Article

UK Space Power: Contextualising the Need for Space Control

By Squadron Leader James Payne

Biography: Squadron Leader James 'Buzz' Payne is an Air Operations (Systems) Officer who has previously served at UK Space Command, RAF High Wycombe. As a direct entrant into the Service, he has completed his higher education part-time, most recently his CAS Fellowship for an MA in Air Power in the Modern World with King's College London's War Studies Department.

Abstract: The modernity of space enterprise brings great innovation and benefits globally, but with it comes additional congestion and competition in the Space domain. Dependency on space for economies as well as national security has driven development of Space Control capabilities to not only protect a Nation's own assets but also to deceive, disrupt, deny, degrade, or destroy a potential adversary's space systems. Thus, there is a need for a shift in both attitude and mindset toward Space and its importance to give it the attention and credence in the face of the evolving threat. This article will contextualise the need for space control by providing a potted history of UK Space Power as well as an overview of the development in global counter-space weapons and the threat today.

Introduction

The diversification and proliferation of capabilities and services derived from space grows with each passing year and with it comes a renewed focus on the domain's importance - not only for military operations, but also UK prosperity. During the Cold War, the first space age was intrinsic to the ideological struggle between the superpowers and its enormous cost meant that it was ruled by only a few nations. The 21st Century by contrast has seen the success of private enterprise, or 'New Space'; companies such as United Launch Alliance and SpaceX operate rockets for launching spacecraft into orbit and there are a plethora of companies offering other services such as imagery, communications, commercial Signals Intelligence (SIGINT), and weather monitoring. What is more, these services can be bought at a relatively low cost, so ownership of satellites and launch capabilities is not necessary for nations and non-state actors alike to access products derived from space.

In December 2019, the United States took the bold step of establishing the world's first independent space force. Coming under the Department of the Air Force, the United States Space Force (USSF) is responsible for the organising, training, and equipping its personnel to 'conduct global space operations that enhance the way our joint and coalition forces fight, while also offering decision makers military options to achieve national objectives.'[1] Also in 2019, NATO's approach to space changed; Allies adopted a new Space Policy and recognised it as an operational domain alongside land, sea, air and cyberspace.[2] Though the RAF has 500+ personnel employed in Space related duties such as the Ballistic Missile Early Warning System (BMEWS) at RAF Fylingdales in North Yorkshire and the Space Operations Centre (SpOC) at RAF High Wycombe, the UK does not have the resource or the capital to start its own independent space service. Rather, it established the joint UK Space Command at RAF High Wycombe on 01 April 2021, under the command of Air Vice-Marshal Paul Godfrey. It is the defence lead for space operations, space workforce and space capability and is responsible for protecting and defending the UK's interests in space. The publication of the National Space Strategy (NSS) followed on September 27, 2021, and brings together civil and defence policy to set out the government's ambitions for the UK in space. The subsequent Defence Space Strategy (DSS) was released on 01 February 2022, and sets out how Defence will support national efforts to become a meaningful actor in space. The UK's Space Power doctrine has also been decoupled from UK Air Power doctrine into a standalone document, Joint Doctrine Publication 0-40.

To emphasise the importance of education, UK Space Command then delivered on establishing the UK Space Academy, which declared its Initial Operating Capability in September 2023 to deliver space training. In November, it was confirmed that the Space Academy will be based at the Defence Academy of the United Kingdom, near Shrivenham in Oxfordshire. The following month, AVM Godfrey announced at the Defence Space Conference that UK Space Command's two operational units have been awarded squadron status, with the SpOC being renamed Number 1 Space Operations Squadron, and BMEWS No.2 Space Warning Squadron.

Historical Background

In 1946, a British Interplanetary Society member Ralph Smith put forward a proposal for a crewed suborbital spaceflight mission using the 'MegaRoc' rocket, which was a design that adapted a V-2 missile that had been seized from the Nazis. Though this spacecraft may had been capable of carrying human beings into space, the submission was rejected due to cost and the UK being essentially bankrupt after the war.[3] The V-2 would however go on to form the basis of both the US and Soviet rocket design programmes, most famously from Operation Paperclip where the German Rocket scientist Wernher von Braun and his team were relocated to the US to lead the development of America's Saturn rockets.[4]

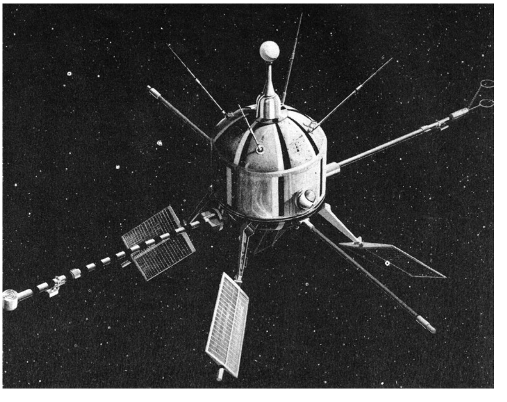
The Space Race started on 30 July 1955, when the US announced its intent to launch artificial satellites for a global scientific project called the International Geophysical Year (IGY) and the Soviet Union responded just four days later with their own declaration to launch a satellite. This competition between the two Cold War rivals became part of the ideology of the time and demonstrations of the technological advantage garnered by superior spaceflight capability was an absolute necessity for national security. Albeit, reaching for the stars involved overcoming great technological and scientific problems and also created new political and legal questions that needed to be answered. Of particular concern to US President Dwight D. Eisenhower were the legal ramifications and the potential reaction of the USSR to an American surveillance satellite passing over Soviet territory. Unlike the operation of an aircraft, that are subject to national jurisdiction and sanction, no rules or procedures had yet been established for the global over-flight of spacecraft. There was not even an agreed international definition of where *airspace* ends and *outer space* starts. The upper limit of airspace is not defined in *The Convention on International Civil Aviation*, signed on 07 December 1944, that established the rules of airspace, aircraft registration and safety. The best definition the *Chicago Convention* can offer is inferred in Annex 7, which defines an aircraft as any machine 'that can derive support in the atmosphere from the reactions of the air.'[5] Thus, if an aircraft is able to fly, then it must be aloft in airspace. For the purposes of the application of air law, the upper limit to a state's rights in airspace is defined as above the highest altitude at which an aircraft can fly and below the lowest possible perigee of an earth satellite in orbit.[6]

Eisenhower's concerns would turn out to be short-lived. The Soviet Union successfully launched the world's first artificial satellite to establish an orbit around the Earth on 04 October 1957. Named Sputnik 1, this satellite overflew many states and realised the ability for spacecraft to pass over any territory completely unrestricted by national boundaries.[7] Following this momentous achievement, the Soviet Union went on to claim the world's second satellite launch with Sputnik-2 on 03 November 1957. This was also the first spacecraft to carry a living creature to orbit, the ill-fated space dog named Laika. The US became the second nation to establish an orbiting satellite with Explorer 1, launched on 01 February 1958. To this day, there is still no universally agreed upon boundary or legal delimitation for the '*edge of space*', even though this very topic has been added to the agenda of the Committee on the Peaceful Uses of Outer Space, or its Legal Sub-Committee, every year since 1959. Wherever space may start, it should be treated as global commons much like the oceans and polar regions. The Outer Space Treaty (OST) of 1967 states that space 'is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means.'[8]

UK Space Power

The success of Sputnik 1 demonstrated a technological advantage held by the Soviet Union and, to a degree, it invalidated the defensive significance of the oceanic barriers surrounding the US. Indeed, if the Soviets could launch a satellite into space, could they also attack America with a missile-based nuclear weapon. This defence concern amid the American administration and the US general public was known as the 'Sputnik Crisis' and triggered a period of uncertainty over a perceived technological gap between the superpowers.[9] Britain and the US both started to develop missiles that could reach targets within the USSR, and the UK named theirs Blue Streak. Capable of delivering a nuclear warhead, sixty Blue Streak missiles were planned to be stored in underground silos across the east of England but, owing to the UK's small size, these would inevitably be located near towns and villages and thus leave the local population vulnerable to nuclear attack. Combined with soaring costs, Blue Streak, as a missile, was cancelled in 1960 before the silos were built.[10]

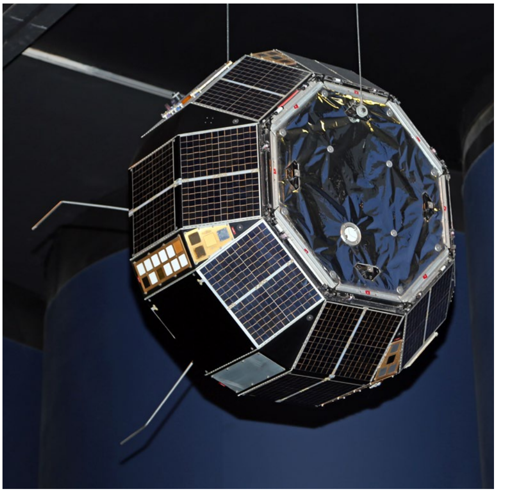
In 1962, the UK would become the third nation to operate a satellite with the launch of Ariel 1. Named after a spirit from William Shakespeare's *The Tempest*, Ariel 1 was launched from Cape Canaveral on a Thor-Delta rocket, on 26 April, and was designed to gather information on the Earth's ionosphere and of sun-ionosphere relationships.



Artist's impression of the Ariel 1 science satellite. (Credit: NASA, Public Domain, via Wikimedia Commons)

However, to say Ariel 1 was UK 'sovereign' would be misleading as it was only partially British. The UK did not have its own space technologies during this period, so Ariel 1 was developed and built in the US by NASA's Goddard Space Flight Center in a US-UK agreement reached in 1960.[11] Another five Ariel satellites were launched between 1962 and the 1980s as part of the programme. The biggest shortcoming for the UK, and what diminished its status as a space power, was its dependence on the US for both spacecraft manufacturing and space launch.[12] In part to save face and investment, the development of Blue Streak continued at Spadeadam to modify it into the first stage of the Europa rocket under a collaboration with the European Launcher Development Organisation (ELDO) to launch satellites. Blue Streak was first launched from the Woomera test site in South Australia in 1964 and had a comparable success rate to the US Saturn V rocket.[13] Also in 1964, the UK began development of its own launch system, known as Black Arrow. Four of these rockets were produced between 1969-

1971, though the first and third launches resulted in failure. The first success came with the fourth launch and was a landmark in UK history; on 28 October 1971, Black Arrow launched from Woomera and the Prospero satellite was inserted into orbit. Britain became the sixth nation to achieve this by means of an indigenously developed carrier rocket, following the USSR, USA, France, Japan, and China. Prospero (named for the protagonist of *The Tempest*, keeping with the theme of Shakespeare characters) conducted a series of experiments to study the effects of the space environment on communications satellites and remained operational until 1973. It remains the UK's first and only endeavour to successfully place a satellite in orbit.

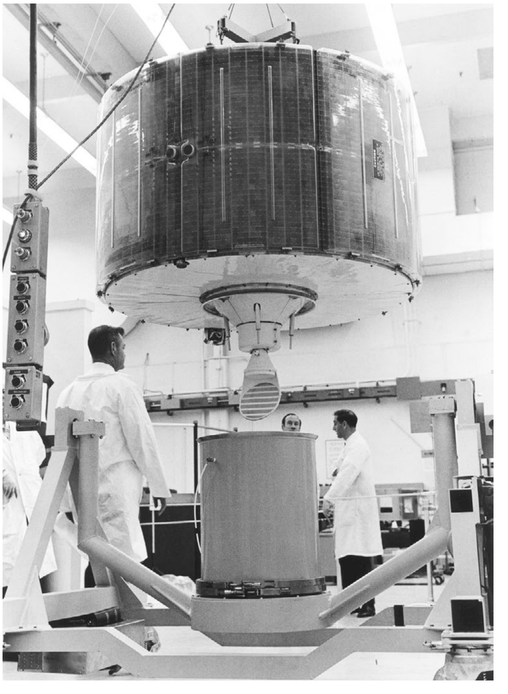


Prospero X-3 satellite flight spare. (Credit: London Science Museum, Public Domain, via Wikimedia Commons)

Black Arrow would have also inserted the next UK satellite, Miranda (again, a character from *The Tempest*), into orbit if the rocket had not been cancelled. Both Black Arrow and Blue Streak were abandoned for political and economic reasons in 1971. The Ministry of Defence (MOD) had decided it would be cheaper to use US rockets as NASA had offered to launch UK payloads for free, but this offer was retracted after the cancellations.[14] The UK is the only nation to have successfully developed and then subsequently terminate a satellite launch capability. Miranda was instead launched on a US Scout-D rocket in March 1974 and was used as an engineering test bed for gyro systems.

With its attempts to keep pace with the larger space powers, Britain would eventually claim its own world's first with the launch of Skynet 1, the first Military Satellite Communications (MILSATCOM) system successfully established in a geostationary orbit (GEO).[15] Skynet was designed to maintain communications links between Britain and the Middle and Far East and to meet the requirements of a defensive, reactive war against a numerically superior enemy. Skynet 1A was built by the US firm Philco Ford then launched on a Thor-Delta rocket from Cape Kennedy's Complex 17 on 22 November 1969. Despite the UK's reliance on the US for its space endeavours, the British telecommunications and engineering company Marconi was involved in Skynet's development process in order to gain experience. After approximately 18 months of operation, Skynet 1A ceased to function due to its Travelling Wave Tube Amplifiers (TWTAs) failing under thermal cycling because of poorly soldered high voltage electrical joints.[16] Skynet 1B was launched in August 1970 but was destroyed when its internal Apogee Kick Motor (AKM) exploded during the insertion into GEO. Skynet 1 was operated by the RAF's No.1001 Signals Unit (1001 SU) located at RAF Oakhanger in Hampshire and was responsible for supporting MILSATCOM for HM Armed Forces worldwide. 1001 SU was made up of four sub-units: Space Operations, Ground Operations, Telemetry and Control, and Support.[17] Space Operations was responsible for operating Skynet with C2 traffic being passed from one of the three ground stations.

Despite the initial setbacks of Skynet 1, the MOD resolved to continue the MILSATCOM programme with the development of Skynet 2, a more powerful satellite than before and built by Marconi itself. Despite some reliance on US technology, Skynet 2 was recognised as the first European-built communications satellite.[18] Skynet 2A was launched in January 1974 in the same manner as Skynet, but this time the Thor-Delta's second stage rocket malfunctioned, and it was initially assumed that Skynet 2A was lost. However, it was subsequently detected in a very low elliptical orbit by the US early warning missile system. Incredibly, Skynet 2A was still functioning, but attempts to boost its orbit by firing its AKM failed, and it ultimately burned up in Earth's atmosphere. Skynet 2B was launched on 22 November 1974, and was a complete success; it was in service up until 1988.



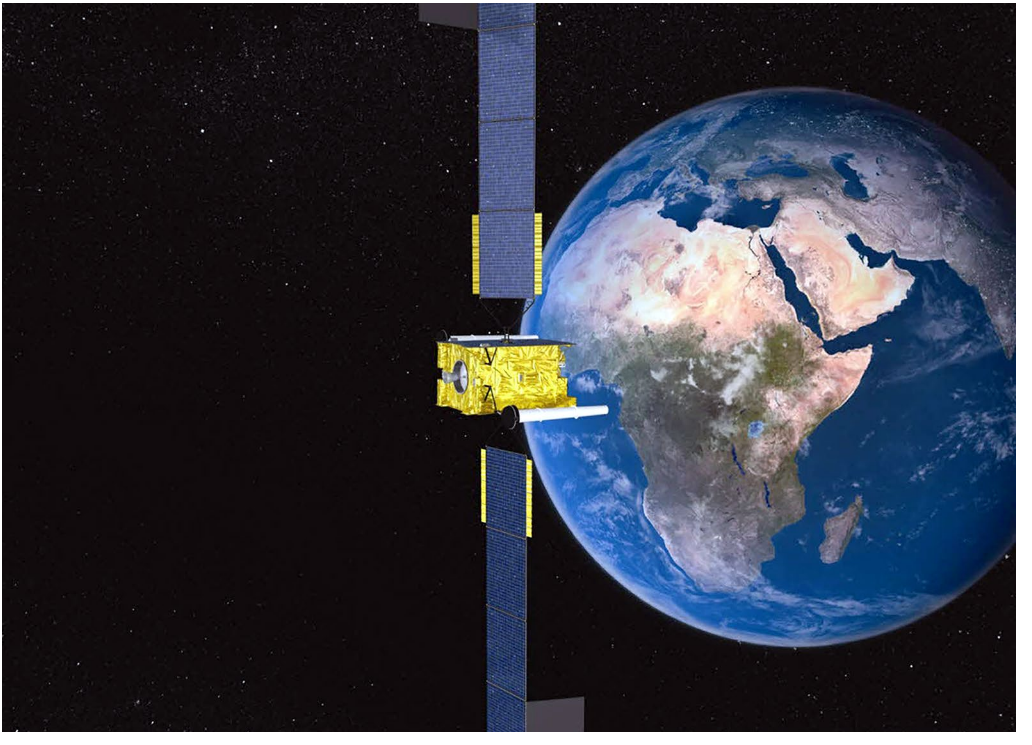
Skynet 2 satellite being packed for shipment. (Credit: USAF photographer, Public Domain, via Wikimedia Commons)

By 1975, Marconi had completed its studies for a further enhanced Skynet 3, but the Labour government decided to stop funding an independent MILSATCOM as part of its defence review. Instead, it opted to rely on the US Defense Satellite Communications System (DSCS) II and other NATO satellites.[19] The interruption to development in UK space industry resulted in many problems and, by the late 1970s, it became apparent that the US/NATO systems were inadequate for Britain's capacity needs. Also, reliance on the US was not cheap as leasing charges had progressively increased throughout the late 1970s. Thus, the development of Skynet 4 was authorised in 1981 and the Falklands Conflict in 1982 validated this decision; though Skynet 2B was operational, it was beyond its planned life and its footprint ended at 23° West, far short of the Falklands at 60° West. Royal Navy ships and some merchant vessels were equipped with Satellite Communications Ocean Transportable (SCOT) that were designed to be compatible with other systems including DSCS, but the UK had to use spare DSCS circuits (though at times, the flow of signal traffic threatened to exceed the circuits' capacity). The Falklands Conflict had exposed the problems faced by UK forces and the need for flexible, expanded capacity communications when operating outside of the NATO region. The House of Commons Defence Committee reported that this situation could not be allowed to happen again. Also, during the Falklands conflict, it was difficult for the Government Communications Headquarters (GCHQ) to gain access to the US National Security Agency (NSA) signals intelligence satellites to monitor Argentine communications within an appropriate tasking window. Thus, it was decided to produce a UK designed and built space-based capability intended to intercept Soviet radio and other signals. The satellite was to be called Zircon and was planned to be launched using NASA's Space Shuttle under the guise of Skynet 4 in 1988. However, it was cancelled in 1987 due to cost. In fact, secrecy surrounding the project's costs, that were hidden from Parliament, led to the 'Zircon Affair'; investigative journalist Duncan Campbell had learned of Zircon and believed the plan violated a 1982 government agreement on informing the House of Commons of military projects over a certain amount. Campbell published an account of the project through the New Statesman magazine ahead of a BBC programme that resulted in an injunction as well as Special Branch police raids on BBC and New Statesman offices and the homes of Campbell and his researchers.[20]

Skynet 4 was designed to have a greater power capacity in order to meet the requirements of man-portable operations and have the ability to change the satellite's location as needed for out-of-area requirements. The Initial funding for the programme was £200 million with British Aerospace (BAe) as the prime contractor for the platform and Marconi as principle sub-contractor for the communications payload and antennae. The Royal Navy picked up 80 percent of the budgetary allocation owing to the continuing importance of MILSATCOM to UK naval forces and operational control was via the Skynet terminal at RAF Oakhanger. In 1987, Skynet 4 was selected as the NATO 4 satellite, beating the US DSCS-3, and two vehicles were procured in a contract worth £100 million, 75 percent of which going to the two British contractors.

RAF Oakhanger was closed in 2003 and all support to Skynet was transferred from the RAF via contract to a Private Finance Initiative (PFI) partnership between Paradigm Secure Communications and the Astrium subsidiary of the European Aeronautic Defence and Space Company's (EADS). Following company restructuring, Skynet 4 and 5 satellites were operated by the rebranded Airbus Defence and Space division, the latter spacecraft being based on the Eurostar E3000 bus design. In 2017, the MOD opted for the non-competitive route with Airbus to replace the Skynet 5 network, partly in order to maintain domestic space capabilities. In July 2020, a contract between Airbus Defence and Space and the MOD was signed to extend and enhance the Skynet fleet with the development, manufacture, cyber protection, assembly, integration, and testing of Skynet 6A, which passed its Critical Design Review (CDR) in July 2022. It is planned for launch on a SpaceX Falcon 9 rocket in 2025.[21]

Also of great importance to the UK is Position, Navigation and Timing (PNT) services derived from a Global Navigation Satellite System (GNSS), such as the US owned and operated Global Positioning System (GPS). A GNSS is an 'invisible utility' that underpins the UK economy; for example, without the timing signal from GPS, many day-to-day services would be severely



A computer-generated image of the Skynet 5D satellite in orbit.
Credit: Astrium via Defence image Library)

disrupted as it enables the synchronisation of computer networks, financial trading, transport systems, electricity transmission, etc.[22] Indeed, PNT is so important that it listed on the UK's National Risk Register despite the UK not owning or operating its own GNSS capability and thus relying on GPS.[23] Redundancy would be preferable to relying on one system, but a GNSS capability is extremely expensive; GPS is a constellation of 24 satellites operating in Medium Earth Orbit (MEO) – an altitude of around 12,000 miles – with the initial constellation costing $12 billion to put into orbit in the 1990s. Thus, the UK entered into a consortium under ESA for the development of the Galileo GNSS in the early 2000s. However, Galileo also features an encrypted signal capability called the Public Regulated Service (PRS) intended for military and government agency use, but with a condition for access of being a European Union (EU) member state. With the UK's withdrawal from the EU, negotiations over future involvement in Galileo broke down, and the UK opted to leave the programme in November 2018. This was done in spite of the UK's investment of £1.2 billion and the fact that the free and open signals remained completely accessible.[24] The UK Government then announced a £92 million investment of Brexit readiness money for plans for an independent UK GNSS, with the UK Space Agency (supported by the MOD) undertaking the necessary analysis, design and engineering studies to develop options for an assured PNT service.[25] The concept was widely questioned for being overly ambitious and some senior civil servants pushed to abandon the 'unaffordable' £5 billion project. In a surprising turn, the UK then announced its £400 million stake in the failed satellite firm OneWeb, who went bankrupt in March 2020 when attempting to deliver a broadband competitor to SpaceX's Starlink system. The winning $1 billion bid came from the consortium led by Indian conglomerate Bharti Enterprises, with the UK government owning a 45% equity stake.[26] In addition to a comms service, compelling lobbying convinced the government that OneWeb could offer an alternative PNT system by redesigning some of the satellites to host a navigation payload. However, this poses significant challenges, even if it were possible at all. One industry executive stated that it 'would be like trying to build a hybrid of a Formula 1 racing car and a dump truck.'[27] Recent updates on a LEO-based PNT capability have gone quiet and it appears that the UK Government has not been particularly committed to the idea beyond it being a talking point during Brexit. In any case, OneWeb and Paris-based Eutelsat announced a $3.4 billion merger in July 2022 which puts a dampener on the possibility for a UK PNT capability.[28] OneWeb's 1st generation broadband constellation in LEO has however been completed, making the UK 'one of the world's largest satellite operators' and supporting the NSS Pillar One: Unlocking Growth.[29] The UK has also recommitted to its close collaboration with ESA in support of the NSS Pillar Two: Collaborating Internationally.

The UK has also sought to gain its own space-based Intelligence, Surveillance and Reconnaissance (ISR) capability; the MOD invested £4.5 million in a small-satellite EO technology demonstrator with Surrey Satellites Technology Ltd (SSTL), owned by Airbus, that launched in 2018. Known as CARBONITE-2, it offered the RAF a demonstration of low-cost video-from-orbit solution designed to deliver 1m resolution images and colour HD video clips with a swath width of 5 kilometres.[30] Since 1981, SSTL has built and launched over seventy satellites and has also as provided training and development programmes, consultancy services, and mission studies for ESA, NASA, international governments and commercial customers, and the Galileo GNSS (before the UK left the programme). Also in 2018, the first all-British Synthetic Aperture Radar (SAR) imaging spacecraft called NovaSAR (developed by Airbus and SSTL) would return its first radar images from space.[31] Later, at the June 2019 Air and Space Power Conference, the MOD announced its new and ambitious space programme, committing £30m to fast-track the launch of a small satellite demonstrator under Team ARTEMIS and that the UK would become a partner nation to join Operation Olympic Defender, a US-led international coalition to strengthen deterrence against hostile actors in space.[32] Also, an RAF test pilot would be seconded to Virgin Orbit's small satellite launch programme with the intent to launch from Spaceport Cornwall. Separate to this, the UK Government would push ahead with Airbus's Project Oberon (also from Shakespeare, a character in '*A Midsummer Night's Dream*'), that would build on research from NovaSAR and also invest in state-of-the-art antennas from Oxford Space Systems (OSS).[33] The ISR initiatives would ultimately be succeeded in the 2022 DSS with £968 million of Defence spending for a multi-satellite system for global ISR operations known as the ISTARI programme. Another £61 million was made available for laser-based communications technology and £145 million for Space Control activity. Unfortunately for Virgin Orbit, a failure of its LauncherOne rocket in January 2023 from Spaceport Cornwall would result in the company ceasing all of its operations permanently, filing for bankruptcy and auctioning its main assets in April 2023. Virgin Orbit recovered just $36 million, barely 1% of the company's value of $3.5 billion in late 2021.[34]

Anti-Satellite Weapons

For nearly as long as there have been artificial satellites in orbit, there has also been the need to counter an adversary's space-based capabilities. Though Skynet is considered to be the 'jewel in the crown' of the UK's space capabilities and, as such, has been allocated £5 billion in funding over 10 years in the DSS, space control activities have only been given £145 million over the same period.[35] The UK has committed itself to promoting the responsible use of space and does not possess a hard-kill Anti-satellite (ASAT) weapon system, such as an Aegis-equipped destroyer.[36] Therefore, to discuss space control systems, the capabilities of other nations must be considered. For the four countries that have been able to successfully destroy their own satellites in ASAT tests – America, Russia, China, and India – comes not only national prestige but also a demonstration of their ability to contest the control of space.

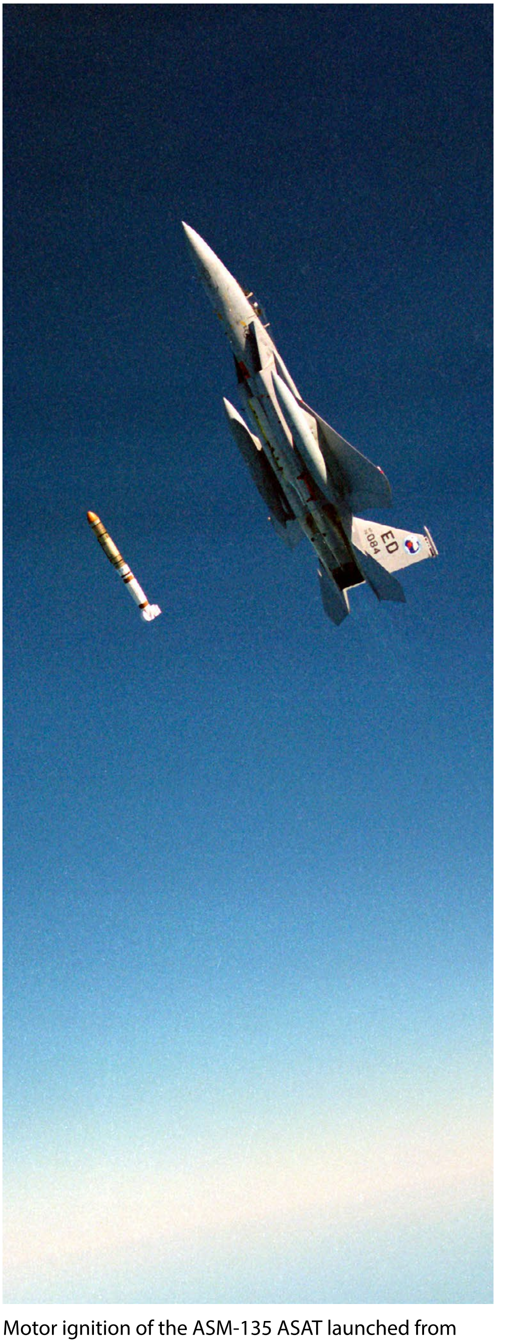
In August 1959, the United States Air Force (USAF) Ballistic Missile Division began preliminary development for a planned Satellite Interceptor (SAINT), though subsequent reviews descoped the programme to the development of subsystems only, forbade flight testing, and references to a satellite 'kill' capability were removed. The restriction of SAINT operations to rendezvous and inspection also brought with it a new name of 'Satellite Inspector' as the Eisenhower Administration was opposed to the development of a weapons system that may contest the principles of freedom in space, preferring to preserve the right of unobstructed passage of reconnaissance satellites.[37] Albeit, the Soviets had made public statements hinting at the value of having space-based nuclear weapons for military operations, or at least the mention of them was meant to intimidate the West. The US and Soviet Union led the development of ASAT capabilities as a defensive measure or as an asymmetric counter to a technologically superior rival. Between 1957-59, USAF was conducting a strategic weapons development programme called Weapons System 199 (WS-199) for Strategic Air Command. Under this programme, the prototype Bold Orion missile, or WS-199B, was developed as an air-launched ballistic missile (ALBM), with the Boeing B-47 Stratojet used as the delivery platform. Bold Orion's final test launch was to trial its capabilities in the ASAT role; conducted on 13 October 1959, the missile was launched from a B-47 at an altitude of 35,000 feet and guided toward the perigee of the Explorer 6 satellite.[38] Bold Orion passed its target at a range of less than 4 miles at an altitude of 251 km and, if the missile had had a nuclear warhead, Explorer 6 would have been destroyed. A satellite in LEO is travelling at approximately 17,500 miles per hour, nearly twenty-three times the speed of sound, making it an extreme technical challenge to achieve a hit. Instead, the concept of detonating a nuclear warhead close enough to the target satellite to destroy it by means of the energy emitted by the weapon's electromagnetic pulse (EMP) was employed, rather than the use of a precision weapon.

Following the election of John F. Kennedy in 1961, Robert McNamara was appointed as new Secretary of Defense. In 1962, in response to Soviet threats against US satellites, McNamara had adopted an eye-for-an-eye policy, telling USAF to 'get on with the SAINT program' and he also approved testing of the US Army's Nike Zeus Anti-Ballistic Missiles (ABMs) for use as ASAT weapons.[39] Named Program 505, tests of the Nike Zeus satellite interceptor revealed that the missiles were limited to a max altitude of approximately 200 miles and, come 12 September 1962, USAF leaders had submitted a preliminary plan to use Thor Intermediate-Range Ballistic Missiles (IRBMs) as satellite interceptors. These much larger rockets had a greater capacity for interception than Nike Zeus and would later be based on the Johnston Atoll in the Pacific Ocean (a small island approximately 750 nautical miles southwest of Hawaii) for a series of high-altitude nuclear tests under the codename Operation Fishbowl. Though previous high-altitude nuclear explosion (HANE) tests had been conducted, they were hasty and inconclusive, so Fishbowl sought much clearer outcomes. One of these tests, named Starfish Prime, took place on 09 July 1962, and came with unexpected consequences, its immediate effects being felt for thousands of kilometres. A Thor rocket was launched with a 1.4 megaton yield thermonuclear warhead which was then detonated at an altitude of 400 km.[40] The explosion generated an EMP that disrupted electricity transmission networks; in Hawaii, hundreds of streetlights were blown and there were widespread telephone outages and disruptions to the power grid. There were also radio blackouts and electrical surges on airplanes. The large amount of charged particles further caused unintended damage to many operating satellites, both from the initial blast and later as the energetic particles remained trapped in the Earth's magnetic field, forming an artificial radiation belt that persisted for many days afterward. One of the effected satellites was Ariel 1 which had sustained damage to its solar panels and resulted in a degraded performance.[41]

The explosion of Starfish Prime. Unlike the characteristic mushroom cloud shape of a terrestrial nuclear explosion, HANEs are spherical.
(Credit: Defense Atomic Agency, Public Domain, via Wikimedia Commons)

The results of Operation Fishbowl, and similar tests conducted by the USSR, demonstrated that the aftereffects of nuclear detonations in space are too wide raging and indiscriminate, causing damage to friendly and adversary spacecraft alike. Coupled with increasing unease amongst the public regarding radioactive fallout, the future testing of such explosions, as well as nuclear testing underwater and in the atmosphere, was prohibited by the 1963 Partial Test Ban Treaty (PTBT). However, the PTBT only bans the testing of nuclear weapons; it does not ban their procession or use in operations. Indeed, the United States' cautious approach to ASAT programmes was abandoned when McNamara cancelled the SAINT programme in 1962, and then approved Program 437 in late 1963 which aimed to have Thor satellite interceptors on 24-hour alert at the Johnston Atoll. These would be launched two at a time (for redundancy), each with a 1 megaton yield nuclear warhead with a 5-mile kill radius. The max altitude was 700 nautical miles and a cross range of 1,500 nautical miles of the Johnston Atoll. Development of Program 437 was smooth with successful test launches with simulated warheads; it was declared fully operational on 10 June 1964.[42] Come 1970, Program 437 was reduced to standby status and the missile and warheads were removed from Johnson Atoll. Launch and ground facilities were also shutdown with a 30-day reactivation period, and Program 437 was eventually terminated on 01 April 1975. Though Programs 505 and 437 were both declared operational, they were only deployed for a brief period and on a limited scale.

Although Program 437 was on a standby status in 1970, the US DoD and USAF had a continuing interest in an air launched ASAT and the Soviets had developed and tested their own interceptor which used a conventional high-yield warhead to destroy a satellite. Without a counter, the US reconsidered the concepts laid out by Bold Orion with the proposal of Project SPIKE; a homing missile equipped with either a nuclear or conventional high-explosive warhead or a camera, launched from a F-106 Delta Dart aircraft. SPIKE ultimately would not be developed but it did lay out some basic design features of an air-launched ASAT.[43] Following approvals from President Gerald Ford in 1975 to start work on an ASAT that could be launched from an F-15 Eagle, the fully developed ASM-135 missile was released on 13 September 1985, and destroyed the Solwind P78-1 satellite at an altitude of 555 kilometres.



Motor ignition of the ASM-135 ASAT launched from an F-15 Eagle approximately 200 miles west of Vandenberg Air Force Base, CA.
(Credit: Paul E. Reynolds, Public Domain, via National Archives Catalog)

It would be more than two decades before the next successful direct ascent ASAT test would take place (that is known of) when China destroyed its Fēngyún-1C (FY-1C) weather satellite on 11 January 2007. Terrestrially launched from the Xichang Space Launch Center (XSLC) – or nearby – the kinetic kill vehicle achieved the intercept of FY-1C in a polar orbit at an altitude of 865 kilometres. However, the Chinese government would not confirm that the test had taken place until 23 January with a statement from Foreign Ministry spokesman Liu Jianchao, who also insisted that China was committed to the 'peaceful development of outer space' and opposed 'the arming of space and military competition in space.'[44] Liu Jianchao also stated China had notified the US and other countries about the test in advance. Following this, the US would destroy a non-functioning National Reconnaissance Office (NRO) satellite (USA-193) in a decaying orbit on 14 February 2008. A DoD statement confirmed that the USS Lake Erie, a US Navy AEGIS warship, fired a modified tactical Standard Missile-3 that hit the satellite at an altitude of approximately 247 kilometres.[45] USA-193 would have re-entered Earth's atmosphere on its own, however there were concerns that its fuel tank would had survived and it contained approximately 1,000lbs of frozen hydrazine, a highly toxic propellant. The DoD further stated that the 'debris will begin to re-enter the Earth's atmosphere immediately,' and 'nearly all of the debris will burn up on re-entry within 24-48 hours and the remaining debris should re-enter within 40 days.'[46] Albeit, some commentators have speculated that USA-193 was instead the US 'flexing its muscles' following China's ASAT test the year before. India would become the fourth country to demonstrate a successful ASAT test with Mission Shakti on 27 March 2019.

Both the UK and the US have accused Russian of an ASAT test that occurred in July 2020 when a weapon-like projectile was sent from Cosmos 2543, a satellite purportedly for survey and inspection. This was the first time that an accusation of an on-orbit weapon has been fired and that the Kremlin had actively hidden the operation. What is more, on 15 November 2021, Russia successfully tested the System A-235 PL-19 Nudol ASAT weapon when it destroyed the Kosmos 1408 satellite, receiving much criticism from the UK and US. The direct ascent Nudol missile can strike a satellite in a much shorter timeframe than a co-orbital ASAT and represents a departure from the 'traditional' Soviet approach.

A different type of ASAT to direct ascent weapons are '*co-orbital*' systems, which were favoured by the former Soviet Union. The 1967 OST only bans the stationing of Weapons of Mass Destruction (WMDs) in space, and therefore does not prohibit the development of space-to-space weapons systems, or indeed any kind of conventional weapon, in orbit.[47] The Russian Istrebitel Sputnikov (IS) system (meaning 'satellite destroyer'), and its successors, began its development during the 1960s before being declared operational in 1973, and then upgraded to IS-M in 1976. The ASAT worked by being carried to orbit by a launch vehicle and reaching its target only after one or two orbital revolutions before achieving the interception by means of a conventional explosive.[48] Though the IS was tested extensively and supposedly achieved a higher degree of flexibility than the early US systems, the orbital trajectories it could reach was limited. The latest iteration was IS-MU that was declared operational in 1991, yet it was reportedly withdrawn from service in 1993. However, the USSR had started developing a follow-up system in the early 1980s called Naryad; also a co-orbital ASAT, Naryad was designed to reach altitudes on 40,000km, and so could threaten satellites in GEO.[49] The present status of Naryad is not currently known, but the Russian Federation continues to benefit from the former Soviet Union's rich history of developing and operating ASAT weapons. The core of the two confirmed co-orbital ASAT systems is technology that allows for Rendezvous and Proximity Operations (RPO), a type of orbital manoeuvre where two spacecraft arrive at the same orbit and approach at a close distance. Russia has been undertaking a series of secretive RPO activities since 2013; on several occasions they have manoeuvred space objects and conducted proximity operations in both LEO and GEO, indicating a revival of Russian efforts in co-orbital counterspace technology development.

The problem of debris

Destructive ASAT weapons do not come without consequences, chief among them is the resulting debris that is created. As space is a near-vacuum, objects travel at extremely high velocities and even the smallest of items can damage or destroy space systems. For example, a window of the Cupola module of the International Space Station (ISS) was chipped by something as unassuming as a fleck of paint![50] Orbital debris is made up of all sorts of space junk, including small items like bolts and tools, to larger objects such as damaged spacecraft, defunct satellites, and rocket segments. Thousands of missions have been launched since the start of the Space Race in the 1950s and the risk of collisions increases as more and more space objects add to the existing junk. At altitudes below 500 miles, atmospheric drag will cause these objects to deorbit and burnup in Earth's atmosphere within a few decades. However, as the effect of Earth's gravity is weaker at greater distances, objects at higher altitudes may remain in their orbit for centuries.[51] The 2007 Chinese ASAT demonstration, at an altitude of 865 kilometres, created around 3,000 pieces of trackable debris in LEO whereas the Indian test at 282 kilometres created about 400 pieces, some of which reached as high as 2,222 kilometres and may remain in orbit for years.[52] The more recent Russian PL-19 Nudol test resulted in over 1,500 trackable objects (and much more besides that are also a threat) which forced the seven crew members of the ISS (which included two Russians) to take shelter multiple times. Across all artificial satellites in orbit, hundreds of collision avoidance manoeuvres are performed every year.

The ultimate doomsday scenario for a build-up of space debris was theorised by NASA scientist Donald J. Kessler in 1978 and is named for its originator as 'Kessler syndrome'; it describes a situation whereby the density of space debris reaches a saturation point where a cascade of collisions exponentially creates more debris and increases the frequency of further impacts.[53] The result could render an effected orbit completely unusable for years if not centuries. Indeed, space is already so congested that a deliberate act is not required to contribute to the problem of space debris; the most severe fragmentation in space (so far) was the accidental hypervelocity collision of US communications satellite Iridium 33 with Russian defunct communications satellite Cosmos 2251 on 10 February 2009. Over 1,800 pieces of debris of a size approximately 10 cm and larger were produced with some of the fragments predicted to remain in orbit through to the end of the century.[54] A dramatized depiction of the catastrophic potential of Kessler's syndrome is shown in the opening scene of the 2013 movie *Gravity* when the astronauts are conducting repairs of the Hubble Space Telescope. They are warned of an approaching debris field created by the Russians after striking one of their own spy satellites, and that this field has already destroyed multiple spacecraft and rendered communications inoperative. On attempting to return to the Explorer space shuttle, the astronauts are bombarded with this debris that then destroys their spacecraft and renders them stranded.

The problem of space debris does, however, have a positive effect, by reason that the risk threatens all spacecraft in an orbit, including any assets belonging to the owner of a destructive ASAT. Thus, this 'mutually assured vulnerability' inherently abates the probability of the use of kinetic kill weapons. Indeed, the Obama Administration sought to enhance diplomatic efforts to protect space assets and suggested that 'globalized entanglement' could substitute national autonomy to protect space functions by means of collectivisation.[55] Further benefits include avoiding a potential arms race and the weaponisation of space, coupled with a perceived political escalation and potential retaliation. It is then perhaps preferable to achieve space control through non-destructive or soft-kill systems to harm – or threaten harming – an adversary's access to space. Soft-kill systems may be characterised as capabilities that can dazzle a satellite's sensor with Directed Energy (DE), jamming its link segment, or cyber-attack.[56] For the latter, the UK's National Security Risk Assessment identifies cyber-attacks as a Tier One risk, and also the possibility of a deliberate attack on Tier Two that disrupts the information received, transmitted or collected by satellites.[57] As soft-kill methods may also be reversable, they give the fighter the ability to effect Critical National Infrastructure (CNI) below the level of actual conflict and be disruptive without causing any physical damage. This allows for states to operate in the 'grey zone' or 'sub-threshold' warfare.[58] The potential normalisation of ASAT capabilities means that space-based systems may come under attack from a range of actors, therefore space should not be considered any kind of sanctuary.

Though the UK does not possess its own space control capability, the space domain is special in that in can also be influenced by cross domain effects. As any space capability is comprised of three distinct components – the space, link and ground segments – an attack on any one of them can disrupt, degrade, deny or destroy a capability. For example, a conventional air strike can be prosecuted against an adversary's ground installation that controls a satellite, or a cyber-attack / electronic jamming directed at the link to cut off communications. The UK can also utilise its diplomatic and economic instruments of national power under UK Defence Doctrine (UKDD) to exert influence and control in the international system.[59] For example, in response to the alleged Russian in-space ASAT weapon, the UK introduced UN resolution in 2020 on security in space in an attempt to halt a dangerous re-energising of the space arms race and also lead the global discussion in responsible space behaviours.[60] To solidify this commitment and promote the notion further, the UK pledged to not test any direct ascent

ASAT missiles in October 2022 by agreeing to a UN Resolution on the matter introduced by the US in April 2022.[61] As of April 2023, the Netherlands, Austria and Italy signed, joining the US and UK along with Australia, Canada, France, Germany, Japan, New Zealand, South Korea, Switzerland to bring the total number of nations to thirteen.[62] However, these types of covenants are only as good as the signatories agreeing, ratifying, and conforming with their content. Indeed, there are views amongst some scholars, chiefly the realist school, that any such international agreement is merely part of a never-ending struggle between states for power and security, and that war is an inevitable end to this struggle.[63]

Orbital Clean-up

After decades of build-up of space junk, LEO is on the verge of becoming much too crowded. This problem is also set to get much worse due to the rise of '*mega constellations*' that require thousands of satellites, such as SpaceX's Starlink which, as of July 2023, has 4,519 satellites in orbit. As such, satellites operators have responsibilities for their spacecraft and, in October 2023, the US government Federal Communications Commission (FCC) issued its first ever fine. A penalty of $150,000 was awarded to Dish Network for failing to move an old EchoStar-7 satellite far enough away from other spacecraft.[64] Debris removal is a global priority, though there is no set consensus on how it could be achieved. In 2018, SSTL launched its RemoveDEBRIS research project to demonstrate four debris removal technologies – a net, a harpoon, vision-based navigation using cameras and LiDaR, and a de-orbit dragsail – at low cost.[65] It was deployed to the ISS in a cargo transfer bag on a SpaceX Dragon spacecraft and

Astroscale COSMIC ADR Mission. (Image courtesy of Astroscale) deployed from the station's Kibo module via robotic arm. Its targets were two CubeSats that the RemoveDEBRIS deployed itself. Following a successful demonstration, RemoveDEBRIS burned up in Earth's atmosphere on 04 December 2021. Furthermore, the NSS released in 2021 set a strategic priority for the UK to lead the global effort to clean up space and, in September 2022, the UK Space Agency awarded a total of £4 million to ClearSpace and Astroscale to design missions to remove space debris. Further funding could be made available to realise the 'UK's first national space debris removal mission launch in 2026.'[66] £1.7 million of the funding awarded to Astroscale is for designing a satellite servicer that can remove multiple retired or defunct satellites in a single mission. The Cleaning Outer Space Mission through Innovative Capture (COSMIC) will employ Astroscale's RPO and Active Debris Removal (ADR) technologies and is due to launch in 2026.

The UK is not the only nation with an orbital clean-up programme. For example, on 24 October 2021, China launched its Shijian 21 (SJ-21) space debris mitigation satellite from XSLC into a geosynchronous transfer orbit (GTO). China's state media described SJ-21 as an On-Orbit Service, Assembly, and Manufacturing (OSAM) satellite that would 'test and verify space debris mitigation technology.'[67] In November 2021, SJ-21 deployed a second, smaller satellite that the USSF's 18th Space Defense Squadron (18 SDS) categorised as a discarded AKM, which SJ-21 subsequently appeared to be conducting sophisticated RPOs with. Further suspicion was drawn in December when SJ-21 disappeared from its orbital slot to rendezvous with a defunct Beidou G2 navigation satellite in GEO. After matching its orbit and docking with Beidou G2, SY-21 then dragged it to a graveyard orbit 3,000 kilometres away before releasing it and returning to GEO.[68] It was commercial space domain awareness from ExoAnalytic Solutions that monitored and reported on SJ-21's activity and has been visualised in an openly available YouTube video. What is of concern with SJ-21 is that the Chinese did not declare its launch or confirm its mission until it had actually done so. With no issued notifications, China has attracted criticism to its lack of transparency and led speculation as to the true purpose of SY-21 and that it could be a space weapon. This is described as a 'dual use' system and use refers to a technology that can be used in defence applications as well as non-military purposes. This distinction can be used as a means to keep a capability in the grey zone and operate outside of military norms.

The term dual use is perhaps not a particularly helpful description as, in reality, almost anything could be considered as dual use if one were imaginative enough. In fact, some military professionals have described the term dual use as being beyond definition, such as Brigadier General Morgan on the disarmament of Germany following WWI: 'Is a field-kitchen war material? Or a field ambulance? Or a motor-lorry? All three are capable of civilian use. When are you to 'call a spade a spade,' and when should you call it an entrenching tool? ….. The list of 'optical' war material, from periscopes to range-finders, alone ran to fifty-two items.'[69]

Regarding space technologies, cameras on Earth Observation (EO) satellites can be used for planning infrastructure, understanding the effects of climate change and disaster relief just as well as monitoring an adversary's activity and informing the planning for military operations. Civilian assets are now capable of producing images that match the quality of products previously only offered at a classified military level. Where a scientist sees a laboratory, the military professional sees a battleground; while the former wants to understand it, the latter seeks to dominate it, and the technology to do so is largely the same. Albeit, it has been estimated that at least 95 percent of space technology is dual use.[70] At the opening of Astroscale's manufacturing facility, Managing Director Nick Shave stated that the company aims for 'debris removal and in-orbit servicing to be part of routine operations by 2030'. Astroscale had previously successfully demonstrated the world's first commercial debris removal mission my means of the magnetic capture technology in a mission launched in 2021.[71]

Dual use with regards to space weapons is nothing new. One type of co-orbital attack system that has been suggested uses a manipulator arm that could be repurposed to physically manipulate or damage a target in space. Indeed, in the 1980s, the Soviet Union believed that the US Space Shuttle – which was operated the civilian space agency NASA – could be classified as an ASAT because its robotic arm could had been used to grab non-cooperative satellites out of their orbits.[72] Though the Space Shuttle programme came to a close in July 2011, there is a new American capability in development that has a striking resemblance to its forebear, the highly secretive space plane known as the X-37. Though the style of its lifting body and its landing profile are like that of the Space Shuttle, the X-37 is one-fourth the size and is uncrewed. Development of the X-37 Orbital Test Vehicle (OTV) started under NASA, but it was passed to the US military which established the X-37B variant. The secrecy surrounding

The Boeing X-37B is a highly secretive robotic space plane.
(Credit: USSF SSgt A Shanks, Public domain, via Wikimedia Commons)

X-37B and its payloads has generated rumours that it could be a sort of space weapon of some sort, though some experts says that it is likely 'too small and not manoeuvrable enough for such work'.[73] On 12 November 2022, the X-37B landed at the Kennedy Space Center in Florida after completing a record 908 days in orbit.[74]

The Chinese have also flown a mysterious spaceplane that is likely similar to the X-37B, itself completing nine-month spaceflight in May 2023. With China's space programme being closely linked with its military, there is speculation that this spacecraft could also be a weapon. According to a Center for Strategic and International Studies (CSIS) report, the vehicle released an object into orbit sometime in October 2022 that then seemed to disappear in January, only to 'suddenly reappear on satellite tracking radar in March'.[75] Furthermore, Jonathan McDowell, an astrophysicist at the Harvard & Smithsonian Center for Astrophysics, has stated that the Chinese 'have been working a lot with robot arms in other contexts, like the Chinese space station' and, if that is also the case for this enigmatic space vehicle, it could indicate that it has some sort of satellite removal capability. Such is the perceived threat from China that the CSIS Space Threat Assessment 2023 states that China is continuing to 'develop and deploy a robust arsenal of space and counterspace Capabilities' and is progressing toward its aim of becoming the world leader in space. China is expanding its space and counterspace assets, maintaining its status as the second most capable space nation after the US, with latter officials regarding the country as a significant counterspace threat.[76] China's RPO technology has been demonstrated in LEO and GEO and, although not weapons tests, they display the technology necessary for this type of attack. China also maintains a sizable kinetic ASAT capability, most notably demonstrated by its debris-creating test in 2007 test, as well as 'numerous subsequent non-intercept tests in the years since'.[77] Non-kinetic counterspace weapons, such as directed energy weapons, are not publicly known to have been tested.

Conclusions

As the UK becomes ever more dependent on space derived products and services, not only for its armed forces but also day-to-day life, its potential adversaries are increasing their counter-space systems. Thus, the UK and its Allies must Protect and Defend its interests in, through and from space against acts of hostility. Critical dependencies with regards to national security are perhaps best summed up in the following extract from the US Center for Strategic and Budgetary Assessments (CSBA): 'In the opening minutes of conflict, [the enemy would] seek to render US and allied forces 'deaf, dumb and blind' by destroying or degrading US and allied Low Earth Orbit (LEO) ISR, Space-Based Infrared System (SBIRS), third-generation Infrared System (3GIRS) sensors and communication satellites. This would be accomplished by employing directed-energy weapons, direct-ascent and co-orbital anti-satellite weapons, or terrestrial jamming, in concert with coordinated cyber and electronic warfare attacks'.[78]

What is more, the Mitchell Institute for Aerospace Studies issued a report on 26 June 2023, stating that the USSF needs new offensive weapons and more sophisticated defences to counter China's rapid deployment of space arms. It also warns that China views the vulnerability of US satellites as its strategic advantage and that the Biden administration's renewed emphasis on diplomacy and seeking norms of space behaviour will not be enough to deter conflict with Beijing.[79] It is perhaps surprising that such statements have been made open source, unless it is a ploy to secure funding for space control capabilities. Albeit, if taken of face value, it does not bode well for the UK if the USSF itself is not fully prepared to counter orbital threats.

UK Space Command should seek to develop suitable systems that focus on soft-kill techniques such as an anti-satellite jamming, dazzling, or cyber-attack. As the UK seeks to expand its portfolio of space-based assets, it must remain cognisant that ASAT capabilities are also proliferating; protecting space assets and ensuring continued access should be UK Space Command's primary goal to secure freedom of action. To maintain competitive advantage, the UK must not stagnate on developing these capabilities. An attack on any of the space segments – space, link or ground – can disrupt, compromise, degrade, or even destroy a capability, so equal attention should be given to the protection of all three components. On the same token, conventional forces have atrophied and the Defence budget is stretched with other advanced procurement programmes, so Defence must also balance its growing ambitions with its fiscal means. Recognising that it cannot afford to match the spending of the US or China, the UK should cut its cloth accordingly. Indeed, many UK space programmes throughout history have been threatened or ultimately cancelled for budgetary, technical, or political reasons, including Skynet itself, so realism must be employed throughout.

Notes

[1] *United States Space Force*, **https://www.spaceforce.mil/About-Us/About-Space-Force/**, (Accessed 8 Jun 2023).

[2] *NATO*, **https://www.act.nato.int/our-work/network-community/natos-approach-to-space/**, (Accessed 8 Jun 2023).

[3] Hollingham, R., **https://www.bbc.com/future/article/20150824-how-a-nazi-rocket-could-have-put-a-briton-in-space**, last modified 25th Aug 25, 2015.

[4] Britannica, **https://www.britannica.com/biography/Wernher-von-Braun**, last modified Jun 12, 2023.

[5] International Civil Aviation Organization, **https://applications.icao.int/postalhistory/annex_7_aircraft_nationality_and_registration_marks.htm**, (Accessed Jun 14, 2023).

[6] Joint Doctrine and Concepts Centre. *JSP 383*: The Joint Service Manual of the Law of Armed Conflict. Swindon: Ministry of Defence, 2004.

[7] Underwood, Jeffery S. 'Presidential Statesmen and U.S. Airpower'. In The Influence of Airpower Upon History, edited by Robin Higham and Mark Parillo, 177-208. Lexington, KY: The University Press of Kentucky, 2013.

[8] United Nations Office for Outer Space Affairs. **https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introouterspacetreaty.html**, (Accessed Jun 14, 2023).

[9] Caldicott, H. and C. Eisendrath. *War in Heaven*. New York: The New Press, 2007.

[10] Baker, H., https://www.spacecentre.co.uk/news/space-now-blog/blue-streak-success-failure-and-extraterrestrials/, last modified May 24, 2017.
[11] Williams, D. R., https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1962-015A, last modified Oct 28, 2022.
[12] Orbital Today, https://orbitaltoday.com/2021/10/31/history-of-ariel-1-the-first-british-satellite-launch-uks-future-space-potential/, last updated Oct 31, 2021.
[13] Baker, H., https://www.spacecentre.co.uk/news/space-now-blog/blue-streak-success-failure-and-extraterrestrials/, last modified May 24, 2017.
[14] Hill, C. N. *Black Arrow. A Vertical Empire: The History of the UK Rocket and Space Programme, 1950–1971*. London: Imperial College Press, 2006.
[15] Whitehall. *UK Military Space Programmes*. Whitehall Papers Vol 35, Issue 1 (1996): 30-43.
[16] Harris, D., https://mraths.org.uk/?page_id=2836, last modified 2018.
[17] Day, B., https://www.rafmuseum.org.uk/blog/the-original-skynet, last modified June 30, 2017.
[18] Whitehall. 'UK Military Space Programmes'. *Whitehall Papers Vol 35, Issue 1* (1996): 30-43.
[19] Ibid.
[20] Federation of American Scientists Intelligence Resource Program, https://irp.fas.org/eprint/alpha/zircon.htm, (Accessed Jul 6, 2023).
[21] Airbus, https://www.airbus.com/en/newsroom/news/2022-07-skynet-6a-satellite-passes-critical-design-review, last modified Jul 13, 2022.
[22] Government Office for Science. Satellite-derived Time and Position: A Study of Critical Dependencies. London: Government of the United Kingdom, 2018.
[23] HM Government. National Risk Register 2023. Crown Copyright, 2023.
[24] Andreou, A. https://bylinetimes.com/2020/06/30/uks-rival-to-galileo-a-brexit-farce/, last modified Jun 30, 2020.
[25] UK Space Agency. Corporate Plan 2019-20. Swindon: UK Space Agency, 2019.
[26] O'Callaghan, J., https://www.forbes.com/sites/jonathanocallaghan/2020/07/03/uk-government-wins-controversial-bid-for-bankrupt-mega-constellation-firm-oneweb/, last modified July 3, 2020.
[27] Ibid.
[28] Dennehy, K., https://locationbusinessnews.com/oneweb-eutelsat-merger-dims-hopes-of-gnss-buildout, last modified Jul 29, 2022.
[29] Department for Business, Energy & Industrial Strategy. *The National Space Strategy in Action*. Crown Copyright, 2023.
[30] Ministry of Defence, https://www.gov.uk/government/news/lift-off-satellite-launched-into-space-on-raf-mission, last modified Mar 1, 2018.
[31] Amos, J., https://www.bbc.co.uk/news/science-environment-46312874, last modified Nov 23, 2018.
[32] Ministry of Defence, https://www.gov.uk/government/news/defence-secretary-outlines-ambitious-space-programme, last modified Jul 18, 2019.
[33] Amos, J., https://www.bbc.co.uk/news/science-environment-49664409, last modifed Sep 11, 2019.

[34] The Guardian, https://www.theguardian.com/science/2023/may/24/virgin-orbit-ceases-operations-months-after-failure-of-uk-space-mission, last modified May 24, 2023.
[35] Ministry of Defence. *Defence Space Strategy: Operationalising the Space Domain*. London: Crown copyright, 2022.
[36] Bowen, B. E. 'The RAF and Space Doctrine - A Second Century and a Second Space Age'. *RUSI Journal 163:3* (2018): 58-65.
[37] Peebles, C. High Frontier: The United States Air Force and the Military Space Program. CreateSpace Independent Publishing Platform, 2012.
[38] Parsch, A., http://www.designation-systems.net/dusrm/app4/ws-199.html, (Accessed Jun 28, 2023).
[39] Peebles, C. *High Frontier: The United States Air Force and the Military Space Program*. CreateSpace Independent Publishing Platform, 2012.
[40] Williams, D., https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1962-015A, last modified Oct 28, 2022.
[41] Space.co.uk, https://web.archive.org/web/20120425173105/http://www.space.co.uk/Features/UKSpaceExploration/ARIEL1/tabid/245/Default.aspx, last modified January 2, 2008.
[42] Peebles, C. *High Frontier: The United States Air Force and the Military Space Program*. CreateSpace Independent Publishing Platform, 2012.
[43] Ibid.
[44] BBC News, http://news.bbc.co.uk/1/hi/world/asia-pacific/6289519.stm, last updated Jan 23, 2007.
[45] CNN, http://edition.cnn.com/2008/TECH/space/02/20/satellite.shootdown/index.html, last modified February 21. 2008.
[46] Ibid.
[47] United Nations Office for Outer Space Affairs, https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introouterspacetreaty.html, (Accessed Jul 5, 2023).
[48] Strauch, A., https://www.obranaastrategie.cz/en/archive/volume-2014/2-2014/articles/still-all-quiet-on-the-orbital-front.html, last modified Dec 15, 2014.
[49] The Aerospace Security Project, https://aerospace.csis.org/space-threat-2018-russia/, last modified Apr 12, 2018.
[50] Feltman, R., https://www.washingtonpost.com/news/speaking-of-science/wp/2016/05/12/a-bit-of-debris-chipped-the-international-space-station-thats-just-one-piece-of-a-much-bigger-problem/, last modified May 12, 2016.
[51] Moltz, James Clay. *Crowded Orbits: Conflict and Cooperation in Space*. New York: Columbia University Press, 2014.
[52] Stickings, A. 'The Normalisation of Anti-Satellite Capabilities'. *Air and Space Power Review Vol 22, No. 2* (Summer 2019): 32-40.
[53] Moltz, James Clay. *Crowded Orbits: Conflict and Cooperation in Space*. New York: Columbia University Press, 2014.
[54] NASA, The Collision of Iridium 33 and Cosmos 2251: The Shape of Things to Come, Oct 16, 2009.
[55] Johnson-Freese, J. Space Warfare in the 21st Century. New York: Routledge, 2016.

[56] Degrasse Tyson, N. and A. Lang. *Accessory to War: The Unspoken Alliance Between Astrophysics and the Military*. New York: W. W. Norton & Company, 2018.
[57] HM Government. A Strong Britain in an Age of Uncertainty: The National Security Strategy. London: Government of the United Kingdom, 2010.
[58] Stickings, A. 'The Normalisation of Anti-Satellite Capabilities'. *Air and Space Power Review Vol 22, No. 2* (Summer 2019): 32-40.
[59] Ministry of Defence. *Joint Doctrine Publication 0-01: UK Defence Doctrine*. 5th ed. Bicester: LCSLS Headquarters, 2014.
[60] Sengupta, K. https://www.independent.co.uk/news/uk/home-news/russia-space-arms-race-anti-satellite-missile-foreign-office-dominic-raab-a9690551.html, last modified Aug 26, 2020.
[61] FCDO, https://www.gov.uk/government/news/responsible-space-behaviours-the-uk-commits-not-to-destructively-test-direct-ascent-anti-satellite-missiles, last modified Oct 2, 2022.
[62] Wall, M. https://www.space.com/netherlands-italy-austria-destructive-asat-pledge, last modified Apr 11, 2023.
[63] Kocs, Stephen A. *Territorial Disputes and Interstate War, 1945-1987*. The Journal of Politics Vol. 57, No. 1 (Feb, 1995), 159-175.
[64] Rahman-Jones, I., https://www.bbc.co.uk/news/technology-66993647, last updated Oct 3, 2023.
[65] SSTL, https://www.sstl.co.uk/space-portfolio/launched-missions/2010-2019/removedebris-launched-2018, (Accessed Jul 5, 2023).
[66] UK Space Agency, https://www.gov.uk/government/news/uk-builds-leadership-in-space-debris-removal-and-in-orbit-manufacturing-with-national-mission-and-funding-boost, last updated Sep 26, 2022.
[67] Burke, K. *China's SJ-21 Framed as Demonstrating Growing On-Orbit Servicing, Assembly, and Manufacturing (OSAM) Capabilities*. China Aerospace Studies Institute, Dec 2021.
[68] Jones, A., https://spacenews.com/chinas-shijian-21-spacecraft-docked-with-and-towed-a-dead-satellite/, Jan 27, 2022.
[69] Degrasse Tyson, N. and A. Lang. *Accessory to War: The Unspoken Alliance Between Astrophysics and the Military*. New York: W. W. Norton & Company, 2018.
[70] Johnson-Freese, Joan. *Heavenly Ambitions*. Philadelphia: University of Pennsylvania Press, 2009.
[71] Pither, S. https://thebusinessmagazine.co.uk/technology-innovation/astroscale-opens-oxfordshire-facility-to-build-space-debris-removal-craft/, last updated Sep 29, 2022.
[72] Degrasse Tyson, N. and A. Lang. *Accessory to War: The Unspoken Alliance Between Astrophysics and the Military*. New York: W. W. Norton & Company, 2018.
[73] Wall, M., https://www.space.com/25275-x37b-space-plane.html, last modified Aug 30, 2021.
[74] Sparkes, M., https://www.newscientist.com/article/2346762-secretive-us-space-plane-x-37b-lands-after-record-908-days-in-orbit/, last modified Nov 12, 2022.

[75] Thompson, J., https://www.space.com/china-mysterious-space-plane-released-unidentified-object-in-orbit, last modified May 27, 2023.
[76] Bingen, K. A., Johnson, K. and Young, M. Space Threat Assessment 2023. Centre for Strategic and International Studies, 2023.
[77] Ibid.
[78] Van Tol, J. *et al*. AirSea Battle: A Point-of-Departure Operational Concept. Washington DC: CSBA, 2010.
[79] Gertz, B., https://www.washingtontimes.com/news/2023/jun/29/report-space-force-urgently-needs-counterspace-wea/, last modified Jun 29, 2023.