
Quantum Technologies and NATO: Securing the Alliance's Technological Edge in an Era of Strategic Competition

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Abstract

Quantum technologies are rapidly moving from scientific research into the arenas of commercialisation and strategic competition, with significant implications for defence and security. While their full military impact may unfold over time, developments in quantum sensing, computing, and communications are already shaping national strategies, industrial ecosystems, and future capability planning. The growing competition among major technological powers highlights the need to act on both the opportunities and risks associated with quantum technologies.

Quantum technologies have the potential to enhance military capabilities across domains, from resilient positioning, navigation, and timing to advanced sensing, computing, and secure communications. At the same time, they introduce new vulnerabilities, including risks to current cryptographic systems, supply chains, and technological dependencies. For NATO, the debate is therefore no longer whether quantum technologies matter, but how quickly the Alliance can adopt, operationalise, and secure them before strategic competitors gain asymmetric advantages.

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This article argues that NATO must pursue a two-track approach: first, fostering quantum innovation, experimentation, and operational adoption across the Alliance; and second, protecting its technological edge, supply chains, critical infrastructure, and security interests against emerging quantum-enabled threats. Achieving a quantum-ready Alliance will require close cooperation among Allies, industry, academia, and NATO entities to translate technological progress into secure and operationally relevant capabilities.

Keywords: Quantum Technologies, NATO, Defence and Security, Quantum Innovation, Strategic Competition.

1 Quantum Technologies: From Emerging Innovation to Strategic Defence Capability

Quantum technologies are reaching both a commercial and strategic tipping point. In 2025, quantum computing companies generated already more than US\$1 billion in revenue,¹ while quantum sensing is beginning to transition from research laboratories to commercial markets.² As inherently dual-use technologies, quantum technologies are becoming increasingly relevant for defence and security. They have the potential to transform how Allied forces communicate, compute, and sense, underpinning NATO's future digital backbone across all operational domains – land, sea, air, space, and cyberspace – and enhancing decision-making, and information superiority. They are also increasingly relevant to current challenges in security and defence.

Russia's military aggression against Ukraine and its persistent hybrid activities across the Nordic and Baltic regions have highlighted a recurring feature of modern conflict: the widespread spoofing and jamming of Global Navigation Satellite Systems (GNSS). These have become routine tools of electronic warfare, degrading navigation, targeting, and situational awareness. While GNSS disruption causes drones to drift off course on the battlefield, spoofed signals can also mislead commercial aircraft, creating

¹McKinsey (2026) McKinsey Quantum Technology Monitor 2026: A commercial tipping point, April 2026. <https://www.mckinsey.com/capabilities/mckinsey-technology/our-insights/mckinsey-quantum-technology-monitor-2026-a-commercial-tipping-point>.

²Quantum sensing markets are projected to grow from ~\$470 million (2025) to \$1.1 billion by 2028. See QED-C (2026) State of the Global Quantum Industry 2026, April 2026. <https://quantumconsortium.org/publication/2026-state-of-the-global-quantum-industry-report/>.

serious aviation safety risks. Russia's extensive use of these capabilities highlights the strategic importance of developing resilient alternatives that can operate independently of contested signals. One such alternative may lie in the fundamental principles of quantum mechanics. By exploiting uniquely quantum phenomena, quantum sensing promises unprecedented levels of precision for Positioning, Navigation, and Timing (PNT), enabling resilient, GNSS-independent navigation and ensuring operational continuity even in heavily contested electromagnetic environments.

The transformative potential of quantum technologies extends far beyond sensing. Across the three fields of computing, sensing, and communications, the potential military applications are extensive. Beyond resilient PNT, quantum sensing could enhance the detection of underground and underwater objects, strengthen intelligence, surveillance, and reconnaissance (ISR), provide ultra-precise timing through optical atomic clocks, and enable GNSS-independent navigation for submarines. Recent advances at the convergence of artificial intelligence (AI) and quantum computing could accelerate progress, with potential benefits for Allied armed forces through improved operational planning, logistics optimisation, enhanced decision-making, and modelling and simulation of complex battlefield environments. At the same time, cryptographically relevant quantum computers could threaten today's public-key encryption and creating significant implications for secure communications, command and control, and information superiority. Germany's Federal Office for Information Security (BSI) estimates that such a capability could emerge around 2036.³ These developments reinforce the importance of quantum communication and cryptography.

Against this backdrop, quantum should be viewed as a strategic capability rather than a distant emerging technology. Several sensing applications have reached high Technology Readiness Levels (TRLs), the first Post-Quantum Cryptography (PQC) standards are being implemented, and cloud-based quantum computing is lowering barriers to experimentation. The debate is therefore no longer whether quantum technologies matter for defence and security, but how quickly nations and alliances can adopt, operationalise, and scale them before strategic competitors gain asymmetric advantages. Consequently, NATO must pursue a two-track approach: fostering quantum

³German Federal Office for Information Security (2026) The status of quantum computer development V2.2. <https://www.bsi.bund.de/EN/Themen/Unternehmen-und-Organisationen/Informationen-und-Empfehlungen/Quantentechnologien-und-Post-Quanten-Kryptografie/Entwicklungsstand-Quantencomputer/entwicklungsstand-quantencomputer.html>.

innovation, experimentation, and operational adoption across the Alliance while protecting its technological edge, critical infrastructure, and security interests against emerging quantum-enabled threats.

2 The Competitive Environment

While strategic competition in fields such as AI, 5G, and semiconductors is already well underway, quantum technologies are now approaching a stage of increasing strategic relevance, with early applications emerging in both civilian and military domains. The broader economic potential of quantum computing is estimated at US\$1.3–2.7 trillion by 2035.⁴ As with other critical technologies, strategic competition in quantum is increasingly shaped by the United States and its Allies on one side, and the People's Republic of China (PRC) on the other. The United States benefits from the world's strongest quantum ecosystem, combining leading universities, national laboratories, venture capital, and major technology companies. Recent Executive Orders and significant public and private investment further reinforce this advantage.⁵

Several NATO Allies in Europe are also already establishing themselves as leading quantum hubs. The United Kingdom maintains one of the world's most advanced quantum ecosystems, combining long-term public investment through the National Quantum Technologies Programme and the National Quantum Computing Centre with leading universities such as Oxford and UCL. Germany has expanded its national quantum strategy, investing in major research and industrial ecosystems centred around institutions such as German Aerospace Centre (DLR), Forschungszentrum Jülich, or Fraunhofer. In 2026, France announced an additional €1 billion investment in its quantum ecosystem, while the Netherlands continues to strengthen its position through QuTech in Delft and the broader Quantum Delta NL ecosystem. Other NATO

⁴McKinsey (2026) McKinsey Quantum Technology Monitor 2026: A commercial tipping point, April 2026.

⁵In 2026, the Trump Administration issued two Executive Orders that established ambitious national objectives, including the development of a utility-scale quantum computer for scientific discovery, the accelerated transition of federal systems to post-quantum cryptography by 2030–2031, and measures to strengthen domestic quantum manufacturing, supply chains, commercialization, and cooperation with allies. In parallel, the U.S. government committed US\$2 billion in strategic investments across nine quantum companies to further strengthen the domestic quantum industrial base and maintain technological leadership. The private sector is matching this ambition with unprecedented investment.

Allies are also strengthening their quantum capabilities: Finland is developing expertise in quantum technologies, supported by institutions such as VTT and companies such as IQM Quantum Computers. Denmark has established a strong position in quantum communication research and ecosystem-building. Canada remains a global leader in quantum computing research and commercialisation, while Türkiye is developing national quantum capabilities through initiatives led by TÜBİTAK and ASELSAN.

The PRC is the principal strategic competitor and has pursued a state-led approach to quantum technologies. It is estimated to have invested approximately US\$15.3 billion⁶ in quantum research and development – the largest public investment globally – and accounts for around 54% of global quantum patents.⁷ It demonstrated its ambitions by building the 1,200-mile Quantum Key Distribution (QKD) backbone between Beijing and Shanghai and launching the world's first quantum communications satellite, Micius, creating the first large-scale hybrid quantum communication network. Through its Military-Civil Fusion strategy and long-term planning, Beijing has laid the foundation for the rapid integration of dual-use quantum technologies into its armed forces. For its part, Russia has also identified quantum technologies as a strategic priority through its National Quantum Project, coordinated by Rosatom. In 2024, Russia announced the development of a domestically built quantum computer with approximately 70 qubits, alongside other initiatives on quantum communication and sensing.

As quantum ecosystems mature, the decisive question is now how to translate quantum innovation into secure, resilient, and defence-relevant capabilities. Allies have already launched defence-related quantum initiatives and funding programmes. Through the Defence Innovation Unit, for instance, the U.S. Department of War is investing up to US\$200 million to accelerate the transition of quantum sensing and timing technologies into operational environments and published its Post-Quantum Cryptography Strategy in April 2026. In February 2025, DARPA's Microsystems Technology Office also launched the Robust Quantum Sensors programme to advance quantum sensors capable of operating reliably in demanding real-world environments. The UK has also strengthened its defence-related quantum efforts through the Defence Science and Technology Laboratory (Dstl), which, for instance, leads research and experimentation on quantum sensing. Similarly, the Netherlands has identified quantum as one of five strategic

⁶QED-C (2026) State of the Global Quantum Industry 2026, April 2026.

⁷QED-C (2026) State of the Global Quantum Industry 2026, April 2026.

technology priorities in its Defence Strategy for Industry and Innovation (2025–2029).⁸ Together, these initiatives demonstrate the transition from quantum research to defence capability development. However, maintaining technological advantage will ultimately depend on scaling adoption, accelerating integration, and ensuring coordinated Alliance-wide deployment of quantum technologies.

3 What NATO is Doing – Fostering Allied Quantum Advantage

Against the backdrop of an increasingly competitive quantum landscape, democratic nations must ask themselves how they can maintain their technological edge. While states retain primary responsibility for developing national quantum capabilities, strategic competition increasingly demands closer cooperation among like-minded nations to accelerate innovation, strengthen resilience, and develop interoperable capabilities. In this context, NATO plays a critical enabling role by providing the framework through which Allies can coordinate their efforts, accelerate capability development, and collectively strengthen their technological and military advantage in the digital age.

While other organisations, most notably the European Union (EU), possess strong regulatory instruments (e.g. the proposed Quantum Act) and economic tools (e.g. the Quantum Flagship), NATO's comparative advantage lies in the defence and security dimension of technological competition. Building on its long-term experience in providing defence and increasingly addressing challenges in cyberspace and emerging technologies, the Alliance is uniquely positioned to foster the adoption, integration, and protection of quantum technologies across the Allied defence ecosystem.

These objectives are reflected in NATO's work on quantum technologies.⁹ With the adoption of its 2023 Quantum Strategy, NATO set the ambition of becoming a “quantum-ready” Alliance. This means fostering a secure, resilient, and competitive quantum ecosystem while accelerating the adoption

⁸By 2027, the Ministry of Defence aims to establish a quantum sensing field testbed, define defence-specific use cases and enable industry consortia to validate quantum sensing solutions in operational military environments.

⁹NATO (2026) Summary of NATO's Quantum Technologies Strategy, January 2024. <https://www.nato.int/en/about-us/official-texts-and-resources/official-texts/2024/01/16/summary-of-natos-quantum-technologies-strategy>.

and integration of quantum technologies into Allied military capabilities across the three quantum domains. At the same time, the Alliance seeks to protect its technological edge by safeguarding quantum innovation and mitigating the risks posed by the malicious or adversarial use of quantum technologies.

Selected Strategic Objectives of NATO's Quantum Strategy

- Allies and NATO have identified the most promising military and dual-use quantum applications, experiments, and integration of quantum technologies that meet defence planning and capability development requirements;
- NATO has developed, adopted, and implemented frameworks, policies and standards for both software and hardware to enhance interoperability;
- Allies have cooperated in the development of quantum technologies with a view to maintain NATO's technological edge and Allies' abilities in the field;
- NATO has identified, understood, and capitalised on evolving quantum technologies advancements, including with enabling technologies and in convergence with other Emerging and Disruptive Technologies (EDTs);
- NATO has a Transatlantic Quantum Community to strategically engage with government, industry, and academia from across our innovation ecosystems;
- NATO has transitioned its cryptographic systems to quantum-safe cryptography;
- Relevant quantum strategies, policies, and action plans are dynamically updated and executed; and
- Allies have become aware of, and act to prevent, on a voluntary basis, adversarial investments, and interference into our quantum ecosystems, which can include, on a national basis, the examination of relevant supply chains.

Source: NATO, Summary of NATO's Quantum Technologies Strategy, January 2024

Building on the Strategy, in 2026, NATO has agreed on a Quantum Technology Roadmap to implement its strategic objectives through the structured development, adoption, and integration of quantum capabilities across the Alliance. The Roadmap is designed as a progressive and adaptable framework that evolves alongside technological advances and changing

operational requirements. Recognising that quantum technologies mature at different rates, it remains sufficiently flexible to accommodate varying levels of technological readiness and commercial availability. To support the full innovation cycle from research and experimentation to capability development and operational integration, the Roadmap is organised around five mutually reinforcing pillars.

The first pillar, *Identifying Quantum Technology Use Cases*, focuses on identifying and prioritising operational use cases and capability requirements across the Alliance. The second pillar, *Testing, Developing and Adopting Quantum-Enabled Solutions*, supports research, experimentation, prototyping, and the adoption of quantum technologies through collaboration across the NATO Enterprise, Allies, industry, and academia. The third pillar, *Quantum Standardization and Interoperability*, aims to seek common standards and interoperability frameworks to enable the coherent integration of quantum technologies across Allied forces. The fourth pillar, *Safeguarding NATO Against Quantum Risks and Threats*, focuses on identifying and mitigating risks arising from quantum technologies, including the protection of critical infrastructure, communications, and military operations. Finally, *Quantum Training and Education* seeks to strengthen quantum literacy across the Alliance by developing the skills, expertise, and awareness required to exploit quantum opportunities while understanding and managing associated risks.

Given the breadth of quantum technologies and their implications across research, capability development, procurement, operations, and standardisation, no single NATO entity can address this challenge alone. Cooperation across the transatlantic quantum ecosystem is therefore essential to achieving the vision of a quantum-ready Alliance. NATO can rely on the complementary roles of key entities throughout the quantum innovation cycle.

NATO Allied Command Transformation (ACT) leads the identification and development of operational use cases, experimentation, and the integration of quantum technologies into future warfare concepts, while NATO Allied Command Operations (ACO) translates these capabilities into operational requirements and supports their transition into operational use. The NATO Communications and Information Agency (NCIA) develops, acquires, and integrates quantum-enabled digital capabilities while ensuring secure and interoperable ICT infrastructure. The NATO Science and Technology Organization (STO) advances collaborative quantum research, provides scientific and technological forecasting to inform NATO's long-term planning, and supports the transition of emerging technologies from research towards

standardisation activities. The Defence Innovation Accelerator for the North Atlantic (DIANA) accelerates the identification, testing, and maturation of dual-use quantum technologies by connecting innovators with end users, investors, and its network of accelerator sites and test centres.¹⁰ Complementary initiatives, including the NATO Innovation Ranges and national quantum test beds, will further strengthen this ecosystem by supporting experimentation, collaboration, and capability development.

A distinctive feature of NATO's Quantum Strategy and ecosystem is the establishment of the Transatlantic Quantum Community (TQC), a concrete implementation mechanism unique among the EDTs addressed by the Alliance. Established in 2024, the TQC is an informal and flexible community through which Allies share expertise, exchange technical information, and coordinate efforts to strengthen their quantum capabilities. It provides a voluntary framework that enables Allies to align national efforts and advance quantum agendas in a transatlantic context. A key achievement emerging from the TQC is the launch of the first-ever TQC Industry Network, led by Denmark. The Network aims to develop partnerships by bringing together companies, start-ups, SMEs, investors, innovation agencies, non-traditional suppliers, and other stakeholders across the quantum ecosystem. To date, more than 270 members from 20 countries have joined the initiative.

Designing the TQC and its Industry Network as a purely Allied-led initiative¹¹ and free from bureaucratic overload, the Alliance has created a tool that enables the quantum ecosystem to evolve organically, guided by market dynamics, innovation, and technological progress rather than administrative processes. This approach is particularly important for a nascent technology such as quantum, where innovation cycles are rapid, commercial developments often outpace government planning, and the most promising applications frequently emerge from industry and academia.

However, the next step is to leverage this ecosystem more systematically. The TQC and its Industry Network should not merely serve as a forum for dialogue, but as a strategic sounding board and sense-checker for emerging

¹⁰DIANA has already supported and funded more than a dozen quantum start-ups through its challenge programmes. The NATO Innovation Fund (NIF), the €1 billion independent venture capital fund for deep tech backed by 24 NATO Allies, is currently invested in UK-based quantum sensing start-up Aquark Technologies. Aquark Technologies also participated in NATO DIANA's programme, highlighting the pathway from NATO-supported innovation to deep-tech investment.

¹¹Since its establishment, the TQC has been chaired by Denmark (2024), the United Kingdom (2025), and the Netherlands (2026). Canada will assume the Chair in 2027.

quantum developments in the Alliance context. It should help identify and mature operationally relevant use cases, provide a platform for showcasing the latest quantum solutions with defence relevance, and facilitate collaboration across industry, academia, start-ups, and NATO bodies and Strategic Commands. In doing so, the TQC can become one of the Alliance's primary mechanisms for translating rapid quantum innovation into military adoption.

4 What NATO Must Protect

NATO's protect pillar in relation to EDTs has two dimensions. First, it requires identifying and safeguarding against threats arising from the adversarial use of quantum technologies. For example, encrypted data collected today by adversaries may become vulnerable once sufficiently capable quantum computers emerge. This highlights the need to accelerate the transition towards quantum-resistant cryptographic standards and ensure the resilience of communications and information systems. Against this backdrop, NATO and several Allies have already begun the transition towards post-quantum cryptography standards.

The second dimension of protection concerns safeguarding the Alliance's quantum technologies and its ability to innovate. This includes strengthening research security, addressing adversarial investments, and reducing critical dependencies. Particularly in this area, a comprehensive understanding of supply chains is essential. Quantum technologies depend on a diverse range of enabling components, including advanced semiconductors, rare earth elements such as erbium and ytterbium, specialised materials, and highly sophisticated hardware and software. While NATO cannot conduct industrial policy, it can support Allies by providing a platform to better understand potential chokepoints, dependencies, and vulnerabilities across the quantum value chain, and assess their implications for the Alliance's technological edge, resilience, and security.

Since progress and technology readiness vary significantly across different quantum technologies and even within individual fields such as quantum computing and quantum sensing, the risks of technological surprise and sudden asymmetric advantage cannot be underestimated. This is particularly relevant in quantum, where progress can be non-linear, difficult to observe externally, and challenging to assess accurately. For example, determining how close a state or company is to a breakthrough, such as demonstrating scalable logical qubits or fault-tolerant quantum computing, remains inherently difficult. At the same time, the field is characterised by significant

commercial hype, strategic signalling, and deliberate ambiguity. This requires continuous horizon scanning, technology intelligence, and strategic foresight to anticipate disruptive developments and translate them into timely policy, capability, and operational decisions.

5 Looking Ahead

Today, more than 30 countries have adopted national quantum strategies. Around two-thirds of them are NATO Allies, reflecting that the Alliance already possesses a substantial share of the world's public investment, scientific expertise, and industrial base in quantum technologies. However, strategic advantage will not be determined solely by the existence of national strategies or the availability of technological breakthroughs. The ability to translate quantum innovation into operational advantage will depend on overcoming several critical challenges that will shape the Alliance's ability to become quantum-ready:

- Connecting innovators with military end-users. Considering the recent defence technology boom, the challenge of connecting innovators with military end-users has come increasingly to the fore. Initiatives such as DIANA and the TQC help bridge this gap by fostering exchanges between industry, academia, and defence stakeholders. Quantum technologies, however, present a particularly distinctive challenge. Unlike drones or AI-enabled decision-support tools, whose defence applications are often readily apparent, quantum innovations frequently emerge from civilian research and commercial sectors where developers do not necessarily recognize the dual-use potential of their technologies. At the same time, military end-users are often unaware of how advances in quantum computing, sensing, communications, or timing could enhance future operational capabilities. Bridging this mutual awareness gap is therefore a prerequisite for accelerating the adoption of quantum technologies in defence.
- Adoption of quantum technologies into military capabilities. While some quantum technologies remain at an early stage of development, others are approaching operational relevance. Quantum sensing capabilities have the potential for near-term deployment, while the transition to post-quantum cryptography is no longer a distant objective but a strategic and operational necessity. Allied armed forces should begin exploring options for accessing quantum capabilities, whether through partnerships, cloud-based services, or dedicated infrastructure,

to evaluate their potential future military applications and build the necessary expertise.

- Understanding where strategic competitors and potential adversaries stand. Assessing the quantum capabilities of strategic competitors and potential adversaries remains challenging. Indicators such as patent activity, scientific publications, investments, and talent pools provide valuable insights into a country's technological capabilities, but they offer only a partial picture. Greater open-source intelligence is needed to better understand how quantum technologies are progressing. This includes the integration of quantum technologies into military capabilities.
- Convergence across Emerging and Disruptive Technologies (EDTs). The greatest strategic value of quantum technologies will emerge through their convergence with other EDTs, including AI, Next Generation Communication Networks (NGCN), biotechnology, advanced materials, and high-performance computing. For example, AI can enhance quantum systems through optimisation and error correction, while quantum computing can accelerate AI by solving complex optimisation and simulation problems. Likewise, integrating PQC into NGCNs, including 5G and future 6G networks, will be essential to securing military communications, while quantum sensing combined with biotechnology could enable breakthroughs in medical diagnostics and human performance monitoring. However, realising these synergies remains challenging. Governments, industry, academia, and defence organisations often develop these technologies in separate communities, limiting cross-domain collaboration and integrated capability development. Breaking down these silos will therefore be essential to maximise the defence value of quantum technologies.
- Access to Quantum Computing Capabilities. Neither NATO nor most Allies are currently developing and operating their own large-scale quantum computers. Nevertheless, ensuring that Allied defence organisations have secure and reliable access to quantum computing capabilities will be essential for future defence applications. This will require stronger Alliance-wide cooperation among governments, industry, and academia to provide access to quantum infrastructure, expertise, and applications across national borders. Several Allies have already recognised this challenge. For example, the Dutch Ministry of Defence, together with Dutch industry, aims to guarantee access to a universal quantum computer with more than one million qubits by 2030.

In parallel, the United States' DARPA Quantum Benchmarking Initiative (QBI) seeks to determine whether an industrially useful quantum computer can be built by 2033.

Ultimately, quantum technologies will not create military advantage through technological development alone, but through the ability to translate innovation into secure, resilient, scalable, and operationally relevant capabilities. The Alliance's challenge is therefore twofold: to foster the conditions that enable quantum innovation and adoption, while simultaneously protecting against emerging vulnerabilities and adversarial use. In an increasingly contested technological environment, NATO's ability to connect expertise, accelerate responsible adoption, and maintain awareness of quantum developments will be essential to preserving Allied technological edge and military advantage.

