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SAFETY OF NAVIGATION SATELLITES

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ABSTRACT

The intensive development of space technologies used in military applications has brought a huge number of applications in the economy. First of all, satellite navigation systems should be distinguished. All systems in operation today are based on signals from satellites located at relatively high altitudes above the Earth. The hegemonic aspirations of some groups that rule in space "powers" provoke states, eager for their own peaceful development, to protect themselves from destructive activities in outer space. An example of such a destructive action in space are attempts to physically destroy inactive satellites, causing the formation of a huge cloud of debris in space from the crashed satellite, threatening the safety of all other space objects passing through it. There are currently known successful attempts to destroy LEO (Low Earth Orbit) satellites orbiting at lower altitudes. The more difficult task is to destroy the GEO satellites - orbiting at much greater heights above the Earth. The satellites of Medium Earth Orbit (MEO) navigation systems are also relatively large distances from the Earth's surface (about 20,000 km), but targeting them is facilitated by the fact that they transmit precise positions in their signal. Providing a potential enemy wishing to destroy these satellites with accurate information about their own location is unacceptable in the event of such a threat. You can turn off beacons, but then all civilian users will no longer be able to use this service. The paper presents the way of functioning of satellite navigation, in which the coordinates of satellites are intentionally distorted, transmitted in the satellite message while continuing relatively accurate positioning.

1. INTRODUCTION

On November 22, 2021, at night, Russian state television released a chilling statement threatening to deploy new ASAT technology against 32 western satellites that NATO uses for military operations. Moscow last week tested a missile against a redundant Soviet-era spy satellite, sending into orbit thousands of debris particles that threatened the security of the ISS.

State-controlled Russian TV channel host Dmitry Kiselov - dubbed Putin's "spokesman" and "chief propagandist" - argued that the satellite attack was a deliberate warning to the West not to cross the Kremlin's red lines in Ukraine. If relations worsen, he said, Russia could destroy 32 GPS satellites that are crucial to NATO's military operations, including missile strikes. "We shot down the old Soviet satellite Tselin-D in space orbit," said Kiselyov. - This was the end of the tests of the Russian anti-satellite system, the accuracy of which (Defense Minister) Sergei Shoigu called jewelry. "This means that if NATO crosses our red line, it risks losing all 32 GPS satellites simultaneously." This would "blind all their missiles, planes and ships, not to mention ground forces."

According to the Moscow Center for Strategy and Technology Analysis, the Nudol satellite - dubbed a "Star Warrior" by the newspaper Izvestia - was tested at least nine times between 2014 and 2020 before being first deployed to destroy the actual satellite on November 15. Videos were shown of the tests suspected of using a new technology that was launched from the Plesetsk military cosmodrome last week.

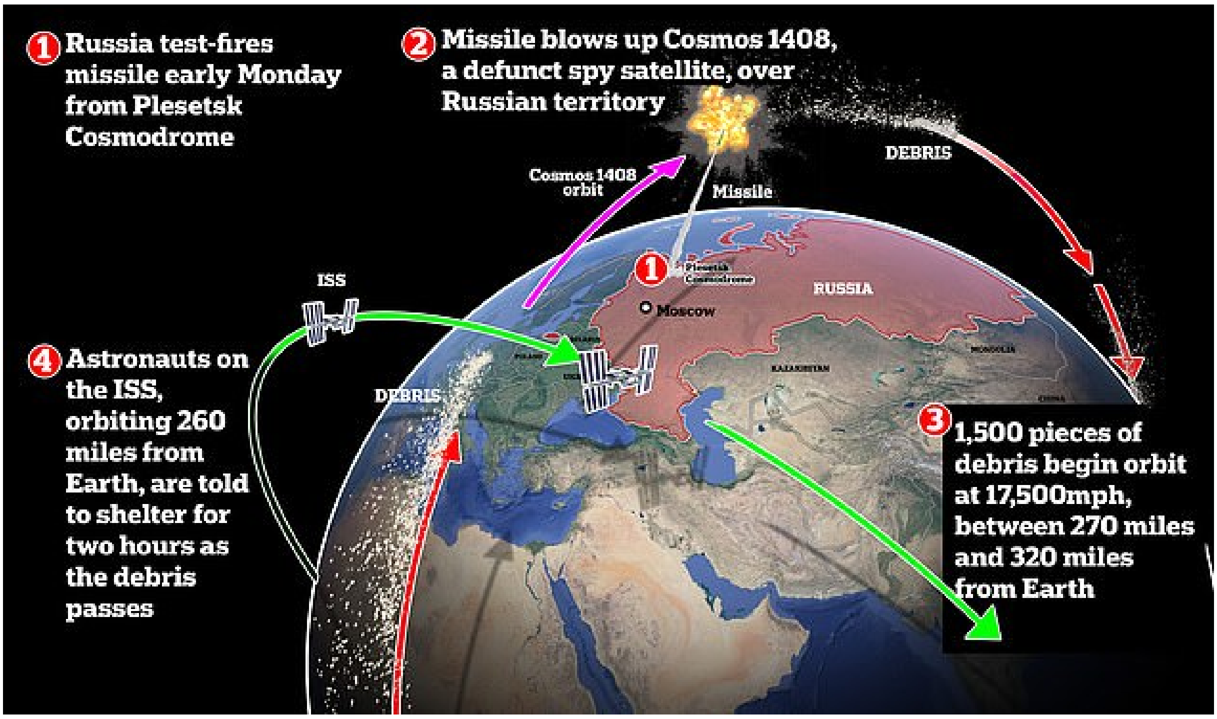

Fig. 1. Russia crashed one of its satellites with a rocket on Monday, November 15, 2021.
The destroyed target was Cosmos 1408, a spy satellite launched in 1982. The impact created a field of 1,500 pieces of debris that threatened the ISS crew.

2. WORLD REACTION

Companies and organizations also reacted immediately to the threat from Russia.

Northorp Grumman - next generation portable NGHTS targeting system operating in environments without GPS signal

Fig. 2. Idea NGHTS (Northop Grumman)
Source: GPS World, 2022/2

NGHTS can perform high-speed target acquisition, laser terminal operation, and laser spot imaging functions. Its high-resolution infrared sensors ensure accuracy and grid capability over extended ranges.

- the fifth and sixth GSSAP (Geosynchronous Space Situational Awareness Program).

-6 satellites join the constellation supporting the US Space Command's space surveillance operations as a dedicated Space Surveillance Network sensor.

GSSAP also supports the Combined Force Space Component Command by collecting information data about the space environment, allowing for more accurate tracking and characterization of human-made orbiting objects. The SSC mission covers the procurement of: launch operations; cosmic domain awareness; positioning, navigation and synchronization; missile warning; satellite and ground-to-ground, command and control and data communications.

Orbital Insight - Orbital Insight has been awarded a contract from the US Department of Defense (DoD) to provide a technology platform to identify deliberate GNSS interference and manipulation operations around the world. The platform will use commercially available data to detect GNSS spoofing, where forged or manipulated GNSS signals are used to confuse opponents or conceal illegal activities, posing a threat to both governmental and commercial operations.

Fig. 3. matejmo / iStock / Getty Images Plus / Getty Images
Source: GPS World, 2022/2

The European Union Aviation Safety Agency (EASA) in the current context of the Russian invasion of Ukraine regarding jamming and / or impersonation of GNSS issued a safety information bulletin on March 17, warning of a GNSS failure leading to a deterioration in the quality of navigation and surveillance. According to a newsletter addressed to national aviation authorities and airlines, reports analyzed by EASA show that since February 24, GNSS counterfeiting and / or jamming has increased in four key geographic areas:

• Kaliningrad Oblast, the vicinity of the Baltic Sea and neighboring countries

• Eastern Finland

• Black Sea

• Eastern Mediterranean, close to Cyprus, Turkey, Lebanon, Syria and Israel, as well as northern Iraq.

Global Spire's Data Exploitation and Enhanced Processing (DEEP) - Spire Global Inc., a provider of space data, analysis and services, uses a constellation of around 40 geolocation satellites to detect GPS interference. Spire collects data for use by the US Space Force, which is a particularly important task in light of Russia's invasion of Ukraine.

Seeker UAV - The Seeker UAV has proved to be an important asset in the recent exercises of the Spanish Navy. UAS, developed by GMV and the Spanish technology company Aurea Avionics, was used to gather intelligence by identifying threats, tracking vehicles and other targets, and assessing terrain, traffic routes and neighborhoods.

Fig. 4. (Photo: GMV)
Source: GPS World, 2022/1

AeroVironment - According to the Pentagon, the drones were quickly developed by the air force specifically to meet the requirements of Ukraine. Ghost drones are manufactured by Aevex Aerospace and have similar capabilities to AeroVironment's UAS Switchblade disposable "kamikaze".

Fig. 5. The Phoenix Ghost drone is similar to AeroVironment's disposable Switchblade drone. (Photo: AeroVironment)
Source: GPS World, 2022/4

Leonardo DRS and Leidos - To help counter attacks that reduce GNSS capabilities on combat vehicles, Leonardo DRS has developed a modified data distribution unit - the DDUx II computer with built-in capabilities for positioning, navigation and synchronization (APNT), which the company calls Assured Positioning.

Fig. 6. Source: GPS World, 2022/5

Built-in computer for navigation and synchronization and (AC²ES) extends standard military PNT sources with technologies such as anti-jamming, anti-spoofing, M-code reception, additional RF sources, vehicle vision navigation with infrared (IR) sensor, wheel rotation and inertia measurement units (IMU).

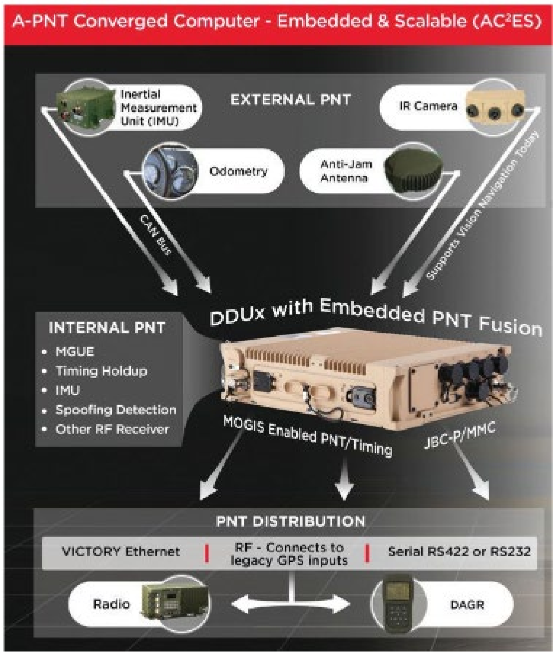

Fig. 7. Functions of a computer equipped with APNT
Source: GPS World, 2022/5

Infrared Navigation - For vision navigation, Leonardo DRS uses software developed by a Leidos partner that extracts data from existing equipment in vehicles, many of which already have infrared cameras. In a GNSS denial environment, this enables the system to be navigated by matching what the IR camera oversees in the image database.

NTS-3 L3Harris - More than 100 experiments will be conducted with satellite navigation technology-3 (NTS-3), which is slated to go live next year, according to a US Air Force official and reported by FedScoop. Unlike mid-earth orbit GPS satellites, the NTS-3 will run in geosynchronous orbit around the earth for one year.

Ultimately, the NTS-3 will identify key aspects for new GPS receivers that contain multiple signals and adapt easily to combatants' needs.

The NTS-3 experiments will also include ground equipment and terminals such as command and control stations and programmable radios. Specific improvements in the ground segment will allow experimenting with automatic "light off" operations, control station failover, and near real-time determination of the environment, generation of error corrections and orbit enhancements. On-board systems will monitor clock accuracy and orbit parameters to mitigate errors and alert the user. The NTS-3 will test a new digital signal generator that can be reprogrammed in orbit, allowing new signals to be transmitted, improving performance by avoiding and eliminating interference, and adding anti-counterfeiting signatures. The AFRL will also study satellite antenna configurations to provide Earth coverage and steerable regional beams across multiple frequencies and signal codes. The NTS-3 satellite will be equipped with 110 antennas that will help counteract GPS jamming attempts. Ultimately, NTS-3 is expected to provide users with increased signal stability, availability, integrity and accuracy.

CACI International - In January 2023, CACI will place two experimental objects in low orbit, the task of which is to operate the GPS system in the field of PNT in the disputed area of space. CACI has completed a critical design review for DemoSat. CACI and its partner York Space Systems will also demonstrate Tactical Intelligence, Observation and Reconnaissance (TacISR) payload. The TacISR payload identifies and captures key signals of interest and works with the CACI Beast ground receiver to demonstrate real-time radio frequency geolocation to deployed US forces.

Fig. 8. The artist's vision of CACI / York Space DemoSat
(Source: CACI)

Xona Space Systems - has completed environmental testing for the upcoming demonstration mission, which is another step towards a high-performance commercial navigation system. The first Xona Demonstration Mission has successfully completed testing at Experior laboratories and is getting ready for launch aboard the Falcon 9 in May.

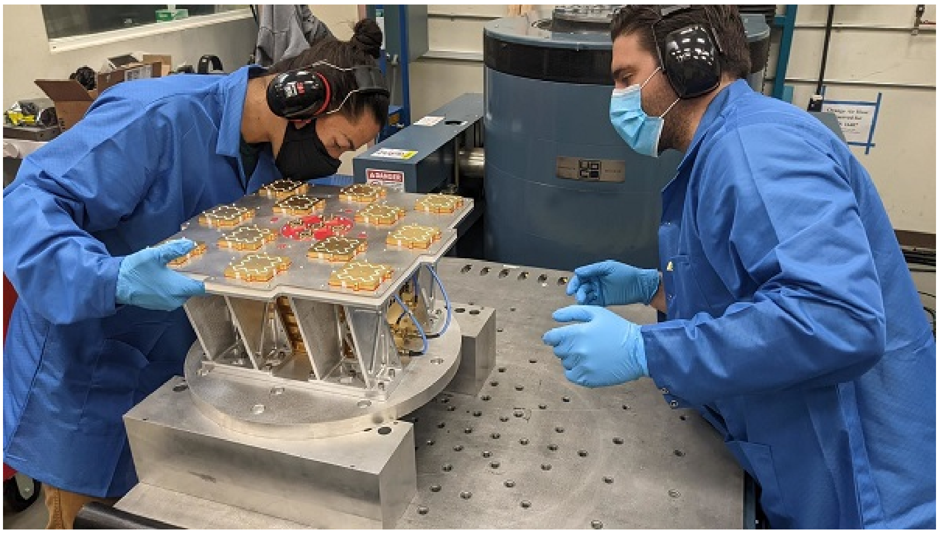

Fig. 9. The LEO satellite of the Pulsar constellation in preparation (Photo: Xona)

The final Pulsar constellation will consist of several hundred LEO satellites delivering safe and reliable, precise PNT services designed to meet the needs of advanced applications such as autonomous cars, precision farming and construction, augmented reality, critical infrastructure, and more.

Xona is backed by the Seraphim Space Investment Trust (LSE: SSIT) and MaC Venture Capital, with Toyota Ventures, Daniel Ammann (co-founder of u-blox) and Ryan Johnson (former CEO of BlackBridge, constellation operator Rapideye). Follow-on investors also include 1517 Fund and Stellar Solutions.

3. DEVELOPMENT OF ASAT IN RUSSIA

After the collapse of the Soviet Union, Russia began developing a much more improved co-orbital ASAT known as the Naryad. Supposedly designed to reach heights of up to 40,000 km and containing many warheads in one actuation. Naryad would likely be a serious threat to GEO satellites. The system underwent limited testing - after one start-up in 1994 - and no confirmed interceptions. Unlike the Soviet Union, Russia has an ASAT kinetic physical arsenal including the water-launched ASAT system with direct missile lift. In December 2018, Russia conducted the seventh test of the PL-19 / Nudol aircraft with the ASAT system with direct output. The PL-19 / Nudol performed its first successful test in November 2015, after two previous failed attempts.

Unclassified reports from the US suggest that both this launch and the previous test in March 2018 used a Mobile Transporter Launcher (TEL) within the Plesetsk spaceport complex instead of a static launch pad. At least six of the seven starts are confirmed to come from Plesetsk. A mobile launch system would theoretically allow ASAT to be launched outside the spaceport, providing greater flexibility in locating LEO satellites at slopes above 40 degrees flying over Russian territory. While not specifically designed as an ASAT weapon for direct use, Russia's S-400 surface-to-air mobile missiles, capable of reaching a maximum altitude of 200 km, could potentially reach the LEO satellite. A continuation of the surface-to-air missile system in the next edition, the S-500, is expected to reach heights of up to 300 km if launched directly upwards. Oleg Ostapenko, Russia's former deputy defense minister once stated that the S-500 would be able to intercept "low satellites and space weapons." After the S-500 was first tested in 2018, the production schedule for the new missile was delayed, and "There is no indication of when the actual S-500 will be released." Like the PL-19 / Nudol system, using the S-400 or eventually the S-500, as the direct climb ASAT requires the use of precision aiming, which has yet to be achieved. The S-500 has been thoroughly tested in 2020 and is scheduled to be completed in 2021 as a replacement for the S-400. According to Russian military sources, the missile is designed to hit space objects, as well as defend areas from space weapons. The head of the Russian Air Force Space Forces said the S-500 is capable of destroying supersonic weapons and satellites in close space. Moreover, by ensuring that the missile class could be used as an ASAT weapon. The deputy chief of SAM RAF troops, Yuri Murawkin, said that "the boundaries between air and space are small and the recognition of whether an air enemy is becoming a space enemy or an air enemy may be gradually removed."

Fig. 10. The Mig-31BM "Foxhound" plane on September 14, 2018, photographed at the Żukowski airport near Moscow. The plane is carrying what has since been identified as a potential anti-satellite weapon. (shipsash / jetphotos.com) (source: CSIS Space Threat Assessment 2020)

A modified Russian MiG-31 fighter was photographed in September 2018 with an unidentified missile that, according to some reports, could be a "mockup" of an ASAT air-fired weapon. This situation is a consequence of the Russian Duma statement in 2013, which expressed the intention of the Russian government to build a designed air-to-space system capable of "intercepting absolutely everything that flies from space", the system shown in the photo from September 2018 will almost certainly be limited to targeting LEO objects due to their size. In 2017, the squadron commander of the Russian Air Force confirmed that the ASAT missile was designed for use with the Mig-31BM aircraft.

On April 15, 2020, Russia tested another PL-19 / Nudol launch, which was publicly condemned by the US Space Command. The PL-19 / Nudol was launched from the Plesetsk cosmodrome in northern Russia, covering 3,000 kilometers and then launching into the Arctic Ocean. This test did not seem to work for kinetic impact against anything in the LEO. On December 19, 2020, Russia tested the system's platform one more time. US Space Command officials stated that "Russia's continuous testing of their systems shows threats to the US and allied space systems." These appear to be the ninth and tenth tests of the system, the last eight of which were successful.

Russia has not publicly announced the development of a new ASAT coorbital program since the collapse of the Soviet Union, but in the past few years, the Russian Air Force has started building a series of small LEO version of "inspector" satellites that demonstrated some of the technology required to operate such a system. In 2017 and 2018, three small Russian satellites - Cosmos 2519, 2521 and 2523 - engaged in maneuvers to meet and approach LEO facilities, sparked a statement of concern at the US State Department. Although after the Russian premiere of Soyuz in June 2017, it seemed that one LEO satellite - Cosmos 2519 was simply located - the second satellite was detected after two months, it was likely sent from the first as its satellite. The Russian Defense Ministry announced that the second satellite was designed to "inspect the state of the Russian satellite". In October 2017, a third satellite was launched from Cosmos 2519. Within a few months, 3 satellites engaged in a series of RPO maneuvers and exercises, including slow passes, close approaches and meetings. In February 2020, Chief of Space Operations General of the US Space Force John Raymond appeared to be referring to these three satellites when he said that he "showed the characteristics of a weapon." Analysis of Russian procurement documentation used and contractor reports published in Jane's Intelligence. showed the relationship with the satellites Cosmos 2519, 2521 2523 with the program name Nivelir. Agreements signed in 2016 between the Nivelir program and a well-known Russian company for the development of radiation absorbing materials suggest that future Nivelir satellites - such as Cosmos 2535, 2536, 2537, or 2538, all launched in July 2019 - May be covered with a protective film that protects before being tracked by optical or infrared sensors from the ground or from space.

The United States accused Russia of proceeding in the coorbital ASAT test in July 2020 this test was more sophisticated than the direct hit ASAT test. It was the Russian Cosmos 2542 satellite that contained the smaller Cosmos 2543 satellite in it. Cosmos 2542 launched the Cosmos 2543 in 2019. On July 15, 2020, Cosmos 2543 launched a small object near the unrelated Russian Cosmos 2535 satellite. This experiment mimicked a similar satellite operation. in 2017, when the Cosmos 2521 satellite was launched from its home satellite Cosmos 2519. In response to the July 2020 test, the US Space Command issued a statement that condemned the test and assured that the small object launched from Cosmos 2543 could be used to track satellites. In response, the Russian defense ministry said these nesting satellites or matryoshkas are routinely deployed as Russia's inspection and surveillance of other space assets. The Kremlin continues to maintain that Russia has always been, and remains, a country committed to the full demilitarization of space and not to deploying weapons in space.

Cosmos 2543 has been very active since its launch from its home satellite. Before the object was dropped in July 2020, the inspector satellite was constantly changing orbit to synchronize it with other Russian satellites. This is not the case with most satellites, which rarely maneuver this way. In June 2020, Cosmos 2543 joined Cosmos 2535 in orbit. Another Cosmos 2536 satellite was separated from one of these satellites. In September 2020, Cosmos 2543 began to move away from the others, but Cosmos 2535 and 2536 remained close together for several weeks. The two satellites were so close to each other that it was possible they did docking maneuvers; however, it was difficult to be sure without Increased Cosmic Consciousness (SDA). One observation was reported by the SDA as a single object instead of two unique objects, which additionally led to speculation that the satellites had docked. On October 12, 2020, Cosmos 2536 and 2535 were separated, and four days later Cosmos 2536 was reportedly 20 kilometers from Cosmos 2535. Until October 21, Cosmos 2536 was again within a kilometer of Cosmos 2535. This was not a weapon test, but these the orbital movements are very unusual and give rise to suspicions about the motivations behind such actions.

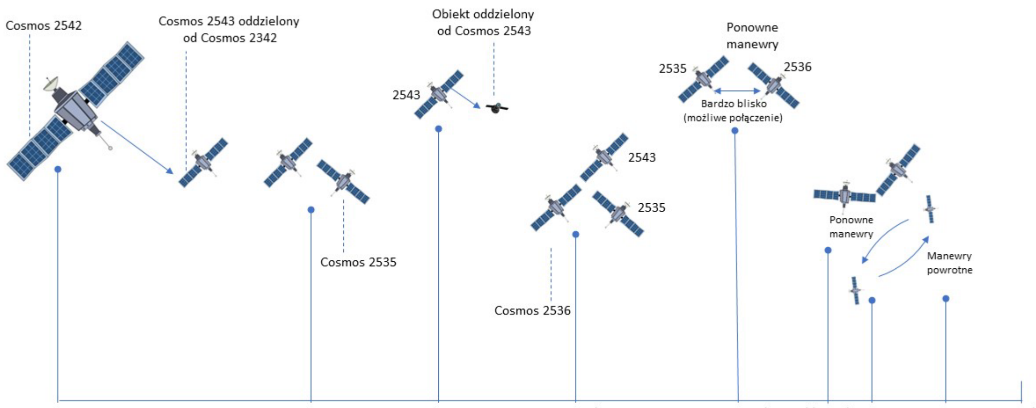

Fig. 11. Russian satellite maneuvers in LEO in 2019-2020
(source: CSIS Space Threat Assessment 2021)

Spying on a spy satellite

On November 25, 2019, Russia launched the small Cosmos 2543 satellite for what the Russian Ministry of Defense described as "the target orbit for monitoring the status of its own satellites." Two weeks later, the ministry announced that the Cosmos 2542 satellite was jointly launched with Cosmos 2543. Three days after launch, Cosmos 2542 performed an orbital maneuver to synchronize its orbit with the US 245 satellite, which is believed to be spying on the US satellite (NRO Bureau Satellite). Amateur satellite observers who record and share satellite observations online noticed that the US 245 satellite made its own maneuver shortly thereafter, perhaps to bypass Cosmos 2542. In January 2020, Cosmos 2542 maneuvered towards and approached the American spy satellite again. at a distance of approx. 50 km. A day later, the USA 245 made another maneuver to distance itself further from the Russian inspector's satellite.

In an interview with Space News, General John Raymond, Commander of the US Space Force and head of the US Space Force Operation confirmed this close approach.

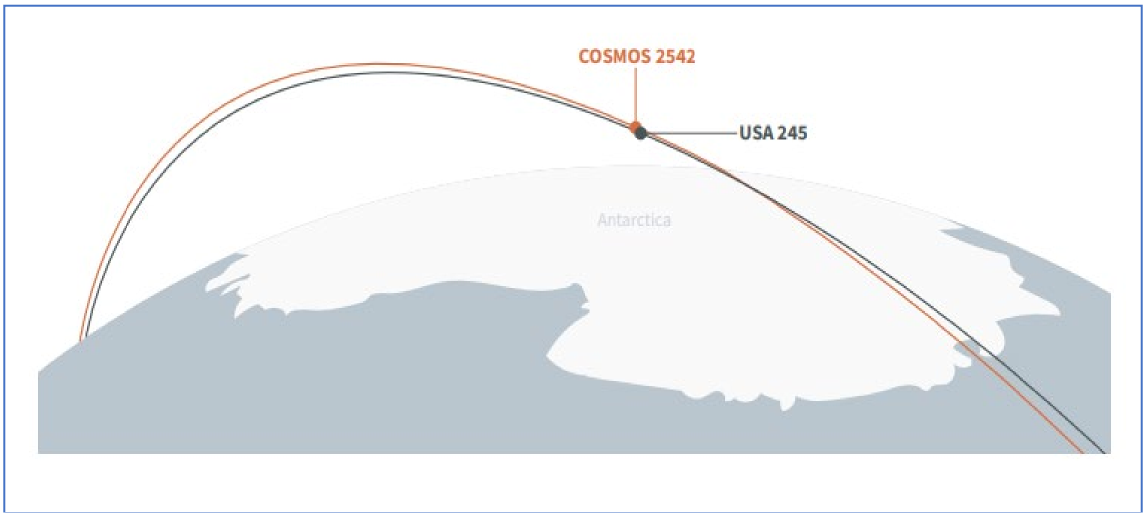

Fig. 12. Orbital trajectories for Cosmos 2542 and USA 245 on January 23, 2020.

The latest Russian co-orbital system can be designed to track GEO satellites. For this, the Burevestnik program was created. This satellite is likely to use low thrust, but a very efficient electric drive for maneuvering. These are light satellites - probably similar to those from the Nivelir program - in the vicinity of the GEO belt. A report published in 2019 indicated that a new ground control center is being built for the Nivelir and Burevestnik programs. In the same place, the Soviets used the Istrebitel Sputnikov mission in the 1960s to control the mission. While there is no evidence yet of maneuvering light Russian satellites in the GEO belt, the larger satellite has been observed engaging in suspicious activity under the ROP regime. The satellite - known as Olymp-K or Łucz - drew attention to the change in position in the geosynchronous belt, occupying at least 19 different positions since its launch in September 2014. Łucz first attracted attention as an object placed between two satellites served by Intelsat, an American satellite communications company. Placing a satellite in GEO in this way could allow for a thorough inspection or potential interception of their communication links. In September 2015, Lucz approached the third satellite, Intelsat 192. The international reaction intensified in September 2018, when French Armaments Minister Florence Parly accused Russia of having committed a "spy act" because he had approached the Franco-Italian military satellite "a little too much". close "in October 2017.

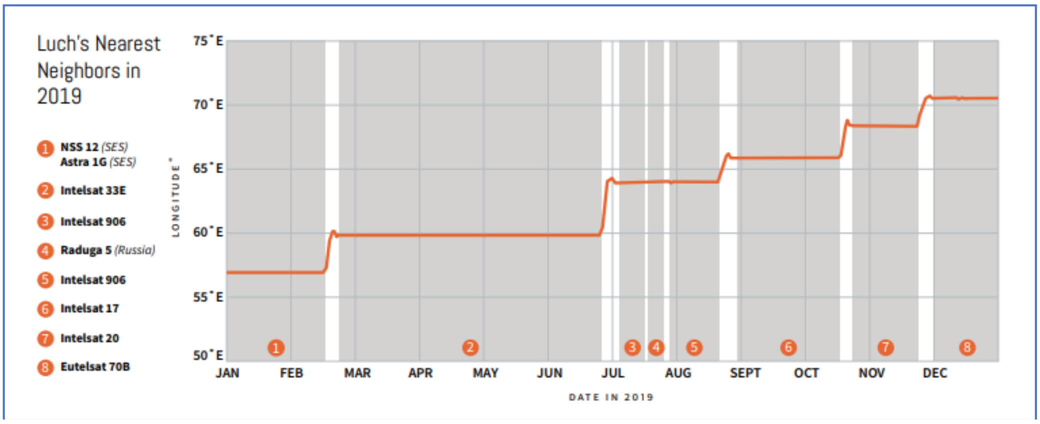

Fig. 13. Łucz continues the exploration of the GEO belt. The Russian satellite has stopped at 19 different positions in the geostationary belt since its launch in 2014, including the one shown here in 2019. (source: CSIS Space Threat Assessment 2020)

An analysis of Lucz's behavior in orbit since its launch in 2014 suggests the satellite has moved closer to 11 Intelsat satellites, four Eutelsat satellites, two SES and at least nine other satellites operated by Russia, Turkey, Pakistan, UK and the European Space Agency. While Lucz appears to be maneuvering around the GEO lane in a systematic, deliberate manner, reports suggest he did not damage any of the neighboring satellites along the way.

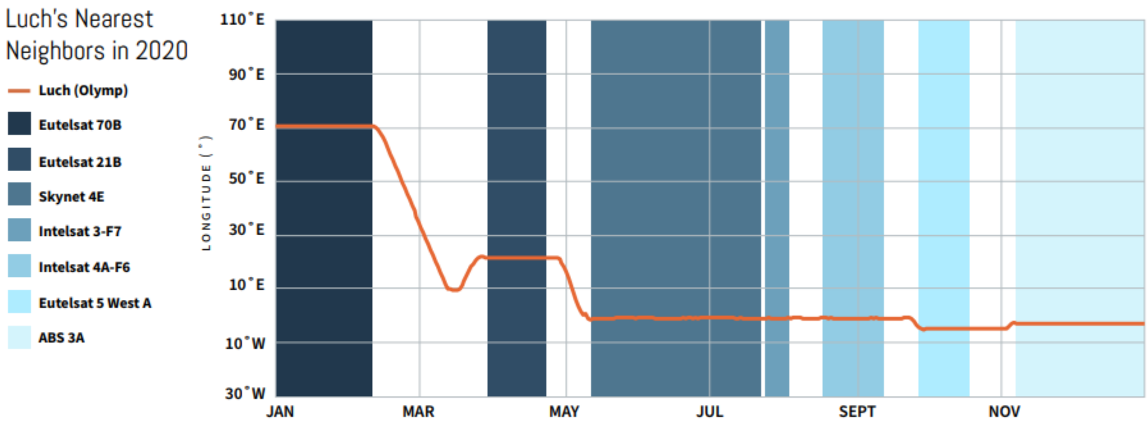

Fig. 14. Łucz close-ups to other objects in GEO in 2020.
(source: CSIS Space Threat Assessment 2021)

4. DETERMINATION OF THE INFLUENCE OF THE CHANGE IN COORDINATES OF GPS SATELLITES PROVIDED IN DEPES ON THE ACCURACY OF DETERMINING THE RECEIVER'S POSITION

Each navigation satellite sends relatively accurate information about its location to the users in the satellite message. The recipients of this information therefore know the position of each navigation satellite with an accuracy that allows them to target their anti-satellite weapon (ASAT). Is it possible to change the orbital data of the satellite in such a way that the PNT navigation of civilian users is still possible with sufficient accuracy for them? Changing the elements of the orbits of the GPS satellites broadcast in their messages may be made in such a way as not to significantly disturb the navigation of civilian users of the GPS system.

The elements of the orbit of GNSS satellites (except GLO) are given in the form of exact linear or angular values and their derivatives over time. Using the classic Kepler elliptical orbit formulas and taking into account the appropriately prepared coefficients taking into account the perturbations of these elements, it is possible to calculate spatial rectangular X, Y, Z coordinates of the satellites.

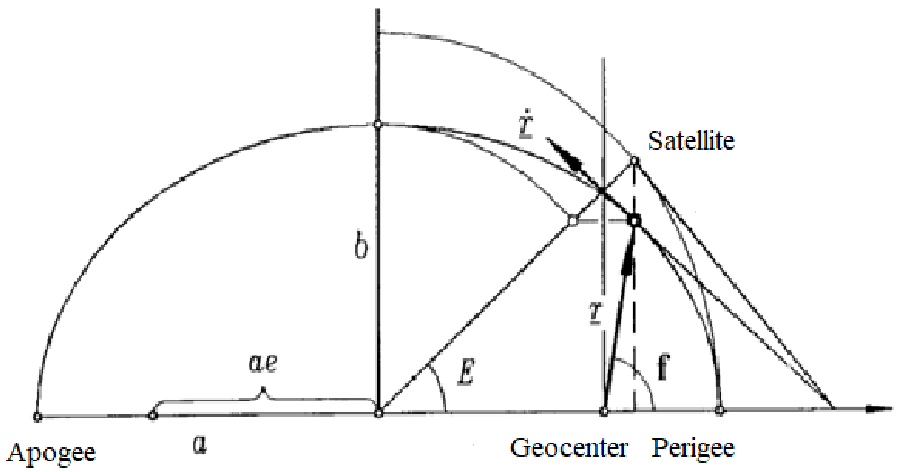

Fig. 15. Satellite in the orbit plane

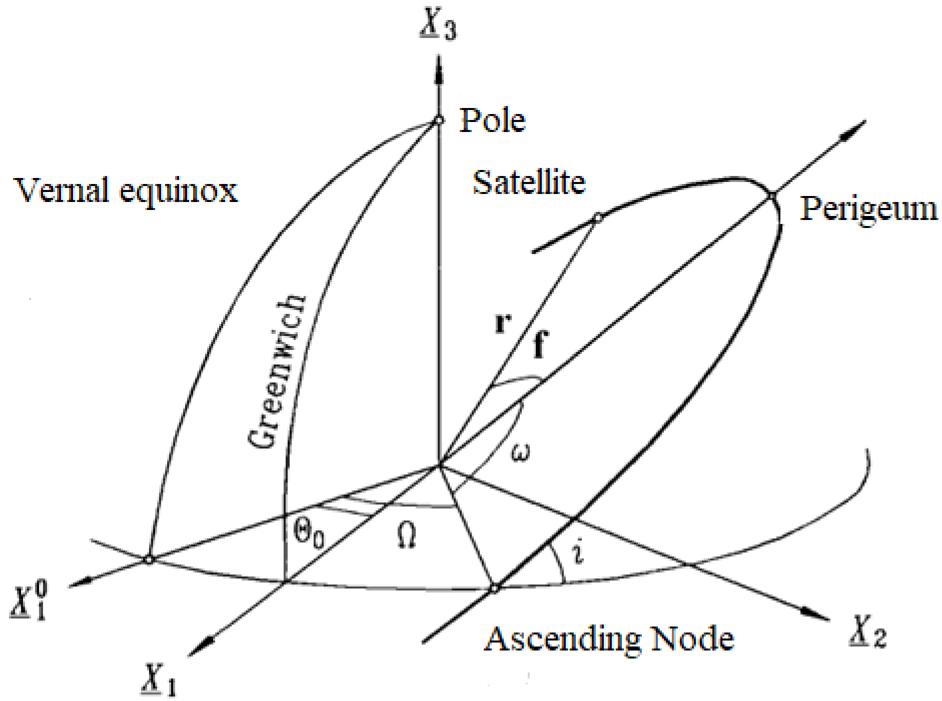

Fig. 16. Satellite in space.

Elements of the orbit:

a - large semi-axis of the ellipse of the satellite's orbit,

b - small semi-axis of the ellipse of the satellite's orbit,

E - eccentric (eccentric) anomaly,

f - true anomaly,

$\vec{r}$ - satellite leading radius,

Ω - rectasensation of the ascending node of the satellite's orbit,

Θ_0- Greenwich mean time,

ω - perigeum argument,

i - the inclination angle of the orbit to the equator.

Satellite coordinate computation GPS	
$a = (\sqrt{a})^2$	semimajor axis
$n_o = \sqrt{\frac{\mu}{a^3}}$	computed mean motion
$t_\lambda = t - t0e$	time from ephemerides reference epoch
$n = n_o + \Delta n$	corrected mean motion
$M_k = M_o + ntk$	corrected mean anomaly
$M_k = E_k - e \sin E_k$	Eccentric anomaly E_k (solved by iteration)
$f = \mathrm{tg}^{-1}\left(\frac{\frac{\sqrt{1-e^2}\sin E_k}{(1-e\cos E_k)}}{\frac{(\cos E_k - e)}{(1-e\cos E_k)}}\right)$	true anomaly
$\Phi_k = \omega + f_k$	argument of latitude
$\delta u_k = C_{us} \sin 2\Phi + C_{uc} \cos 2\Phi_k$	argument-of-latitude correction
$\delta r_k = C_{rs} \sin 2\Phi_k + C_{rc} \cos 2\Phi_k$	radius correction
$\delta i_k = C_{is} \sin 2\Phi_k + C_{ic} \cos 2\Phi_k$	inclination correction
$u_k = \Phi_k + \delta u_k$	corrected argument of latitude
$r_k = a(1 - e\cos E_k) + \delta r_k$	corrected radius
$i_k = i_0 + \delta i_k + (IDOT)t_k$	corrected inclination
$x_k^{'} = r_k \cos u_k$ $y_k^{'} = r_k \sin u_k$	coordinate in the orbital plane
$\lambda_i = \Omega_0 + (\dot{\Omega} - \omega_e)t_i - \omega_e t_{0e}$	corrected longitude of ascending node ω_e = 7,2921151467×$10^{-5}\,\frac{rad}{s}$ (earth rotation rate - WGS-84)
$x_k = x_k^{'} \cos\lambda_k - y_k^{'} \cos i_k \sin\lambda_k$ $y_k = x_k^{'} \sin\lambda_k + y_k^{'} \cos i_k \sin\lambda_k$ $z_k = y_k^{'} \sin i_k$	satellite coordinate (WGS 84)

The formulas used above (Tab. 1), together with the ephemerides sent in the message, make it possible to calculate the spatial coordinates X, Y, Z with an accuracy of a few meters.

In this paper, some changes were made to the messages containing the elements of the orbits of all observed GPS satellites in such a way that the position of the satellites changed from zero to ± 1000 m. participating in the performed measurements.

The determination of the receiver position was determined by the method of determining the position of a single point using the pseudo-range method, such as is used in single navigation receivers.

The study covered real measurements and the position of the satellites changed accordingly. Measurements were made with two receivers in two different places, marked as receiver 1220 and 1221 (located in Poland) on March 4, 2022.

Unchanged ephemeris of one of the satellites (GPS No. 13)

```
13 22  3  5 10  0  0.0 2.717291936278D-04 6.252776074689D-12 0.000000000000D+00
5.900000000000D+01-6.475000000000D+01 4.357324357192D-09 2.300855851219D+00
-3.414228558540D-06 5.811860784888D-03 1.097843050957D-05 5.153676685333D+03
5.544000000000D+05-1.117587089539D-08 5.239085319218D-02-1.452863216400D-07
9.690862111762D-01 1.710312500000D+02 9.513104194060D-01-7.853184259504D-09
-4.264463346301D-10 1.000000000000D+00 2.199000000000D+03 0.000000000000D+00
2.000000000000D+00 0.000000000000D+00-1.117587089539D-08 5.900000000000D+01
```

Changed ephemeris of the same satellite.

```
13 22  3  5 10  0  0.0 2.717291936278D-04 6.252776074689D-12 0.000000000000D+00
   5.900000000000D+01-6.475000000000D+01 4.357324357192D-09 2.300855851219D+00
  -3.414228558540D-06 5.811860784888D-03 1.097843050957D-05 5.153681536236D+03
   5.544000000000D+05-1.117587089539D-08 5.239085319218D-02-1.452863216400D-07
   9.690862111762D-01 1.710312500000D+02 9.513104194060D-01-7.853184259504D-09
  -4.264463346301D-10 1.000000000000D+00 2.199000000000D+03 0.000000000000D+00
   2.000000000000D+00 0.000000000000D+00-1.117587089539D-08 5.900000000000D+01
   5.482200000000D+05 4.000000000000D+00
```

Header of the observation made by the receiver No. 1220 for the zero variant of the observation (ephemeris values unchanged)

```
 3661025.8959 1172665.0835 5072536.1381              APPROX POSITION XYZ
     1     1                                         WAVELENGTH FACT L1/2
  2022     3     5     8    16   56.0000000     GPS         TIME OF FIRST OBS
  2022     3     5     9     3   20.0000000     GPS         TIME OF LAST OBS
     1.000                                        INTERVAL
     7    C1    L1    D1    P1    P2    L2    D2            # / TYPES OF OBSERV
    20                                           # OF SATELLITES
   G05   226   226   226    44    44    44    44            PRN / # OF OBS
   G10  2602  2602  2602  2461  2461  2461  2461            PRN / # OF OBS
   G12  1492  1492  1492  1492  1492  1492  1492            PRN / # OF OBS
   G13  2785  2785  2785  2780  2780  2780  2780            PRN / # OF OBS
   G14  2785  2785  2785  2780  2780  2780  2780            PRN / # OF OBS
   G15  2785  2785  2785  2780  2780  2780  2780            PRN / # OF OBS
   G17  2779  2779  2779  2774  2774  2774  2774            PRN / # OF OBS
   G19  2699  2699  2699  2687  2687  2687  2687            PRN / # OF OBS
   G23  2746  2746  2746  2731  2731  2731  2731            PRN / # OF OBS
   G24  2652  2652  2652  2620  2620  2620  2620            PRN / # OF OBS
   G30  1729  1729  1729  1717  1717  1717  1717            PRN / # OF OBS

   R05   794   789   794   789   789   789   789            PRN / # OF OBS
   R06  2714  2692  2714  2692     0     0     0            PRN / # OF OBS
   R07  2720  2715  2720  2715  2715  2715  2715            PRN / # OF OBS
   R08   672   650   672   650   650   650   650            PRN / # OF OBS
   R09  2743  2743  2743  2743  2743  2743  2743            PRN / # OF OBS
   R15  2743  2743  2743  2743  2743  2743  2743            PRN / # OF OBS
   R17  2616  2611  2616  2611  2611  2611  2611            PRN / # OF OBS
   R18  1780  1780  1780  1780  1780  1780  1780            PRN / # OF OBS
   R24  1879  1866  1879  1866  1866  1866  1866            PRN / # OF OBS
  9 R05  1 R06 -4 R07  5 R08  6 R09 -2 R15  0 R17  4 R18 -3 COMMENT
    R24  2                                         COMMENT
    18                                             LEAP SECONDS
                                                   END OF HEADER
```

GPS and GLO satellites were monitored. The analyzes were performed taking into account only the GPS navigation system in the calculations. GLO satellites ephemeris were not included. The position changes of all 11 observed GPS satellites were made in a similar way every ± 50 m from the zero value to 1000 m. The zero value is the ephemeris accepted without any changes. Similar analyzes were performed for the ephemerides observed by two receivers: 1220 and 1221. The results of the analysis are presented below in the form of graphs showing changes in the position of the receivers, calculated using the pseudo range method.

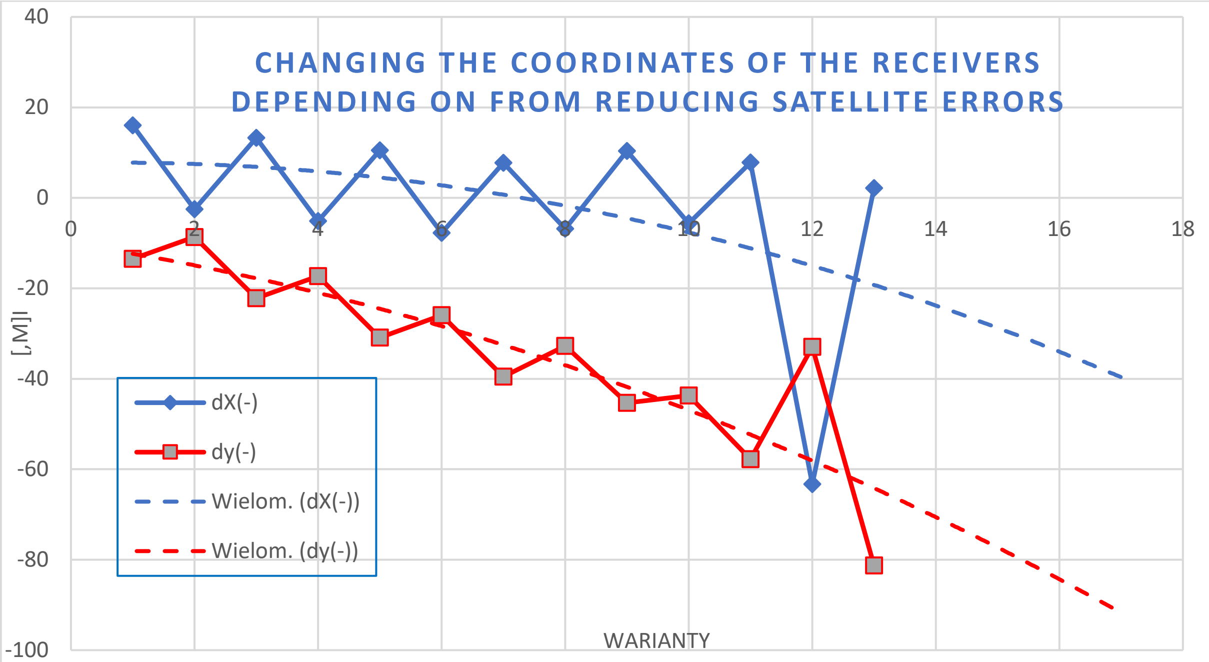

Fig. 17. The size of the distortion of the position of the receiver No. 1220 taking into account only the GPS signals in the range up to -250 m of changes in the position of the GPS satellites.

The position of the receiver in the variants taking into account the distortions of the ephemeris of satellites from 300 m to 1000 m in the diagram were not included due to their too large errors p.

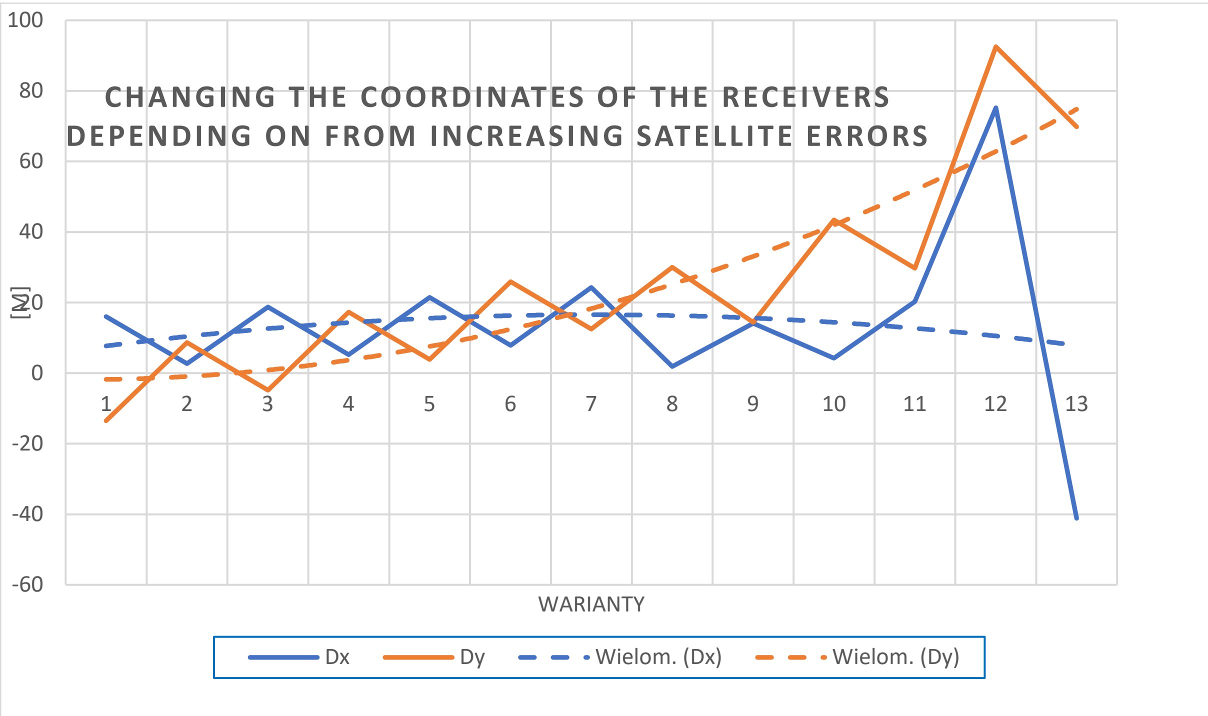

Fig. 18. The size of the distortion of the position of the receiver No. 1220 taking into account only the GPS signals in the range up to +250 m of changes in the position of the GPS satellites.

The position of the receiver in the variant taking into account the distortions of the satellite ephemeris from + 300 m to +1000 m in the diagram was not included due to too large errors in the receiver's position.

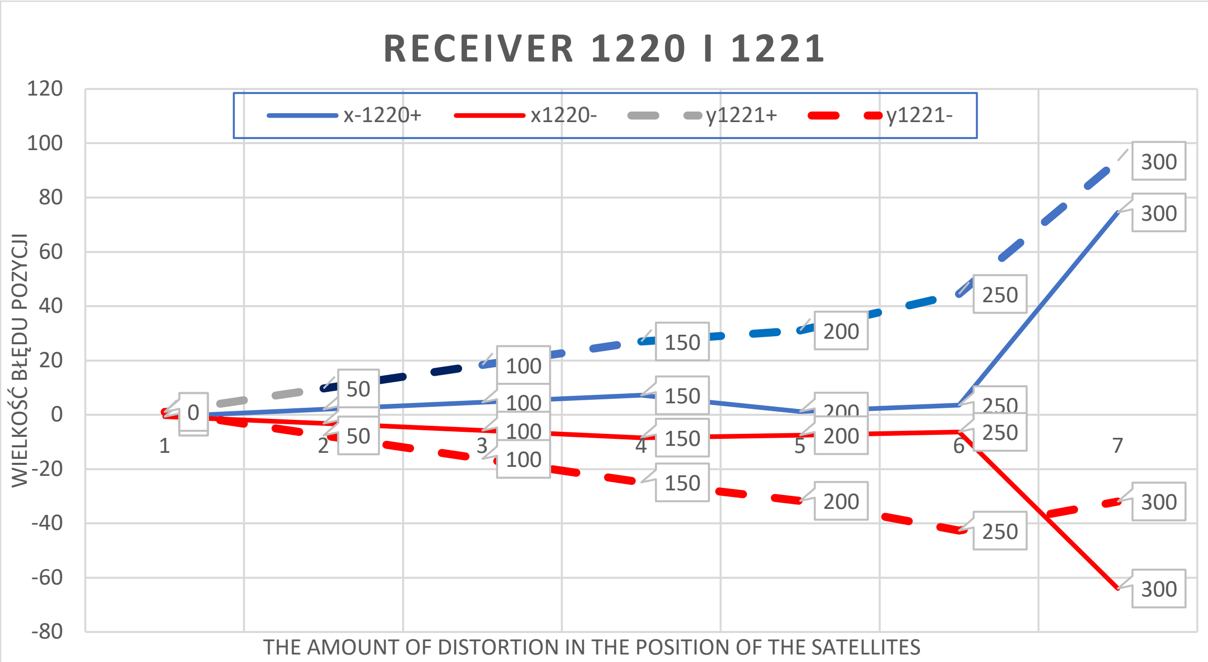

Fig. 19. The size of the distortion of the position of the receivers 1220 and 1221 receiving only GPS signals when the position of the GPS satellites changes up to ± 250 m.

The positions of the receivers in variants taking into account the distortions of the satellite ephemeris from ± 300 m to ± 1000 m in the diagram were not included due to too large errors in the position of the receivers.

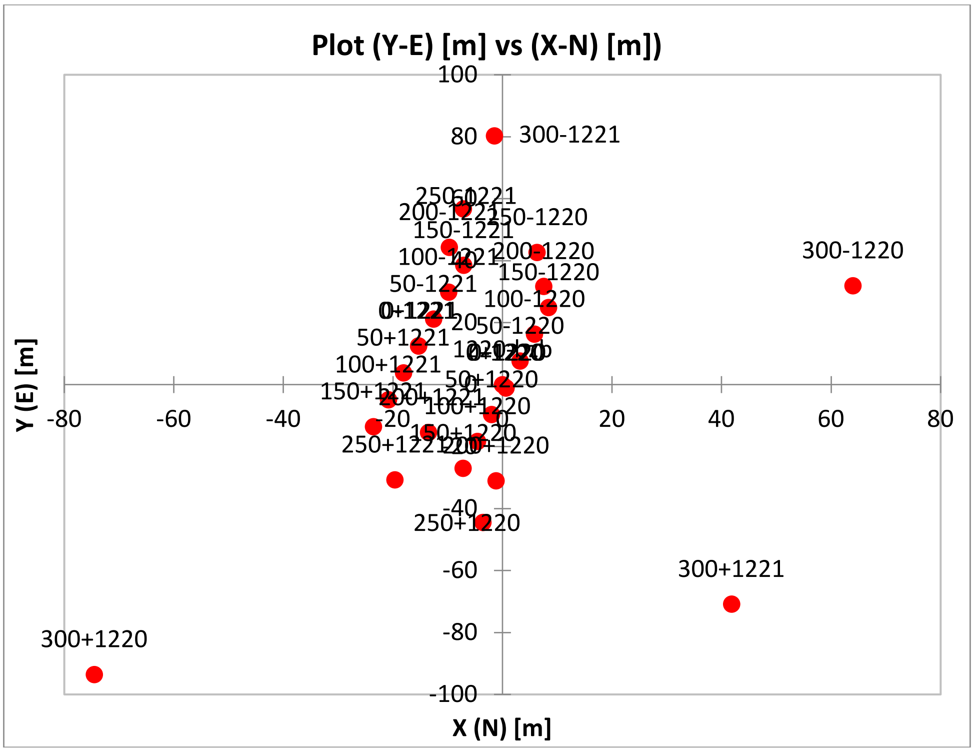

Fig. 20. Receiver positions depending on the magnitude of satellite ephemeris errors.

The positions of the receivers in the variants taking into account the distortions of the satellite ephemeris from ± 300 m to ± 1000 m in the diagram were not included due to too large errors in the receiver position.

Changes in the parameters of the orbits of GPS satellites, made in this study within the range of ± 300 m, cause changes in the two-dimensional position in the range of ± 40 m, which is too large in relation to the current capabilities of the system. However, by changing the parameters of many variables defining the orbit, it is possible to achieve results similar to those currently obtained.

5. NOTES AND OBSERVATIONS

By analyzing the threats resulting from the possibility of destroying GPS satellites by madmen who are obsessed with power (which, however, is possible), you can protect yourself in various ways. The following are required:

• Securing communication of control stations with satellites against cyber-attacks,

• Securing all organizations cooperating with the main control station against cyber-attacks,

• Securing global satellite communications used for the transmission of satellite data,

• Changes in the parameters of the orbits of GPS satellites, made in this study within the range of ± 300 m, cause changes in the two-dimensional position in the range of ± 40 m, which is too large in relation to the current capabilities of the system. However, by changing the parameters of many variables defining the orbit, it is possible to achieve results similar to those currently obtained

• Satellite coordinates in the form of their ephemeris can be used to target ASAT weapons. In the event of a threat, it is possible to confuse a potential enemy by entering false data into the memory of satellites, preventing the exact targeting of the ASAT weapon, but not preventing the determination of a two-dimensional position for all civilian users. This method is described above.

• In the event of loss of GPS signals, receivers and other devices controlled by GPS signals should be capable of receiving signals from other systems GNSS.

6. REFERENCES

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