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Assessment of the Usefulness of Observation and Tracking Heads of the Long-Range for the Stratospheric Aerostat Recognition System

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Abstract. The paper presents the problems of applications of stratospheric systems to increase the tactical and reconnaissance capabilities of the Polish Armed Forces. The paper contains the results from examples of simulations which were designed to determine the cost/performance ratio of the production and operation of aerostats with strictly identified technical parameters in the context of their operational capabilities. It also describes the principles of operation of aerostats for the support of intelligence collection and the limitations imposed on aerostats by the specificity of tropospheric and stratospheric regions.

This work has been compiled from the paper presented during the 21st. International Conference on Computer-Aided Design, Manufacturing and Maintenance, Jurata, Poland, May, 8-12, 2017.

Finally, the article presents basic information about optoelectronic parameters of tracking and targeting units intended for operation in the stratosphere with a selection of optoelectronic tracking and targeting unit designs developed by Polish and leading global manufacturers.
Keywords: mechanics, optoelectronic head, stratospheric aerostat (HAPS)

1. BACKGROUND

Stratospheric imaging of the surface of the Earth provide a vast selection of information types which would be problematic or impossible to collect with ground-based systems. Stratospheric imaging technologies have been quickly growing in the number of their commercial and defence applications, from geodesy and cartography through oceanography, forestry, marine management and research, climate change research, the proactive prevention of natural disasters (with the assessment and improved combating of the effects thereof), and visual monitoring of ground-based objects in surveillance areas (the examples of the latter include tracking of launches / take-offs of aircraft and various types of operations and phenomena in near outer space).

Stratospheric surveillance is a method of remote intelligence collection which sometimes replaces and more often complements aerial and ground-based surveillance. Stratospheric surveillance consists of remote intelligence collection by passive surveillance or ‘marker-painting’ of areas of interests to measure the reflected radiation of the marker. Stratospheric surveillance most often uses systems operating in near and far infrared radiation spectra, the visible light spectrum, and the microwave spectrum, to name the most popular ones.

Due to their specific characteristics, stratospheric instruments provide deliverables the characteristics of which are somewhat different from and cross-complementary with the deliverables of aerial and ground based instruments. While aerial or aeronautical surveillance methods offer a greater flexibility of surveillance and intelligence gathering, given the relatively straightforward performance of immediate orders for imaging very specific areas of the Earth, they fail when the environmental information to be collected covers extensive areas or requires long-term and uninterrupted surveillance (Fig. 1). Stratospheric imaging is provided from much higher altitudes and enable systematic image recording of much larger surface areas of the Earth in successive sequences of time and at virtually any imaging frequency.

The primary hindrance of passive optical instruments is cloud cover, smoke, fog / mist and rain, which prevent production of actionable images. However, a stratospheric aerostat with a substantial payload capacity can use radar-based imaging to become capable of imaging under political, technical and other conditions that would render the mission of other aircraft types extremely difficult or impossible (e.g. in remote areas, over foreign territories, or within borderline zones).

The flexibility of applying the extensive capabilities of stratospheric aerostats is important to government agencies as it will facilitate an increasingly faster collection of intelligence. This will result in novel technologies of intelligence data processing and transmission, new capabilities for operational command and coordination of agencies, and much more, while related to the novel capabilities of operating stratospheric aerostats for electronic warfare.

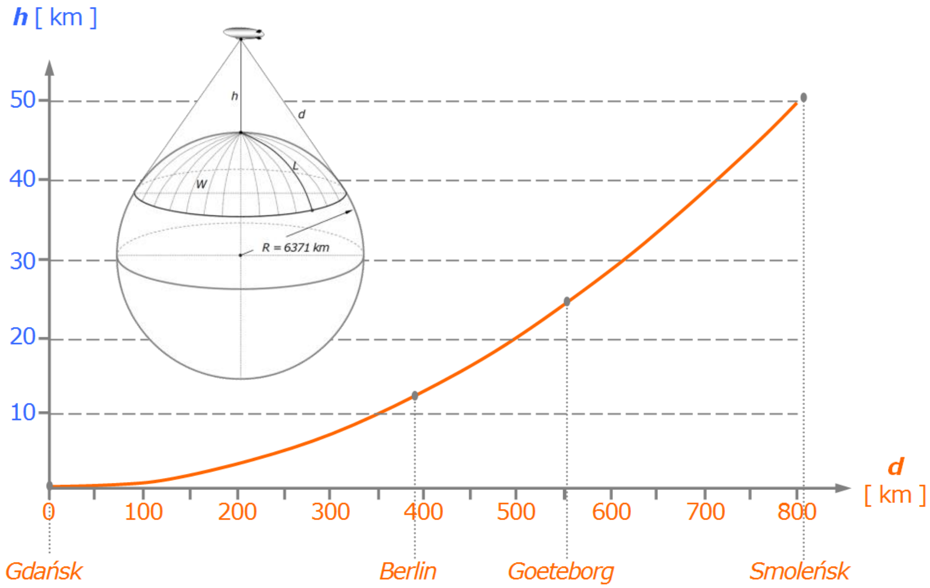

Fig. 1. Effect of surveillance altitude, *h*, on the surveillance perimeter diameter, *d* [3]

Optical and radar imaging provided by a stratospheric aerostat may provide different types of intelligence data, irrespective of cloud cover, weather, and certain interferences; this in turn will provide precise three-dimensional terrain models. The analysis of such intelligence data uncovers a wealth of detailed information, ranging from the evaluation of drought or flood-stricken areas on the scale of entire countries, or crop yield forecasts, to the assessment of the dynamics of urban sprawl evolution, or even soil settlement measurements with an accuracy down to millimetres.

It is undisputed that this outline of features and requirements of stratospheric surveillance will affect the detailed design engineering solutions applied in surveillance and tracking units and algorithms thereof developed for stratospheric surveillance missions of various natures and intents.

2. EXPECTED TECHNICAL PARAMETERS OF LONG-RANGE SURVEILLANCE AND TRACKING UNITS

An indispensable feature of state-of-the-art reconnaissance systems include surveillance and tracking units. The design of surveillance and tracking units includes optical assemblies, image converters / detectors and laser rangefinders; these units are usually called optoelectronic (OE) units. An OE unit must provide capabilities for surveillance of not just a specific part of terrain or air, but also for airborne or space-borne targets both at day and night, with the measurement of the target's motion parameters required for targeting. The Polish Armed Forces now operate subsonic cruise missiles capable of striking long-range targets (such as the AGM-158 JASSM with a range of 370 km, or the Naval Strike Missile with a range of approx. 200 km), they still require systems capable of recognising and acquiring targets to be struck with this ordinance. The time of residence within the striking range of these weapon platforms is a critical parameter of a surveillance system, its second primary task is to maximise the facility of target detection and identification. This can be achieved with a surveillance unit equipped with a CCD video camera, an IR (thermal imaging) video camera, a target tracking system, and an image stabilisation system. Such unit must feature controls of its position, data exchange interfaces, and an imaging system. The criteria which should be applied in the process of selecting a surveillance unit include:

- technical specifications of the unit;
- functions to be performed;
- the price of unit purchase / production;
- operating experiences;
- the quality of operation in tenuous atmosphere, with exposure to elevated UV radiation levels, at low temperatures (-60°C), maintenance-free operation, and permanent installation aboard a stratospheric aerostat;
- optimised use of the unit's parameters and functionalities in stratospheric conditions.

An analysis of the technical specifications of long-range tracking and targeting units should include a major technical parameter abbreviated to NETD. NETD, or noise equivalent temperature difference, is a measure of image noise in thermal imaging cameras. It is also a measure of the sensitivity of a detector of thermal radiation in the infrared, terahertz or microwave portions of the electromagnetic spectrum. NETD is a temperature difference of the image equal either to the detector's internal noise (and expressed as 'detector NETD') or the total electronic noise of the measurement system (and expressed as 'system NETD'). The usual NETD value for non-cooled bolometric cameras is 80-200 mK.

Cooled thermal imaging cameras with detectors based on HgCdTe (LWIR or MWIR) or InSb (MWIR) can reach a NETD of 10 mK. For the microwave radiation portion of the spectrum, NETD values usually range from several hundred microkelvins to as many as several kelvins.

The development of a new surveillance and tracking unit intended for long-range reconnaissance systems aboard stratospheric aerostats would require a study of diverse technical parameters and considerable experience in design engineering and operation. It should not be restricted just to the rudimentary parameters which directly result from the need to comply with general commercial and defence standards. Designers of OE units should also follow the parameters which can hardly be found in product catalogues or information materials (and which may include, for example, the types of applied components or systems required by the pursuit of unification, diagnostic susceptibility, operating life, resistance to ionising radiation, etc.). When developing a dedicated stratospheric OE unit, the following technical parameters should be considered first:

- time to standby [min];
- unit weight [kg];
- mass of the day/night temperature compensation and control blocks [kg];
- mass of service / diagnostic interfaces [kg];
- unit dimensions [mm];
- angles of vision [deg.];
- scanning speed [deg./s];
- LOS stabilisation;
- input voltage / current [V/A];
- detector field size [”];
- detector FOV [deg.];
- detector array pixel count;
- electronic zoom power [x];
- minimum illumination of the detector [lux];
- maximum focal length [mm];
- type and specific parameters of the laser generator;
- laser rangefinder wavelength [µm];
- laser class;
- laser energy output [mJ];
- beam divergence [mrad];
- rangefinder range [m];
- measuring accuracy [m];
- measuring rate [1/s];
- unit tracking system;
- minimum target size [pix];

- minimum contrast [%];
- tracking speed [rad/s].

Access to the experience and work of a global leader in this industrial sector is very limited, mainly due to the small number of solutions and the design of stratospheric platforms. On the one hand, design engineers who develop stratospheric platforms use solutions known from air and satellite reconnaissance instruments. The following part of this work presents the proposed designs which can be operated between high air space and near outer space, and meet the functionalities expected from instruments used at those altitudes.

Fig. 2. Examples of long-range surveillance instrument solutions [1]

The common features of long-range surveillance and tracking units for stratospheric aerostat reconnaissance systems include: dynamic image stabilisation (to offset the effects of vibration, temperature, radiation, etc.), application of state-of-the-art technologies, autonomous operation algorithms, and a number of performance features which permit easy integration with various types of radar platforms, remote data transmission and telecommunication systems, EW and ECM systems, and stratospheric missile killer combat systems.

For the sake of operator's convenience, integrated assemblies, or pods, have been developed for visual reconnaissance to facilitate recon operations from different platforms, including those not necessarily dedicated to such operations. The fit-out of a reconnaissance pod depends on the mission parameters, and on the carrier platform to some extent. An example of a reconnaissance pod is the U.S.-made Goodrich DB-110, with several units operated by the Polish Armed Forced (Fig. 3).

The reconnaissance pod configuration can be adapted by installing and removing different types of sensors and recorders. A reconnaissance pod usually carries a video camera and an IR camera. It can operate in two-channel simultaneous image acquisition mode during target flyby or without any need for a target flyby.

Fig. 3. Goodrich DB-110 reconnaissance pod Source:
http://utcaerospacesystems.com/cap/products/Pages/db-110-reconnaissance-system.aspx

Note that the higher the altitude of visual / image reconnaissance, the worse are its conditions, even with the reconnaissance range improved. Poland is a climatic region which enjoys relatively few days with high atmospheric clearness; hence, land reconnaissance in VIS spectrum at flight altitudes above 12 km should be limited to auxiliary reconnaissance functions only. Therefore, an air and ground reconnaissance system with a FOV below its stratospheric aerostat should also operate in other portions of the electromagnetic spectrum. This necessity has provided a major significance to the Concept of Air Surveillance, MC507, developed by NATO and defining the requirements for radar reconnaissance. According to this Concept, the Basic Volumetric Coverage (BVC) required for securing Air Policing missions with air penetration between 3 and 30 km (10,000 to 100,000 ft) is deployed over the NATO territory and extends 185 km (100 NM) beyond its borders

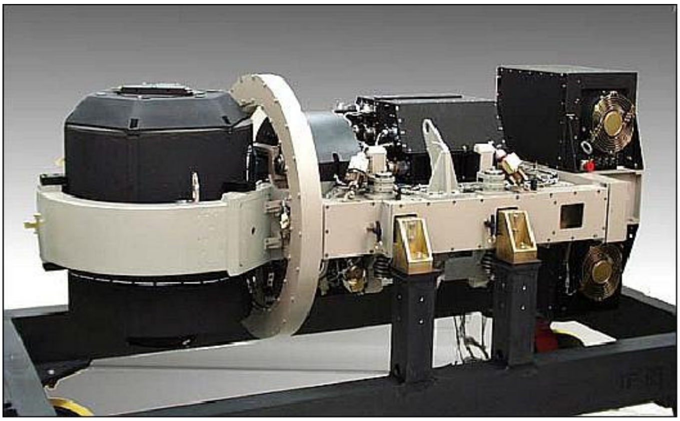

Fig. 4. SYERS-2 image reconnaissance system aboard a satellite platform
Source: https://directory.eoportal.org/web/eoportal/satellite-missions/o/ors-1

The air data (gathered by radar and imaging intelligence) managed by the personnel who operate automatic collection, processing and analysis systems for the data enables recognition, identification and tracking of aircraft within the controlled space. Hence, since Poland is missing its own stratospheric radar reconnaissance measures, does it really have a full capability of command and control of military aircraft operating in the Polish airspace?

A similar importance is assigned to other systems which can be installed aboard stratospheric aerostats. The systems mainly include ESM (Electronic Warfare Support Measures) and typical EW (Electronic Warfare)[1]. Acquisition of a properly outfitted stratospheric aerostat will facilitate better accomplishment of strategic objectives related to radio electronic intelligence and reconnaissance, incapacitation by jamming of air defence electronic warfare measures and systems, command over combat, radio-navigation and long-range assets, as well as central government and military communications of strategic and operational use. Operational and tactical objectives can be achieved by continuous and intensive reconnaissance, incapacitation of radar, radio navigation and communication measures operated by ground and air forces by jamming and/or beam weapons. As dictated by the practical experience from modern warfare, the first casualties of the battlefield include the missile and artillery, air defence, and air force electronic systems.

As a part of information warfare, electronic intelligence can aid in the identification of vectors and areas of high electronic activity of the enemy and the determination of the locations of enemy assets. Hence, electronic intelligence includes RF, electronic and laser reconnaissance.

Deploying a reconnaissance unit aboard a stratospheric platform can unlock new capabilities which target satellite reconnaissance. Satellite reconnaissance has been qualified by numerous experts hired by the leading military powers as the primary and most important type of intelligence at peace and war alike. Satellite reconnaissance couples imaging with wide-range electronic intelligence. Stratospheric visual reconnaissance with an upward field of vision is devoid of the drawbacks which plague and severely hinder reconnaissance of the ground beneath stratospheric reconnaissance platforms. Atmospheric clarity upward from a stratospheric reconnaissance vehicle is very good with no or little cloud coverage, interference from particulate matter, or high traffic of other stratospheric vehicles or rocket ships. Hence, automated detection, warning and surveillance and tracking systems is easier than for downward-looking systems, which also improves operating effectiveness. Intelligence gathering of data concerning near outer space permits a fast analysis and modelling of reconnaissance satellites and space debris, which enter the atmosphere.

Aboard a stratospheric aerostat, it is easier to detect a ballistic missile launch and its trajectory, satellite hunter-killers, space collision modelling and prediction, and trajectory management of beam weapons, which has become a factor, given their current state of development.

[1] See: Dymanowski K. *Zmiany w koncepcji walki elektronicznej NATO*. Przegląd Sił Powietrznych 2009, vol. 11.

3. IN SEARCH OF THE TARGET SOLUTION

The search for an optimum design of long-range surveillance and tracking units capable of being applied in stratospheric aerostats is an extremely difficult task, due to the following conditions which, more often than not, are mutually exclusive:

1. Altitudes at and above 20 km above sea level feature extremely adverse conditions, including:
   - Winds of varying direction and roughness (and which can reach 100 km/h), capable of triggering vibration of the stratospheric carrier/platform vehicle, despite the average air density being ten times lower than at the ground: this requires active stabilisation systems (and these adverse effects do not occur in LEO satellites, which travel at 28,000 km/h at an altitude of 160 km).
   - Extremely low temperatures (Fig. 2), which can drop down to -80°C: this factor requires electronic systems completely different from those applied in ground or satellite-based systems.
   - Cosmic radiation (with outer space helium protons and nuclei which generate primary radiation) and ionised particle radiation (so-called secondary radiation) which, especially during solar storms, can destroy poorly hardened electronic and detection equipment.
   - UV radiation, which degrades many types of plastic polymers: polypropylene, polyethylene, polymethyl methacrylate (organic glass), aramids, etc. UV absorption degrades the polymer chains and reduces their strength in multiple locations of the structure at the same time. The rate of this destruction increases over time and with the intensity of exposure to sunlight.
2. Not unlike in aircraft systems, the design of stratospheric surveillance instruments requires ultralight and extremely strong composites for enclosures and mechanical parts.
3. The imaging devices of a stratospheric platform require hardening against failure or degradation caused by high-powered laser beams emitted from the ground.
4. Given the costs of acquisition/development and the practical military importance, the know-how of satellite technologies and long-range imaging equipment is under the special protection of its governmental and non-governmental users.
5. The design of long-range surveillance equipment requires something called ‘deep factoring’, which means the consideration of the intellectual and processing capabilities of the potential Polish manufacturer; international cooperation is generally disqualified here due to the increased confidentiality risks.

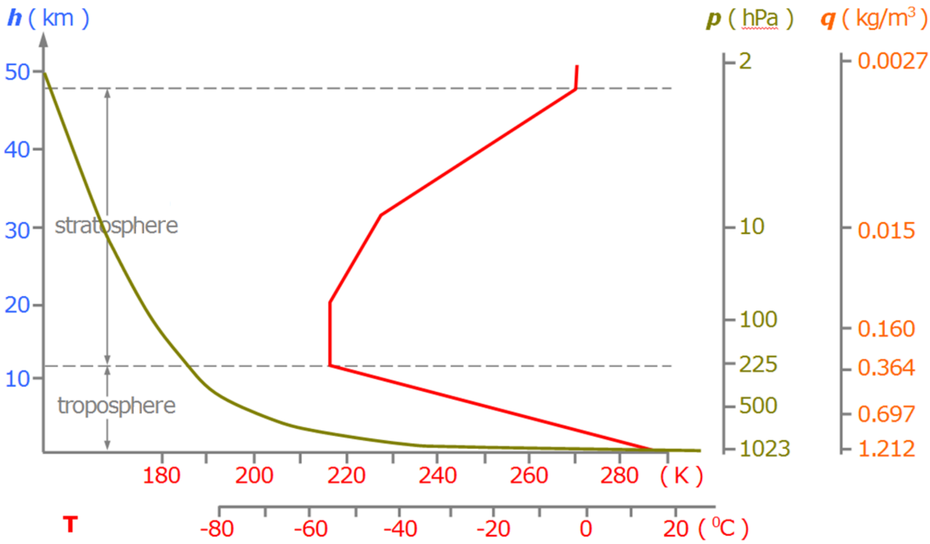

Fig. 5. Temperature (*T*), atmospheric pressure (*p*) and air density (*q*) vs. altitude (*h*) above sea level [4]

It is the opinion of the authors that the process of development and application of long-range surveillance and tracking units in Poland must follow a high volume of all-round analysis, comparisons and simulations designed to provide answers to the following questions: What is the objective? Using what measures and technologies will the objective be achieved? When and for what cost will the objective be achieved?

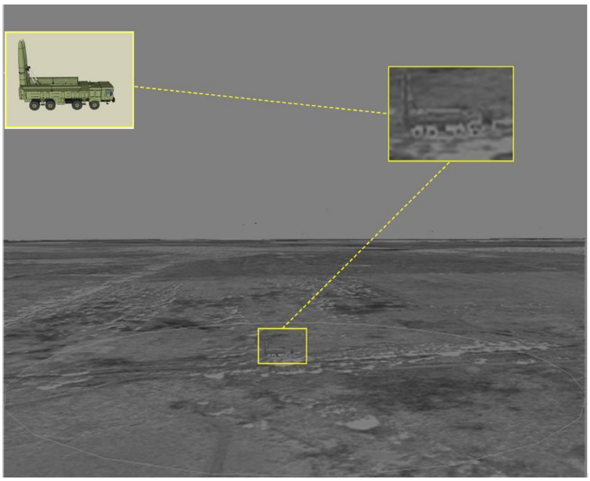

Fig. 6. Application of Google Earth™ for simulating the imaging of the Iskander-M mobile short-range ballistic missile system platforms [4]

An example of such an analysis which provides aid for the computer-aided design of long-range surveillance systems is a simulation developed by the authors with Google Earth™ to demonstrate the imaging visibility of various ground-based objects. The application allows placing and surveying 3D vectorised objects on a geographical map with all angular dimensions retained as resulting from the orientation between the surveillance site and the surveyed objects. For this simulation, a 3D model of an Iskander-M (SS-26 stone, max striking radius of 500 km) mobile short-range ballistic missile system was developed and deployed within the Kaliningrad Oblast. Figure 6 shows an example of a FOV visualisation for an IR camera monitoring an Iskander-M launcher from an altitude of 20 km and a distance of 200 km, with the following simulated performance parameters of the IR camera:

- Image resolution: 640 x 512 pixels (corresponding to the detectors at the disposal of PCO S.A.)
- Camera FOV angle: 1 mrad (0.0573°)

It is evident that by an intuitive visualisation of the simulation results, the method permits a very fast verification of the assumptions and arguments for specific engineering solutions of long-range IR cameras; this largely simplifies the correct calculations of the optical performance of such equipment.

4. CONCLUSION

The information provided so far herein suggests that image data acquisition systems applied in reconnaissance, including continuous and detailed updating of large-scale digital maps are now developed without interruption. This trend is also stimulated by the development of new technologies for generating DEM (digital elevation models) based on stereoscopic image correlation. While novel commercial satellite imaging systems can provide data on demand, instantly, and in digital formats, in multi-spectrum and panchromatic ranges, with assured temporal repeatability, high radiometric definition and good stereometric accuracy, the specifics of the defence sector requires stealth-like imaging that must be competitive to air photography and at low acquisition costs. On the other hand, the excellent three-dimensional resolution of the data acquired by stationary stratospheric aerostats will make the air vehicles increasingly popular on the global market. Air imaging will shift from photography to digital processes and (most likely) integrated with commercial satellite companies.

Building and outfitting Polish stratospheric platforms will take reconnaissance and electronic warfare operations to the next level. The tactical and operational advantages of stratospheric platforms will unleash new opportunities and horizons for strategic defensive capability and security management, military command, research and development centres, optical and electronic industries, state administration and multiple agencies with a vested interest in a secure source of up-to-date and reliable ground and air data.

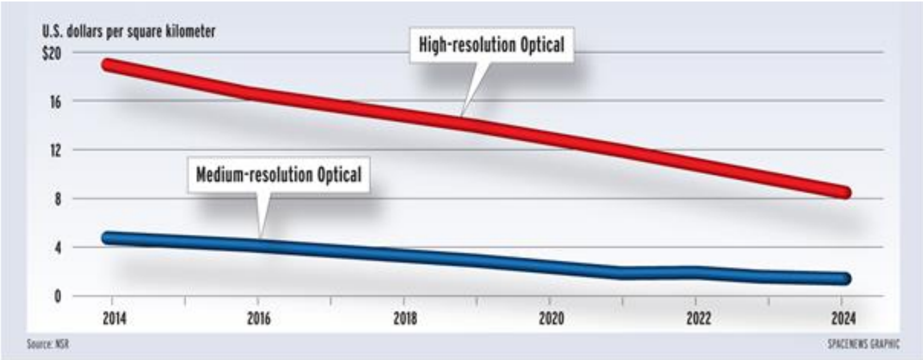

Fig. 7. Forecast of a decrease in the pricing of imaging data acquired for commercial use [13]

The ownership of such an innovative and competitive asset, given its increasing capabilities, will become a deterrent to aggressive forces and organisations. The imaging data and other intelligence acquired about events in the space controlled with stratospheric aerostats could become commercialised within a time frame that will return the costs of its development and/or acquisition.

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Ocena przydatności głowic obserwacyjno-śledzących dalekiego zasięgu dla systemu rozpoznania aerostatu stratosferycznego

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Streszczenie. W artykule przedstawiono problematykę wykorzystania systemów stratosferycznych do zwiększenia możliwości taktycznych lub rozpoznawczych Sił Zbrojnych RP. Przedstawiono wyniki przykładowych symulacji, których celem jest określenie wskaźnika koszt/efekt wykonania i zastosowania aerostatów o ściśle określonych parametrach technicznych w kontekście ich możliwości operacyjnych. Opisano także zasady wykorzystywania aerostatów do wspierania sposobów pozyskiwania informacji wywiadowczych oraz ograniczenia aerostatów wynikające ze specyfiki obszarów troposfery i stratosfery. W artykule podano podstawowe informacje związane z parametrami optoelektronicznych głowic śledząco-celowniczych, przeznaczonych do pracy w stratosferze oraz przedstawiono wybrane konstrukcje optoelektronicznych głowic śledząco-celowniczych firm polskich i zagranicznych przodujących na rynku światowym.

Słowa kluczowe: mechanika, głowica optoelektroniczna, aerostat stratosferyczny