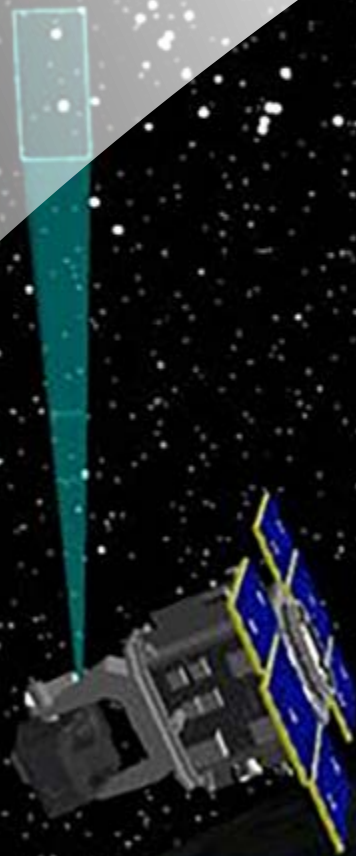


# Space Situational Awareness Warfare

Dr Stuart Eves



## About the Freeman Air and Space Institute

The Freeman Air and Space Institute is an inter-disciplinary initiative of the School of Security Studies, King's College London. The Freeman Institute is dedicated to generating original knowledge and understanding of air and space issues. The Freeman Institute seeks to inform scholarly, policy and doctrinal debates in a rapidly evolving strategic environment characterised by transformative technological change which is increasing the complexity of the air and space domains.

The Freeman Institute places a priority on identifying, developing and cultivating air and space thinkers in academic and practical contexts, as well as informing, equipping and stimulating relevant air and space education provision at King's and beyond.

The Institute is named after Air Chief Marshal Sir Wilfrid Freeman (1888–1953), who was crucially influential in British air capability development in the late 1930s and during the Second World War, making an important contribution to the Allied victory. He played a central role in the development of successful aircraft including the Spitfire, Lancaster and Mosquito, and in planning the wartime aircraft economy – the largest state-sponsored industrial venture in British history.

---

# Space Situational Awareness Warfare

Dr Stuart Eves

## About the Author

In 2018, Stuart Eves founded his own space consultancy company, SJE Space Ltd, after spending 16 years with the UK Ministry Of Defence, and 14 years with Surrey Satellite Technology Limited (SSTL).

Stuart has been heavily involved in a number of satellite programmes, including Skynet, TopSat, TDS-1, and NovaSAR.

His recent book 'Space Traffic Control', describes the measures that are needed to maintain the space environment and protect satellites from both natural hazards and man-made threats.

Stuart has an MSc in Astrophysics, a PhD in satellite constellation design, and has been a fellow of both the Royal Astronomical Society and the British Interplanetary Society for more than 25 years.

He has previously written space-related articles for a wide range of publications, and has also taught GCSE Astronomy evening classes.

## Abstract

In the past few decades, access to the capabilities provided by satellites has become a critical element of modern conflict. Unsurprisingly, this has led to the creation of a range of anti-satellite weapons, some of which have been tested against satellites in orbit.

Over the next decade, it is anticipated that technologies will be developed which will have the specific aim of complicating the task of a space aggressor by limiting the space situation awareness (SSA) information on which any attack would be based.

The article describes this probable evolution in satellite design and operations as 'SSA Warfare', and considers the possible techniques that could be adopted by a nation wishing to defend its space assets, particularly in a time of crisis.

The SSA Warfare techniques that could be implemented might involve the permanent or temporary modification of a satellite's observable signatures, or changes to a satellite's concept of operations. Other, more active options include deliberate attempts to interfere with SSA system operations; amongst which are the sorts of RF countermeasures that are already a well-established feature of terrestrial military operations.

## Introduction

Arguably during the First World War, and certainly by the time of the Second World War, control of the air domain became a key component of military conflicts. For this reason, aircraft became the targets of increasingly sophisticated anti-aircraft weapon systems; and this, in turn, led to the development of a range of technologies designed to make air systems more survivable.

In the past few decades, access to the capabilities provided by satellites has become a critical element of modern conflict. Unsurprisingly, this has led to the creation of a range of anti-satellite (ASAT) weapons, some of which have been tested against satellites in orbit.

By analogy, over the next decade, it is anticipated that technologies will be developed which will have the specific aim of complicating the task of a space aggressor by limiting the space situation awareness (SSA) information on which any ASAT attack would be based.

This probable evolution in satellite design and operations is 'SSA Warfare'; a topic which is discussed in detail for the first time in this paper.

The techniques that could be implemented by a nation wishing to defend its space assets could involve the permanent or temporary modification of a satellite's observable signatures, ie satellite 'stealth', or changes to its concept of operations (CONOPS), including manoeuvres to modify its orbit or alterations to its pattern of transmissions.

Other, more active options include deliberate attempts to interfere with SSA system operations, including radio frequency (RF) countermeasures that are a well-established feature of air operations.

## Satellite Signatures

A satellite in orbit around the Earth creates a number of potentially observable signatures. Since most satellites are partly composed of RF-reflective materials, (eg metals), the technique most used to detect and track most satellites in low Earth orbit (LEO) is active radar.

The altitude range typically associated with LEO is 500–1500 km and achieving acceptable detection thresholds at these ranges requires a significant radar facility. Currently, objects in the physical size range 5–10 cm and larger can be detected by an instrument such as the missile warning radar at RAF Fylingdales.

The effective radar cross-section of a potential target depends on a variety of factors including its material composition, its shape, and its rotational motion with respect to the radar. The current catalogue of objects in LEO comprises more than 20,000 objects, and it is anticipated that when the new Space Fence radar comes online its higher operational frequency will allow it to detect an order of magnitude more objects in the size range 1 cm and above.

Due to their comparatively low orbits, satellites in this regime spend in the order of 10 minutes or less within view of a tracking station on the Earth's surface on any given pass. On occasions when LEO satellite passes occur in twilight conditions, they can also be tracked optically. For about an hour after sunset, and for an hour before dawn, (when the ground site is in darkness, but the target object is illuminated by the sun) it is possible to derive very accurate orbits using both passive optical telescopes and laser rangefinders.



*RAF Fylingdales, a potential victim of SSA Warfare*

In higher orbits (specifically the Medium Earth Orbits (MEO) used by the navigation constellations, and the Geostationary Earth Orbits (GEO) which are principally exploited by communications satellites), the majority of the tracking is performed by optical telescopes since the altitudes (around 20,000 km for MEO and 36,000 km for GEO) are too great for effective radar tracking.

In practice, this tends to limit opportunities for tracking from a specific ground site to the night-time hours, when the satellite is still illuminated by the Sun. Optical detection thresholds in GEO are on the order of 20 cm currently, and again this affected by a number of factors including, fairly obviously, the size of the object, but also its reflectivity or albedo. There is considerable variability in this signature, however. For example, the solar panels on GEO satellites are effectively large mirror-like surfaces which can reflect sunlight back towards the Earth at certain points in their daily rotation. At dates close to the equinoxes these reflections can be seen with the naked eye, at which times the satellites can appear brighter than 5th or 6th magnitude stars for short periods. (The brightest stars are designated 1st magnitude; the dimmest ones visible to the naked eye are designated 6th magnitude and are a factor of 100 dimmer. The brightness difference between two magnitudes on this scale is thus around 2.5. Some large GEO satellites can reach 4th magnitude.)

More typically, though, GEO satellites have a brightness of perhaps 12th–14th magnitude, which is approaching a factor of 10,000 dimmer. With high-end commercial telescopes it is possible to maintain custody (ie near-continuous, tracking of a positively identified object) of the majority of the operational satellites in GEO. By locating suitable instruments at a range of longitudes, the commercial company Exo-Analytic has managed to reduce the ‘untracked’ portion of a GEO orbit satellite to a 6-hour period centred around time of local noon at the sub-satellite point. Smaller debris objects in GEO have visual magnitudes closer to 20, and necessarily require larger telescopes to detect them. The difficulty which arises is that very large aperture telescopes tend to have very small fields of view, and consequently they make relatively poor search tools.

The active satellites that orbit the Earth, (currently perhaps 10% of the total catalogue of objects larger than 10 cm in size), also provide radio frequency signatures.<sup>1</sup> Most satellites transmit lower data rate telemetry signals which monitor the state of health of the satellite platform, and higher data rate signals associated with the payload functions of the mission. Both constitute signatures that can be exploited to assist in the identification and characterisation of the mission.

Many satellite systems now exploit encryption techniques to protect both their commands and telemetry, with the aim of making the ‘internal’ content of the transmissions unintelligible to eavesdroppers, but the frequencies used, and other ‘external’ characteristics like bandwidth, signal strength, data rate, etc can still be exploited to provide some information on a satellite’s state of health. Telemetry data is sometimes transmitted continuously, (since, in the event of a malfunction on the satellite, it may be impossible to switch on a telemetry stream to provide information for fault diagnostics). Payload transmissions can also be continuous, as is the case for GEO communications satellites, but most LEO missions currently transmit data only when in view of a host ground station. In the case of a typical mission in a near-polar sun-synchronous orbit with a period of between 90 and 100 minutes, this may involve transmissions once or twice per orbit, for periods of 10 minutes or less on each occasion.

Another satellite signature which can, in theory, be exploited is its infra-red emission. The interior temperatures of active satellites are maintained close to room temperature (of the order of 20° C), but their external surfaces can range from over 100° C to -40° C over the course of a typical LEO orbit which takes the satellite into and out of eclipse for periods of 40 minutes or so.

GEO satellites, by contrast, are illuminated most of the time, and their maximum eclipse durations last about 72 minutes. GEO satellites pass into the Earth’s shadow on roughly 90 days each year; their eclipse seasons being divided into two periods, lasting about 45 days each, centred around the spring and autumn equinoxes. Hence, their thermal profiles are also dictated by their orbital period, and they normally experience one thermal cycle per day, rather than the 13–15 cycles per day seen by a satellite in LEO.

Since active satellites are thus significantly above the -270° C background of space, there is a considerable signal-to-noise ratio that can aid detection.

Finally, at least in theory, all satellites will have a spectral signature dictated by the materials from which they are constructed. Assuming that these can be characterised effectively, the absorption lines seen in the light reflected from a satellite can provide information that will “fingerprint” the mission and aid the task of distinguishing it unambiguously from the rest of the orbital population.

# The Principles of SSA Warfare

SAA Warfare encompasses the range of measures by which a space actor might seek to attain information superiority in the space domain. It is suggested that SSA Warfare might involve three key principles:

1. To maintain the accuracy of one's own SSA information.
2. To degrade the accuracy of the opposition's SSA information.
3. To avoid collateral hazards that could imperil the operations of non-combatant space operators.

The rationale for the first two principles is probably self-evident, but the third may merit a little amplification. SSA warfare measures that permanently degraded the overall SSA capability worldwide would reduce the accuracy of the overall catalogue of space objects. As a consequence, the operators of commercial satellites would then have less confidence in the conjunction warning messages that they received, and the likelihood of an inadvertent collision would increase. In view of the many safety-of-life applications that satellites currently support, (navigation, communications, meteorology, etc.), any reduction in capability in these areas could result in the loss of life of non-combatants outside the theatre of operations; a concept that is considered illegal under the rules of armed conflict.

One of the important issues associated with SSA superiority is the geographic location of the sensors involved. It is not difficult to find information on the locations of the US tracking network, for instance, and clearly an adversary could use this information to assess when its satellites are likely to be subject to surveillance.

Moreover, the nature of the sensors at each of the locations is also widely reported; as an example, the radar sensors at Clear, Thule, and Fylingdales are part of the ballistic missile early warning system and are located at high latitudes because of the perceived risk of Russian missiles coming 'over the pole' towards targets in the West. These radars provide frequent opportunities to track LEO satellites in near-polar orbits, but provide no coverage at all of satellites in low inclination orbits.

Another feature of the US tracking network is that there are significant gaps in external SSA surveillance coverage over a number of probable theatres of operation. A US satellite equipped with appropriate detectors (radar warning sensors, laser illumination sensors, etc) could potentially determine the fact that it was being tracked by active sensors in Russia or China, for instance. If that satellite was equipped with a continuously active intersatellite link system (ISL), it might also be able to report the fact that it was being tracked in near-real-time, but there is clearly a significant challenge for the US to have external 'eyes on' its own assets when they are not orbiting over the US or allied territories.

This geographic limitation potentially extends to probable military theatres of operation in, for example, the Middle East. The development by Russia of mobile anti-satellite laser weapons and the potential response by the US, lead to a requirement to coordinate and extend SSA capabilities if such assets are to be used effectively to achieve and maintain space control over remote theatres.

# SSA Warfare Techniques

## Passive signature modification

A long-established principle in air operations is the use of stealth technologies to make targets harder to detect, harder to track, and hence harder to target. In the air domain, this can include the use of radar absorbent materials and specular reflecting surfaces to reduce the effective radar cross-section of the target.

Applying stealth technologies without compromising the performance of the host system presents some additional challenges. Reducing a satellite's optical signature by making some of its surfaces permanently dark is certainly possible, but has the potential to compromise the thermal control of the mission (as demonstrated by the recent attempts by Starlink to make one of its satellites less of an inconvenience to the astronomy community). A more plausible approach could be to use electrochromic or thermochromic materials, which change colour in response to variations in charge or temperature respectively, to modify a satellite's signature temporarily while it is in view of potentially hostile SSA sensors.

Additional difficulties arise in the RF domain, where creating an RF reflective (or absorptive) surface oriented towards the Earth is very likely to interfere with the operation of a satellite's sensors. In addition, the satellite will, in almost all cases, require RF contact with the ground at a suitable frequency to communicate its data, so some degree of transparency in any 'RF sheath' around the satellite will be essential. This was, allegedly, the scenario investigated by the US in their Misty satellite programme.<sup>2</sup>

Once a satellite has been stabilised in orbit, the wide-beamwidth RF links that are used to achieve this can potentially be switched off in favour of more directional, higher-frequency links with narrower footprints which are harder to intercept. Some satellites may also be able to exploit inter-satellite links, which, if operated at frequencies above 50 GHz, would be very difficult to detect from the ground. Next-generation systems could also reduce their radio signatures by making greater use of optical laser downlinks rather than RF ones.

However, perhaps the hardest stealth-related challenge is disguising the infra-red signature of a satellite. Maintaining one 'cold' face, oriented towards potential tracking sites on the Earth, might be possible temporarily, although this would be difficult owing to the thermal inputs to the satellite from the sun and the Earth's albedo. Inevitably, however, the excess heat from the satellite would need to be radiated in another direction, and this would provide an opportunity for on-orbit IR sensors to detect the target satellite instead.

All of these signatures depend to some degree on the physical size of the satellite in question, and in this regard the progress of technology is making satellite stealth easier to achieve. In recent years, the performance of very small satellites in the cubesat class has increased dramatically, with the result that militarily-relevant performance is now possible from satellites that are very difficult to detect and track. Simply making satellites smaller will not prevent them being tracked by some of the most capable sensors planned in the future (eg the new US space fence), but it will certainly make the job of an aggressor much harder.

A satellite operator also has the option of selecting an orbit that provides comparatively few tracking opportunities. An inclination of 30° or less would limit the number of sensors that could acquire the satellite, and since many of the low latitude sites are optical facilities, which require a satellite to pass overhead in twilight conditions, the occasions when a low inclination satellite would be trackable could be relatively infrequent. The corollary, of course, is that a low inclination satellite can only provide services to a limited band of latitudes centred on the equator.

## CONOPS modifications

To make a satellite harder to track, an operator has the option of changing its pattern of transmissions. This could involve limiting its transmissions when in range of potential RF tracking sites (an approach that is analogous to the 'emcon' procedures adopted by military aircraft in a combat situation).

An alternative approach is to modify the signal characteristics that a satellite transmits: by changing the frequency or modulation of its transmissions, a satellite operator may achieve some level of surprise and make it more difficult for a potential aggressor to retain unambiguous custody of a planned target. 'War modes' are a well-established element of traditional conflict and could also play a role in SSA warfare.

At the cost of propellant, an operator can conduct randomised, unexpected manoeuvres. Rather than following a predictable station-keeping pattern, the manoeuvring satellite would then be more likely to appear as an uncorrelated object and force an aggressor to devote additional tracking resources to regain custody of the object in question. Satellites in higher orbits have relatively predictable orbits, but another SSA warfare technique could be to deliberately eschew this advantage and operate in a very low Earth orbit (below 400 km altitude) where natural variations in the drag experienced by the satellite would continuously generate uncertainties in its position, making it harder to target.

Satellites are now expected to de-orbit at the end of their operational lives, and another possible manoeuvre-related technique could be to make a series of orbit lowering adjustments, simulating a satellite retirement, and then boost the mission to a higher orbit, hoping that, when the mission fails to appear in the expected location, an aggressor might mistakenly assume that it had re-entered the Earth's atmosphere.

Another defensive approach would be to maintain a satellite relatively close to the upper stage of the rocket that launched it. Normally the two objects drift apart when the active satellite commences station-keeping operations. The two objects would typically have different ballistic coefficients too, with the result that perturbing forces including atmospheric drag and solar radiation pressure would affect them differently, and they would start to separate even if the satellite did not conduct manoeuvres.

A rocket body is usually considered to be space junk following the launch phase, but if it is not immediately deorbited, (which is becoming commonplace) an operator could choose to exploit it as a decoy object for the active mission that it placed in orbit. Assuming that the rocket body is inert, and that the two objects do indeed have different ballistic coefficients, it would require active station-keeping by the satellite to keep them close together.

This could, however, present an aggressor with a challenge to distinguish the two objects as separate space objects, and might lead to uncertainties about which one constitutes the real target. Even if an aggressor does successfully discriminate the target, some forms of ASAT weapon might not work well in a scenario of this sort. For example, an ASAT missile that is designed to home in on a bright optical or IR target might lock on to the rocket body rather than the intended satellite.

The above approach would probably lead to criticism that the operator was not following the now well-established practice of trying to limit the lifetime of rocket bodies, but there are variants of this technique that might work just as well, if not better.

The simplest approach might be to command the satellite from a recent launch to rendezvous with a rocket body from a previous mission, thereby avoiding the charge of deliberately adding to the debris population. Some rocket bodies are very large indeed and might obscure the new satellite from ground-based tracking sites almost completely.

Slight differences in the eccentricity values of the two objects would cause them to appear to 'rotate' around one another over the course of an orbit, and if the phasing of this rotation cycle was adjusted carefully, could place the target satellite 'behind' its partner on those sections of its orbit when it might be tracked by a hostile power.

Another rendezvous option is with another allied satellite, since the manoeuvres of the two objects could then be coordinated, making it even harder for a potential aggressor to differentiate them. More challenging to achieve, and certainly more provocative, would be to conduct a rendezvous with either a third-party satellite or one operated by the potential aggressor themselves. This concept, which has been described as a 'companion satellite', is more difficult to maintain, since the non-cooperative rendezvous partner would have the option of changing orbit to increase the separation between the satellites, and might, in the process, direct a propellant plume towards the satellite that had performed the rendezvous in the first place.

There is also the risk that, with two active satellites in close proximity performing uncoordinated manoeuvres, a collision could occur. Nevertheless, an aggressor would certainly need to think carefully about engaging a target satellite in close proximity to another, especially one of their own missions, because of the risk of collateral damage.

If this approach seems somewhat implausible, it should be noted that there are a number of GEO missions, operated by the US, China, and Russia, which appear to be conducting relatively long-range proximity operations in this orbital regime currently.

A further technique which might create temporary confusion would be to 'fake' the demise of a satellite. Switching off transmitters and allowing the satellite to tumble might lead an adversary to conclude that the mission no longer constituted a threat. If it were then to be returned to service, this might catch an adversary unawares.

The above techniques apply to individual satellites, but there are also SSA warfare techniques that could be implemented at the constellation/fleet level. For instance, synchronising manoeuvres by many satellites simultaneously could create a significant number of uncorrelated targets that would temporarily confuse a possible adversary.

Another technique to overwhelm, potentially, the available tracking resources might be to conduct a surge launch campaign, involving multiple satellites on each launch vehicle. This could, in theory, add several hundred active objects to the catalogue in a short period of time, making the job of an aggressor much harder.

Both of the above approaches might have maximum success if conducted at the time of a major solar event. In the past, such eruptions on the sun have modified the Earth's atmosphere to a significant degree, with the result that many objects failed to correlate with the catalogue when subsequent attempts were made to track them.

During times of high solar activity, variations in the ionosphere also degrade the accuracy of radar measurements, and this combined effect of variable drag and unreliable measurements means that the quality of the catalogue is likely to be degraded for some time; providing a window of uncertainty in which SSA warfare techniques may have the greatest success.



## Active measures

In a warfare scenario, it is anticipated that a variety of more aggressive measures might also be employed in an attempt to gain information superiority.

One such could be to employ cyber techniques in an attempt to degrade the quality of an adversary's space catalogue. By modifying, adding, or deleting data, it would be possible to create confusion, and potentially delay or prevent hostile attacks against one's own satellites.

It is expected that a significant number of small objects will be added to the US catalogue when the new space fence radar comes online. If this facility is the only source of data on objects of 1-2 cm in size, then there is the potential for some 'creative accounting' in the expanded catalogue.

Imagine, for a moment, that you are the operator of a satellite which the US might consider hostile. An update to the US catalogue appears in which there is a cloud of small objects in orbits very similar to that of your own satellite. In such a circumstance, would you trust the US catalogue and take evasive action to avoid a potential conjunction with these objects, or would you suspect that these were 'ghost satellites' invented by the US with the aim of distracting your satellite from performing its stated mission?

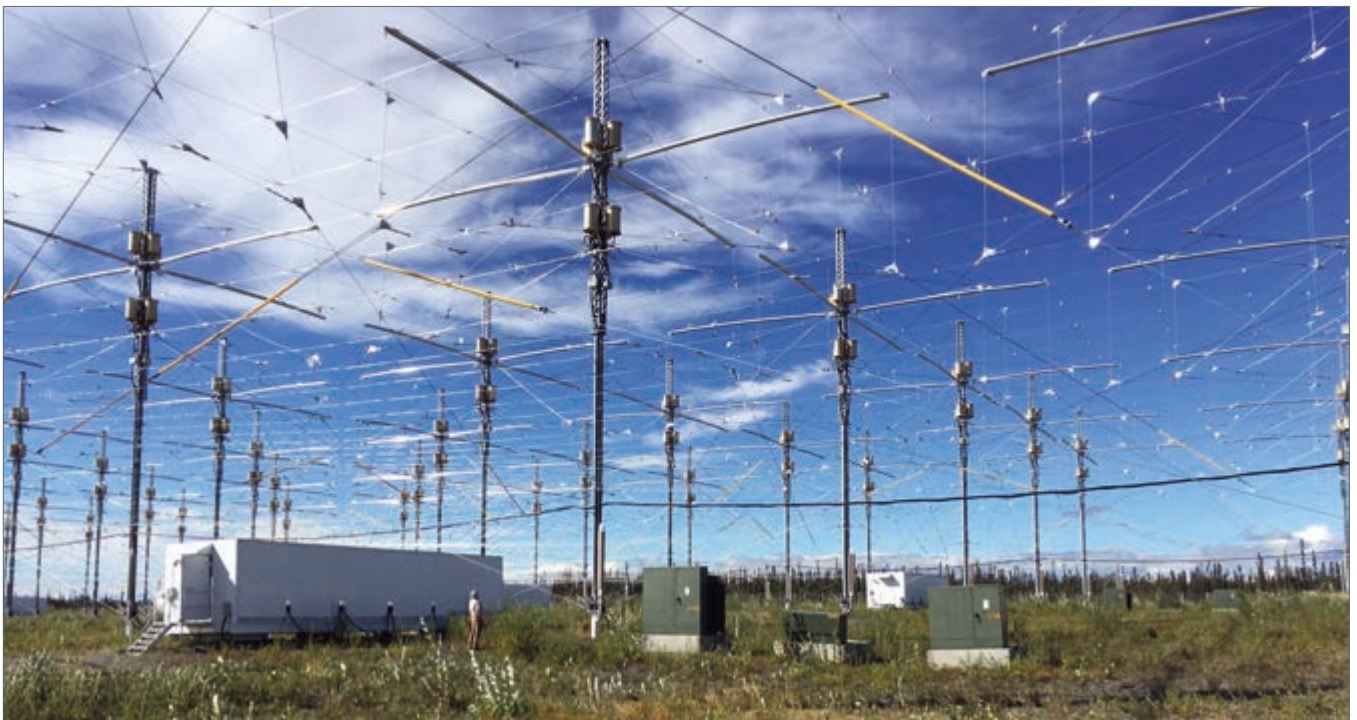
As sensor capabilities improve, and many more objects are added to the catalogue, there will be plenty of scope for 'accidental mis-classification' of some of the new items. The US does not, currently, publish element sets for its own operational satellites, a fact which tends to focus attention on them. By adding a genuine, operational mission to a list of newly tracked small debris objects, the US might seek to disguise its true nature.

More active responses to hostile tracking of one's satellites could include deliberate measures intended to reduce the quality of the orbits derived by a potential adversary's SSA sensors. Modern digital signal processing techniques would allow a satellite to conduct deliberate jamming of a space tracking radar, using an on-board software defined radio to transmit in-band energy that would mask the reflected radar signature of the satellite.

However, this is a 'brute force' approach in comparison with some of the subtler options that are available. Instead of alerting an adversary to a problem with their SSA information by jamming, an SSA warfare practitioner might programme the on-board transmitter to manipulate the radar returns to disguise the position of the satellite, or transmit 'cancelling' waves which would suppress the satellite signature altogether.

A less sophisticated response might simply be to utilise the data from a radar or laser detection monitor on the target satellite to automatically trigger a manoeuvre, or make an attitude change, if it determines that the satellite has been tracked while over enemy territory. This could degrade the enemy's orbit determination or target identification process, and thereby lessen the probability of a successful ASAT engagement.

It has been demonstrated at sites such as the High-frequency Active Auroral Research Program (HAARP) facility in Alaska that by transmitting radio waves into the atmosphere, it is possible to modify the characteristics of the ionosphere, and hence affect how radio signals propagate through this region.<sup>4</sup>



*High-frequency Active Auroral Research Program (HAARP)<sup>3</sup>*

If it were possible to target the geographic location of this effect, it might be possible for an aggressor to limit a space tracking radar's access to large proportions of the sky by creating some form of synthetic aurora. Such techniques might also be used to create 'lights in the sky' that would compromise optical surveillance assets too.

At present, the majority of space situational awareness data comes from external sensors. This may change in the future, with increasing amounts of space-navigation data being collected by sensors such as GPS receivers on satellites themselves. Such a change could create another SSA warfare attack vector for an adversary: by manipulating the navigation data reaching the satellite, a variety of effects might be achieved, ranging from missed data collection opportunities through to complete confusion of the satellite's attitude and orbit control (AOCS) system. Similar confusion could be generated by deliberately inserting optical or IR artefacts into the star cameras or infra-red Earth sensors used by the satellite to determine its orientation.

Lastly, in extremis, a satellite operator could seek to protect a satellite by deploying decoy objects from it, rather in the manner of aircraft. The precise nature of the decoy would depend on the nature of the threat envisaged, and the mass budget on the satellite that needs to be defended. It is not impossible to envisage, however, a small solid motor propulsion system, (principally intended to deorbit a satellite at the end of life), being detached, turned around, and being fired back at an incoming ASAT.

Implementation of some or all of these possible active measures by an adversary clearly implies the need for a significant enhancement to our current levels of SSA.

## Countermeasures and conclusions

Inevitably, if adversaries implement SSA Warfare techniques against us, we will require more capable SSA sensor systems to avoid being deceived.

Using multiple sensors to interrogate the objects orbiting above us is one potential resilience technique, since it is more difficult for an adversary to produce a deception at multiple wavelengths simultaneously.

Increasing the number of available sensors will also be important, since this will limit the time when an adversary satellite is 'out of sight' and hence able to implement some of the SSA warfare strategies described above.

Finally, having mobile SSA capabilities, including novel sensors in orbit, will make it far more difficult to implement a number of the techniques outlined in this article. The wider range of viewing geometries, the multiple illumination angles, and the higher resolutions, that would result from having more proximate surveillance from space-based sensors would provide greater insurance against becoming victims of SSA warfare.

# Endnotes

- 1 Statista estimates the number of active satellites as 3368, <https://www.statista.com/statistics/897719/number-of-active-satellites-by-year/#:~:text=In%202020%2C%20there%20was%20an,2%2C298%20active%20satellites%20in%202019>. ESA estimates 29,000 space debris objects in orbit, [http://www.esa.int/Safety\\_Security/Clean\\_Space/How\\_many\\_space\\_debris\\_objects\\_are\\_currently\\_in\\_orbit](http://www.esa.int/Safety_Security/Clean_Space/How_many_space_debris_objects_are_currently_in_orbit).
- 2 See <https://www.wired.com/2006/02/spy-3/?pg=3> and <https://www.washingtonpost.com/wp-dyn/articles/A56171-2004Dec10.html>.
- 3 Secoy, A, CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0>.
- 4 See <https://haarp.gi.alaska.edu>.

## About the Freeman Air and Space Institute

The Freeman Air and Space Institute is an inter-disciplinary initiative of the School of Security Studies, King's College London. The Freeman Institute is dedicated to generating original knowledge and understanding of air and space issues. The Freeman Institute seeks to inform scholarly, policy and doctrinal debates in a rapidly evolving strategic environment characterised by transformative technological change which is increasing the complexity of the air and space domains.

The Freeman Institute places a priority on identifying, developing and cultivating air and space thinkers in academic and practical contexts, as well as informing, equipping and stimulating relevant air and space education provision at King's and beyond.

The Institute is named after Air Chief Marshal Sir Wilfrid Freeman (1888–1953), who was crucially influential in British air capability development in the late 1930s and during the Second World War, making an important contribution to the Allied victory. He played a central role in the development of successful aircraft including the Spitfire, Lancaster and Mosquito, and in planning the wartime aircraft economy – the largest state-sponsored industrial venture in British history.

---

### Find out more

[kcl.ac.uk/research/freeman-air-and-space-institute](https://kcl.ac.uk/research/freeman-air-and-space-institute)  
[@freeman\\_air](https://twitter.com/freeman_air)