NATO OTAN

Science & Technology Organization (STO)

Space Technologies

Briefing paper

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The economics of space have changed significantly over the past decade. Driven by increased commercial interests, launch costs have been drastically reduced by improvements in reusability, efficiencies and miniaturisation. Consequently, increasingly powerful, much smaller and more numerous satellites are presenting considerable opportunities in communications, scientific exploration and defence capabilities (e.g. space-based intelligence, surveillance and reconnaissance). Equally, legal, political and military challenges are being created.

Implications

Economic Implications – Space capabilities are predominantly driven by the commercial sector, while new technologies and production methods have optimised the availability and cost of accessing space. Space-derived data and connectivity is the main driver of commercial space use. The number of active objects in orbit has more than tripled since 2020, and the global space industry is expected to grow considerably by 2040.

Military Implications – Increasing military reliance on space technologies requires nations to protect their critical space-based assets. Space is a key enabler of military operations, primarily for Global Navigation Satellite Systems (GNSS), ISR and communications. Increasing sensor resolution will further emphasise space as an operational domain. GNSS jamming has been extensively used and several Anti-satellite (ASAT) weapon tests have raised concerns of a future space arms race.

Societal Implications – With increasing civilian usage and the prospect of a potential space arms race, the governance of space is a pressing concern. A more contested and congested space environment may lead to conflicts between different commercial and governmental/military actors, as well as conflicts of interest over the use of individual space assets for different purposes. Civilian trends will also likely lead to increased accessibility of human spaceflight, planetary exploration and greater availability of space-based surveillance. Increasing space debris (from collisions or ASATs) is also expected to cause a chain reaction in which the amount of space debris exponentially increases to the point of being unstoppable. This reaction is likely to not only cause catastrophic service disruptions, but it could also render affected orbits unusable (hence making repairs extremely difficult if not impossible).

Key Technology Areas

Communications and Sensors – Satellites in low geostationary orbits are used for communications, command and control, navigation and ISR, and are a critical asset in support of military operations. The development of miniaturised, light-weight, low-power, wide-band sensors for communications and remote sensing will improve operational effectiveness. As the radio frequency spectrum becomes more congested, next-generation space communications and sensors, such as laser communications relays and synthetic aperture radars, will greatly enhance space-based situational awareness and communication capabilities.

Platforms and Propulsion – Somewhere between 18,000 and 26,000 small satellites are expected to be launched in the next decade, increasing both space congestion and the risk of collisions. Overall, these developments will drive demand for In-Orbit Servicing platforms and more sophisticated space traffic management systems. Meanwhile, in-orbit assembly combined with improved rapid, reusable launch systems and propulsion technologies could reduce costs and increase the number of space launches.

Counter Space – As increasing civilian and military applications harness space-based assets, the risks from ASAT systems will increase Allies' vulnerability. Developments in "inspector" satellites, dazzlers, directed energy weapons, cyber-attacks, and jamming increase the need to harden space-based infrastructure across the cyber, electromagnetic, and physical spectrums. These issues will be critical as space continues to become more contested, congested and militarised. Developments such as ultra-secure quantum key distribution, and physical and electromagnetic defensive capabilities will be needed to enhance resilience of space assets.

Technology Convergence

Energy, Propulsion, Materials and Hypersonics – Significant improvements are expected in propulsion technologies from chemical (low efficiency, high thrust) to electric (high efficiency, low thrust), and in development of nuclear thermal propulsion. Cheaper and more rapidly (re)usable launchers are expected to benefit hypersonic systems – as would exotic materials, energy storage, miniaturisation, novel designs and manufacturing methods for space assets.

Artificial Intelligence, Autonomy and Quantum – Increased autonomy and embedded AI can improve space data collection and management, onboard processing, and inter-satellite coordination. Currently, power limitations and sensor sensitivity severely restrict satellite design and operation. Space-based quantum sensors, data processing capabilities and quantum communication will further enhance space-based assets. Additionally, actively collaborating satellites (such as constellations and swarms) will increase operational effectiveness.