up to 25 kg to attitude of up to 150 meters. [5].

Figure 8. BOS-2 aerostat demonstrator — first variant with simplified stabilizers - on International Defense Industry Exhibition MSPO in Kielce, Poland (Ireneusz KRAMARSKI).

Technology demonstrator was used in full scale trials in semi real conditions. Because of lack of radar system with small mass, only EO system was used during tests. In those times EO system was analog system with heavy weight optics and complicated stabilization in gimbals. But we have learned a lot about handling, operating and transport of tethered aerostat system.

In the next years aerostat demonstrator was used in trials with new lighter EO system in cooperation with Polish Instytut Techniczny Wojsk Lotniczych (Air Force Institute of Technology) and in such configuration has taken part in International Defense Industry Exhibition MSPO in Kielce, Poland.

On the base of trials new stabilizers were designed with bigger size and better aerodynamic efficiency.

But in the meantime some progress was made in electronics and optics, as well as in gimbals stabilization and communication subsystems.

So on this base a new project was started under name SOPEL. It is small tethered aerostat system with multipurpose gondola (stabilized gimbals with day and low light camera and infrared camera as well, weather sensors, pollution sensors). Weight of the gondola is up to 7 kg. Aerostat has length of 6.5 meters and diameter of 2.3 meters with volume more 20 cubic meters. It can operate on altitudes up to 150 meters.

It is now introducing for UAV vehicles testing as a mean to monitor flying vehicles and retranslate theirs signals to ground command station. Bigger aerostat is planned for small sophisticated radar system which can be used in monitoring of land, seaside and water.

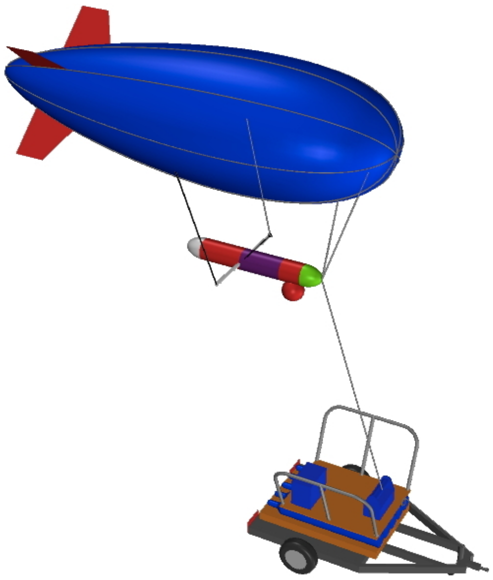

Figure 9. SOPEL aerostat system with multipurpose gondola and trailer with winch and compressor (Ireneusz KRAMARSKI)

6 CONCLUSION

Lessons learned

1 It is feasible to design and manufacture aerostat radar system with satisfactory performances (radar range and weather resistance) and reasonable costs of purchase and operations;
2 Steady progress in electronics provide new possibilities for aerostat system market utilization and for new applications;
3 Specific needs generate specific radar and EO equipment and on this base should be designed tethered aerostat system;
4 More volume of aerostat more problems with handling, transportation and operation, and more all purchase and operational costs (helium, crew, ground station or mobile station etc.);
5 Smaller aerostat systems allow for helium recovery in reasonably time by using mobile compressors; more volume less capability of mobility.

After a lot of years aerostats are returning to operational use. Main reason is theirs long time on station and resistance for weather conditions.

It is possible to operate a few of tethered small/medium monitoring systems in non crew mode.

Tethered aerostats, and especially those in positions of mobile lead observations in a variety of field conditions. Position BOS-2 was tested in forest areas to observe fire hazard. Attempts were also conducted follow-up of road traffic on the routes of communication. Platform together with the observation system has met expectations.

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