EXPLORING SECURITY CHALLENGES IN SPACE

APOGEE

DIGITAL REVOLUTION

AI Powers Innovation Era for Space Warriors

NEW AGE OF WARFARE
Mastering algorithms vital

PLAYING DEFENSE
Autonomous sats hold key

TACKLING THE OVERLOAD
Orbital data centers in sight

> "A superintelligent AI will be extremely good at accomplishing its goals, and if those goals aren't aligned with ours, we're in trouble."
>
> ~ Stephen Hawking

APOGEE ILLUSTRATION

INTRODUCTION

DEAR READERS:

Artificial intelligence and machine learning, the technology sweeping through everyday life on Earth, promises transformation in space as well. This is especially true in space defense, where AI can inform and accelerate crucial decision-making, first moves and reactions.

In this issue of Apogee, we explore how military and commercial interests are applying AI to the newest warfighting domain. The journey begins with a survey of the landscape by a United States Space Force operations officer, who notes that the AI transformation is being shaped in small pockets across the U.S. military — and just as decades-old space systems are beginning to show a need for a technical refresh.

One application of AI in space might help ease the burden this energy glutton is placing on Earth's resources. We report on how top technology companies and the European Union are experimenting with high-capacity data centers on orbit. As Jeff Bezos of Amazon and Blue Origin said, solar energy is always plentiful up there: "No clouds, no rain, no weather. We'll be able to beat the cost of terrestrial data centers."

AI also is enabling satellites to operate more autonomously, keeping course and conducting tracking and analysis on their own. A top researcher and a commercial operator describe how this emerging capability will help the military carry out its missions more effectively. An analogy commonly used to describe this revolution: the rise of self-driving cars.

Replacing human toil with machine toil is a space defense game changer, but it's one that raises a host of ethical questions. What if the AI system is operating with bad data and leads to civilian casualties? Who is accountable when that happens? Ethics experts tell us that human oversight of AI is a moral imperative and that a range of controls can help contain the risks. But they agree that how controls are applied will remain an enduring challenge.

Tapping into AI advancements in the private sector has become a matter of policy for the U.S. government; that's where the innovation is. For the Space Force, the challenge includes attracting companies and fitting their technology into existing security frameworks, the service's acquisitions personnel tell us. This can mean balancing the rigor required with the life-or-death consequences of military operations against the need to open doors to the latest garage-lab breakthroughs. The urgency is reflected in the words of Air Force Secretary Troy E. Meink: "We need this skill set in everything we do or we're not going to be successful."

Closing out this issue of Apogee, the director of India's Defence Satellite Control Centre reviews the long history of space cooperation between his country and the U.S.: "The space economy for both nations is crucial and thrives on collaboration, innovation and a collective vision. Amid evolving trade challenges, the need for a cohesive and collaborative strategy becomes even more compelling to advance the shared space ambitions of the U.S. and India."

Regards,
Apogee Staff

APOGEE

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Our Mission In Space

U.S. Space Command, working with allies and partners, plans, executes and integrates military space power into multidomain global operations in order to deter aggression, defend national interests, and when necessary, defeat threats.

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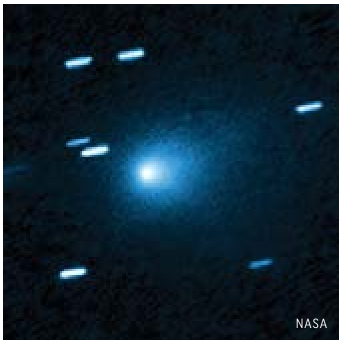
FEATURES

DEPARTMENTS

WHAT IS THIS?

APOGEE STAFF


NASA

A COSMIC VISITOR from beyond our neighborhood is briefly gracing the solar system — and then vanishing forever. Known as **Comet 3I/Atlas**, captured here by NASA's Hubble Space Telescope on July 23, 2025, it is only the third confirmed interstellar object observed to pass through the sun's domain, making it a rare scientific prize.

Discovered on July 1, 2025, by the NASA-funded Atlas survey telescope in Chile, 3I/Atlas displayed unusual characteristics. It then was racing through space at about 221,000 kph, much faster than typical solar system comets. That speed, combined with its sharply curved, hyperbolic trajectory, told astronomers it was not bound to the sun's gravity. The object was simply passing through, a traveler from another solar system.

Follow-up observations, including those from the Hubble telescope, revealed a substantial body. Scientists estimate the comet's nucleus measures 427 meters to 5.6 kilometers wide — large enough to hold valuable clues about its origin. As it neared the sun, the comet developed a glowing coma, a cloud of gas and dust released from its icy core, confirming it is a comet rather than an asteroid. Asteroids are rocky, metallic bodies of the inner solar system, while comets are from the outer solar system.

3I/Atlas made its closest approach to the sun on October 30, 2025, skimming just outside Mars' orbit. Despite its dramatic arrival, it posed no threat to Earth, never coming closer than an estimated 274 million kilometers. By some time in 2027, it will exit the solar system at the same blistering speed at which it entered.

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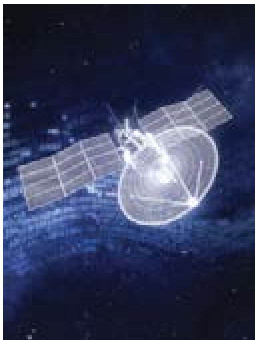

About the cover

The 21st century's artificial intelligence explosion is spreading to the highest military domain, transforming the ways space defenders make decisions, defend orbiting assets and synthesize battlefield data. APOGEE ILLUSTRATION


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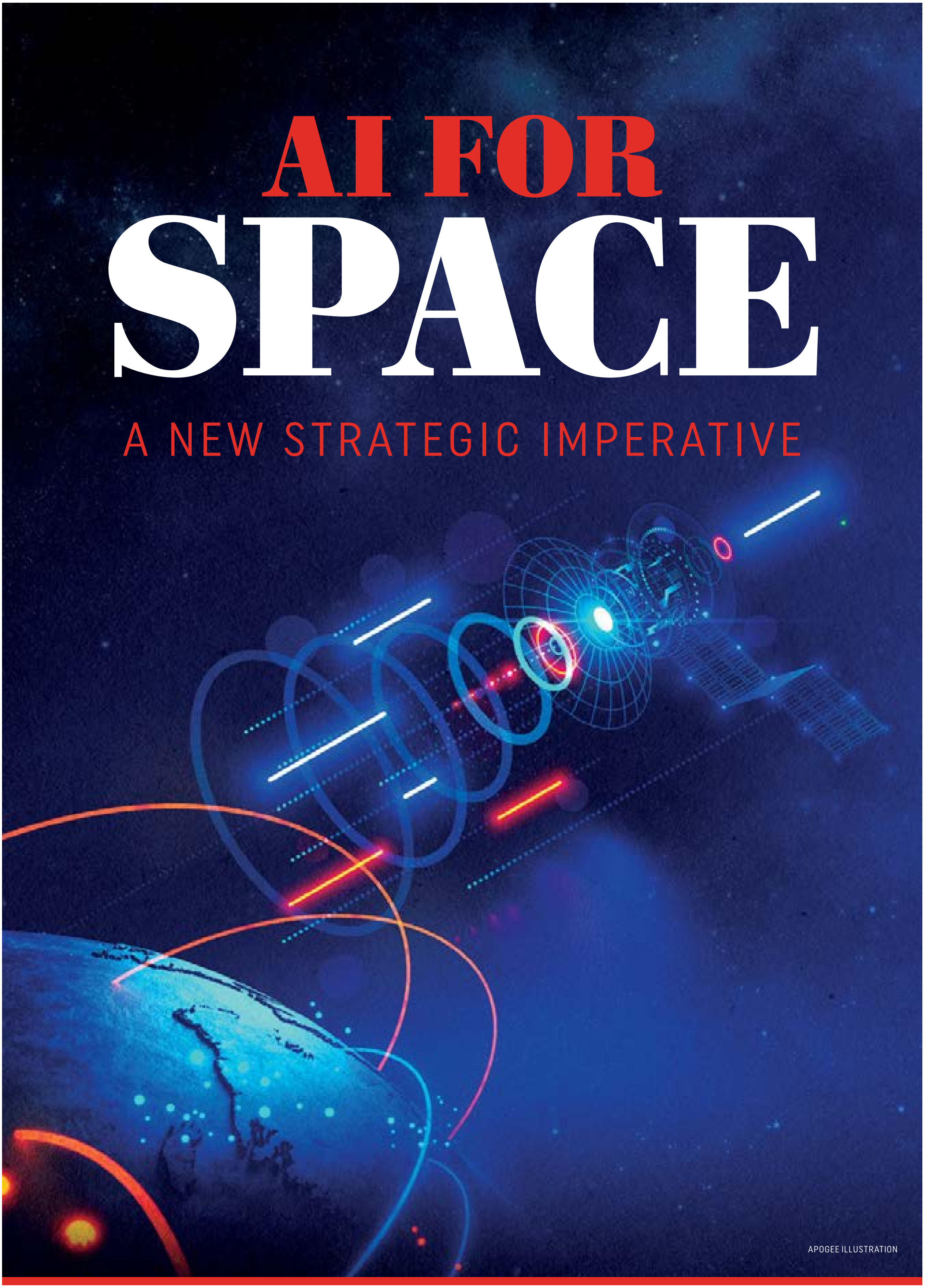
AI FOR SPACE

A NEW STRATEGIC IMPERATIVE



APOGEE ILLUSTRATION

MAJ. CHRISTOPHER HUYNH/U.S. SPACE FORCE

ON December 9, 2025, United States War Secretary Pete Hegseth announced the launch of GenAI.mil, a platform placing the power of artificial intelligence (AI) into the hands of every U.S. warfighter. The platform brings one of the most capable frontier models to every government workstation across the department. Eventually, the platform will add three — and perhaps more — foundational models to its site, arming military professionals with tools to enhance productivity and multiply output.

Space professionals may wonder whether a similar renaissance will transform space systems — several of which are decades old and in desperate need of a technical refresh. In small pockets across the U.S. Space Force and U.S. Space Command (USSPACECOM), this work is being done.

AI FOR SDA? WHY?

Space Domain Awareness (SDA) could be the greatest beneficiary of AI technology. SDA underpins almost every other function in space — from missile warning to environmental monitoring, to space control and orbital warfare. It is a highly complex process. Practitioners of this mission may describe it as determining the who, what, when, where and why a space object may behave the way it does using tiny specks of information gathered from across the widest domain around the globe.

However, if one were to examine this SDA kill chain, we can see that AI can augment discrete segments to yield exponential results. For example, the necessary process of performing conjunction analysis can take hours or days, depending on the number of space objects involved, the orbital regime the conjunction occurs in and the number of sensors that can see where the conjunction would occur.

How does one prioritize what conjunctions are likely? A trained AI agent can perform these duties, sorting through thousands of potential cases to call the operator's attention to the scenarios that are likely to occur. The operator then can focus on these cases, running additional analyses as needed, and notify the owner or operators of those satellites to prevent a collision.

The U.S. military is encouraging every warfighter to find ways to use artificial intelligence. The initiative was rolled out in December 2025 by War Secretary Pete Hegseth and includes posters at the Pentagon and other military installations.

PETTY OFFICER 1ST CLASS ALEXANDER KUBITZA/U.S. NAVY

This process is not as easy as it seems. Training data is often sparse, and when available, it is frequently classified, complicating the appropriate training of these conjunction or detection models. While there is utility in using synthetic data to better train models or AI tools to help extrapolate existing data to theorize what may have

AI FOR THE SPACE DOMAIN

Here are five ways artificial intelligence can help improve space domain awareness, as outlined in an issue brief by U.S. Space Force Maj. Christopher Huynh that was published in June 2025 by Georgetown University's Center for Security and Emerging Technology.

Catalog maintenance
Accelerate the association of unknown space objects to known orbit tracks for lists such as the Space Force's space-track.org.

Orbit determination
Reduce the time it takes to predict a satellite's future position to seconds instead of minutes or hours.

Conjunction assessment
Narrow thousands of object pairs to the few that are most likely to collide, then rapidly assign each a risk score.

Data integration
Harmonize disparate types of data from a variety of sensors.

Sensor scheduling
Help set priorities for overtasked satellites and other sensors.

During the April 2025 Space Symposium in Colorado Springs, Colorado, Space Force Gen. Stephen N. Whiting, head of U.S. Space Command, lauded the growth of commercial and allied partnerships through the command's Commercial Integration Cell and Joint Commercial Office. SPACE FOUNDATION

happened in a sensor gap, there is no true replacement for hard data. Commanders performing space defense missions — more often than not — will prefer to accept some data over no data.

Therefore, the exponential growth and interest in commercial companies wanting to contribute to this mission presents unique opportunities to provide higher-fidelity data, which would make space a safer domain to operate in. Providers such as Slingshot Aerospace, LeoLabs and BlackSky bring new capabilities to the table, adding different sensing modalities and providing more coverage in space than ever. The Space Force and other consumers of space data would benefit greatly in not dismissing the power of commercial data.

Moreover, the overlap between government and commercial entities could be highly beneficial for space enthusiasts. In particular, access to commercial data facilitates data sharing with allies and partners because there are fewer classification and foreign disclosure hurdles. Some of the most impressive work is being done by the Joint Commercial Office, a team that augments the U.S. National Space Defense Center's mission to protect and defend U.S. and allied space capabilities exclusively through the use of commercial data.

In parallel, the Space Force could benefit from a technical refresh of its government SDA architecture. Some may describe it as archaic, nonmodular, network-centric and stovepiped. Day by day, this system is being burdened by the exponentially growing number of tracked objects in space. New systems built on modernized software architectures, such as the Advanced Tracking and Launch Analysis System, can alleviate some of these issues.

Sophisticated cybersecurity is a critical component of successful space operations. In the Space Force's efforts to modernize its SDA architecture, there must be a mindfulness toward implementing robust cybersecurity tools such as zero-trust practices; modernized identity, credential and access management protocols; and decentralized data-centric security.

AI AGENTS ABOARD THE SATELLITE?

One of the best use cases for AI in space is putting the technology onboard the satellites. Some of the most

Missile warning is one area of space domain awareness that is likely to see the greatest benefit from adopting artificial intelligence.
NORTHROP GRUMMAN

promising areas of AI development for space lie in the miniaturization of hardware, combined with more robust data, and the steady maturation of object-based sensing algorithms. Though space is a unique domain, the process of building robust models suitable for satellite survivability holds the same principles as training a robust earthbound system.

These technologies help push computation to the edge — to the satellite in space — enabling it to perform all the necessary calculations needed for autonomous responses to adversaries on orbit. Until quite recently, these complex calculations relied on first sensing the threat, computing possible response options using powerful computers on the ground, and then uploading a series of commands for the satellite to execute.

These critical minutes or hours could determine the life or death of a satellite. If a satellite possessed a combination of the three pieces of the AI triad on board — algorithms, computing power and data — it could significantly improve its chances of survival against a novel or unforeseen threat. This could prove highly valuable in situations where a satellite may be out of contact with no possible intervention by a human operator.

In a study by the China Aerospace Studies Institute at Maxwell Air Force Base in Alabama, researchers concluded that the Chinese Communist Party's (CCP) "lack of consistent access to a worldwide network of ground sensors" pushed it instead to design an SDA architecture that is space-based, rather than ground-based, from the beginning. In contrast, the U.S. did not take such an approach. The early days of our SDA architecture have roots in missile warning, using ground radars to detect intercontinental ballistic missiles from the former Soviet Union. As space lift technology improved and the first satellites were launched into space, it evolved to track space objects, painting the foundation for SDA.

Moving forward, such architecture may not be enough. The U.S. and allied nations would benefit from bolstering its on-orbit SDA sensor coverage. This would provide resilience and better coverage of difficult-to-track regions of space, such as geostationary orbit and cislunar space.

Homing in on satellite technology, this coverage would benefit from novel detection techniques such as pose estimation. Pose estimation, traditionally used to track the arm and leg movements of humans, is quickly adapted to track the orientation, shape and movement of satellites in space. This subset of computer vision AI technology is proving to be a game-changing approach

Satellites in the Geosynchronous Space Situational Awareness Program support U.S. Space Command's surveillance operations. U.S. SPACE FORCE

U.S. Space Force Capt. Jake Schneider addresses participants at the hackathon dubbed the U.S. Space Force Generative AI Challenge. U.S. SPACE FORCE

to tracking objects in space using space-based sensors. Teams such as the Space Rendezvous Laboratory at Stanford University in California provide some of the most advanced research in this critical field.

Economies of scale will matter. As pose estimation technology matures, acquisition professionals must be mindful of cost. Procuring expensive technologies in space — in hardware or software — may not be the best answer. We must be ready to account for attrition of satellites should conflicts extend into space.

Why stop there? The possibilities of AI applications onboard satellites are immense. Some essential capabilities that researchers and space practitioners also must consider are technologies that make satellites more efficient and resilient. Models or agents that are capable of autonomously detecting and responding to satellite anomalies, such as link failures, are necessary. AI-enabled satellites could be developed that are capable of formation flying in space — similar to technology being developed for the U.S. Air Force's Close Collaborative Aircraft combat system or the U.S. Marine Corps' experimentation with small, unmanned aerial systems.

WHAT HAPPENS TO THE HUMAN?

The roles may change, but humans still will play a central role in space operations. AI will make the operator's role easier by reducing repetitive and mind-numbing tasks. It also will enhance their ability to detect microscopic perturbations in data telemetry that could indicate a threat.

In other ways, AI will make the operator's role more difficult. With the onboarding of new capabilities, operators may be forced to study a wider variety of satellite failure modes. When a unique failure mode occurs, will the operator understand the root cause? Will the operator have the knowledge and tools to confidently and correctly respond to the failure? Operations crews will need to be ready to respond to these possibilities — at all hours of the day and night — in the absence of expert assistance.

To facilitate this challenge, there must be emphasis on operator trust, and this will need to be an enduring requirement. One method is to increase the audits and transparency of AI tools applied to space systems. Simple interfaces, such as callouts that explain how an AI agent

Autonomous, artificial intelligence-enabled satellites could be developed to perform formation flying in space — similar to technology under development for the U.S. Air Force's Collaborative Combat Aircraft, above. U.S. AIR FORCE

reached a decision — and what factors it applied to its analysis — could significantly facilitate operator trust and willingness to use the tool in a time-sensitive situation. This methodology, coined Local Interpretable Model-agnostic Explanations or LIME by AI researchers, improved user trust in AI models that operators have not interacted with before.

As AI capabilities grow, military training pipelines must evolve to account for the shift. This is where the Air Force shines.

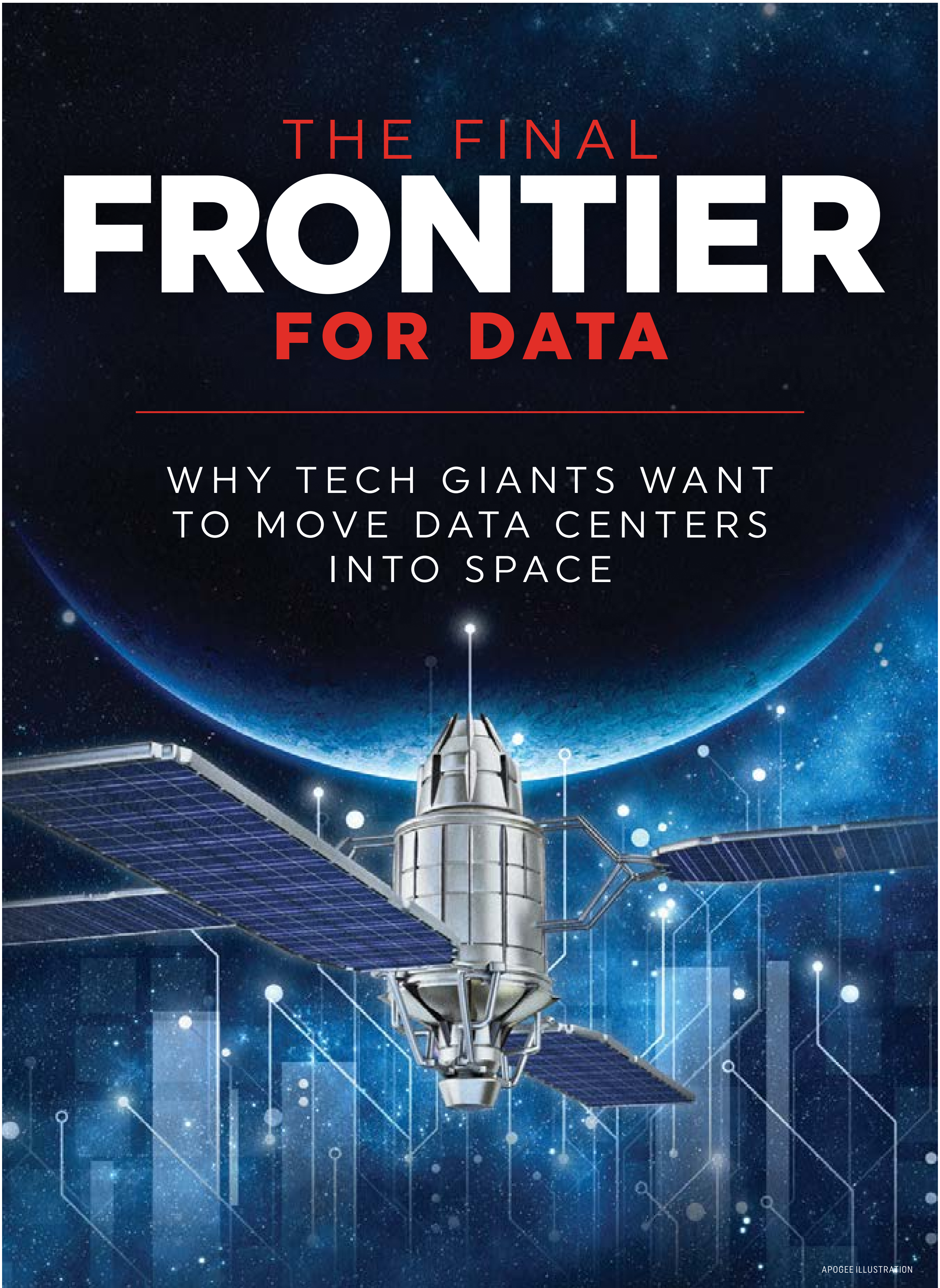
As AI capabilities grow, military training pipelines must evolve to account for the shift. This is where the Air Force shines. Its vision of recruiting, training, retention and education created a compelling model to attract AI talent. Programs such as direct commissioning and constructive service credit present excellent pathways for aspiring Airmen or Guardians with unique skill sets — such as AI — to join technical roles. For those who are less inclined to serve in uniform, opportunities such as Gig Eagle enable civilians to take on part-time roles that fulfill Department of War needs in critical areas.

Growing a cadre of AI-minded space professionals will be a difficult but necessary task. As space becomes more contested, degraded and operationally limited, leveraging AI technologies will be a strategic imperative. It will be critical to leverage all capabilities to respond to rapidly growing and adapting adversaries. ✷

About the author: U.S. Space Force Maj. Christopher Huynh is a space operations officer at Headquarters, United States Space Force, under the deputy chief of space operations for cyber and data. He was previously a National Defense Fellow at Georgetown University's Center for Security and Emerging Technology and is a graduate of the Air Force Institute of Technology and U.S. Air Force Academy.

THE FINAL FRONTIER FOR DATA

WHY TECH GIANTS WANT TO MOVE DATA CENTERS INTO SPACE



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For decades, the cloud has been a metaphor for boundless digital capacity — a weightless abstraction where data lives in endless abundance. But that cloud is getting heavy. Artificial intelligence (AI), high-frequency trading, streaming and autonomous systems are devouring bandwidth, power and land. The global data center industry already consumes nearly 3% of the world's electricity. By 2030, that figure could double, surpassing the power use of Japan, according to the International Energy Agency (IEA).

Now, a new idea is taking shape in boardrooms and laboratories from Redmond, Washington, to Turin, Italy: moving the cloud into actual space. Amazon founder Jeff Bezos, SpaceX's Elon Musk, Alphabet CEO Sundar Pichai and a swarm of startups are betting that the next generation of computing power will orbit Earth — or even sit on the moon. These companies see space-based data centers not as science fiction but as the logical next step in humanity's digital evolution: limitless solar energy, zero land costs and near-constant uptime.

"It will soon make much more sense, with the abundant energy and cold temperatures, to build data centers in space than it does to build them on Earth," Philip Johnston, CEO of Redmond, Washington-based startup Starcloud, told the October 2025 Future Investment Initiative (FII) in Riyadh, Saudi Arabia. "For the first time, the technology really is there to make data centers in space our reality."

FROM GROUND TO ORBIT

The concept sounds over the top: Take the vast server farms that hum quietly in places like Ashburn, Virginia, or Dublin, Ireland, and move them into orbit. The idea isn't unprecedented. In 2021, Hewlett Packard Enterprise's Spaceborne Computer-2 began operating on the International Space Station, processing workloads ranging from DNA sequencing to image analysis. The project proved that commercial-grade computing hardware could function in microgravity without catastrophic failure.

Since then, the vision has grown exponentially. In November 2025, Starcloud launched an Nvidia H100 graphics processor — the same kind used in terrestrial AI training — aboard a satellite roughly the size of a minifridge. The company says the processor is 100 times more powerful than any previous space-based computer. Sometime in 2026, Starcloud plans to launch its first commercial "micro data center" constellation.

Others are not far behind. Florida-based Lonestar Data Holdings successfully tested a shoebox-size storage device on the moon in early 2025. Its next step: six satellites to serve as secure off-world data vaults. Axiom Space is building "orbital nodes" for AI processing, while Abu Dhabi's Madari Space is preparing to launch toaster-sized computing payloads for on-orbit data analytics in 2026.

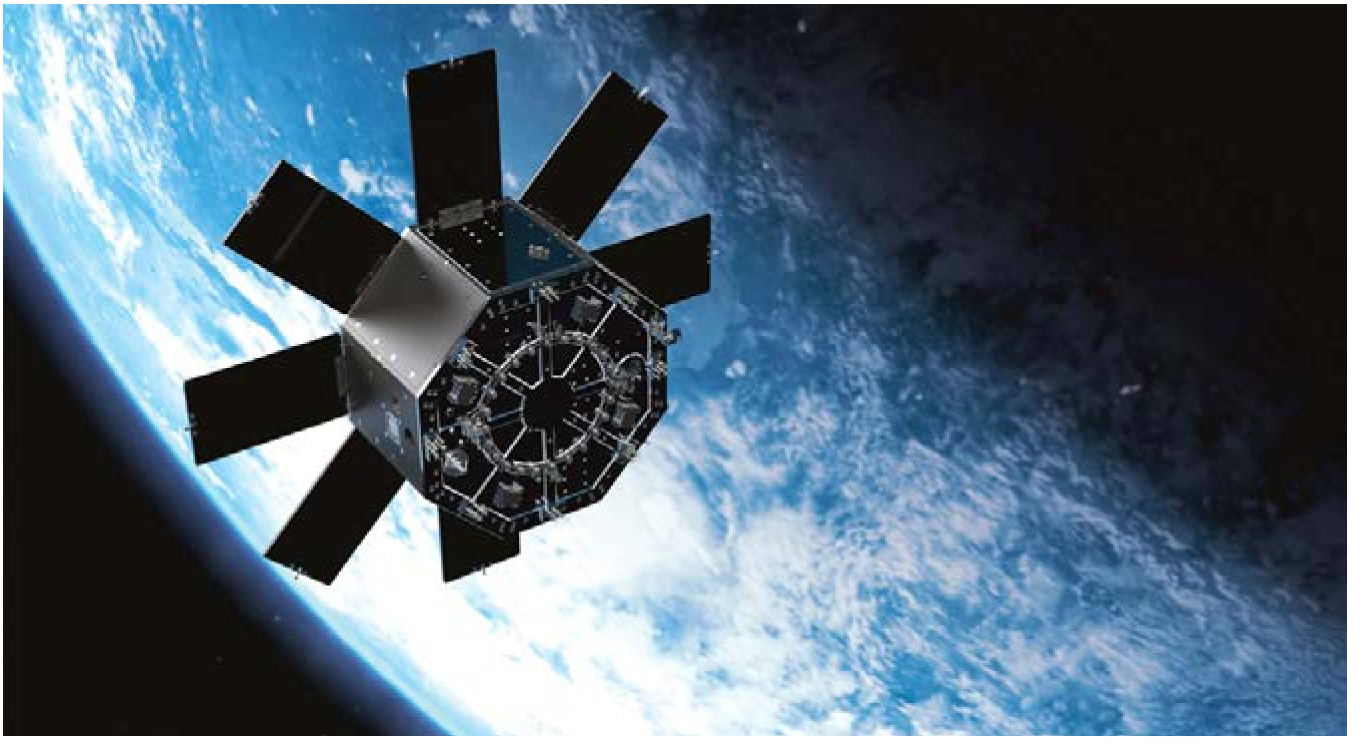
Europe, too, is moving quickly. The ASCEND project, led by aerospace giant Thales Alenia Space and funded by the European Union, envisions a 200-megawatt constellation of orbiting data platforms — roughly equivalent to a medium-sized terrestrial data center — assembled on orbit by 2035. ASCEND stands for Advanced Space Cloud for European Net Zero emission and Data sovereignty. The consortium believes such infrastructure could transform the European digital landscape while cutting emissions from Earth-based computing.

> **"IT WILL SOON MAKE MUCH MORE SENSE, WITH THE ABUNDANT ENERGY AND COLD TEMPERATURES, TO BUILD DATA CENTERS IN SPACE THAN IT DOES TO BUILD THEM ON EARTH."** ~ **Philip Johnston**, Starcloud CEO

Why space? The answer lies partly in Earth's limits. Data centers are energy gluttons, requiring vast tracts of land and millions of gallons of water for cooling. In Europe and parts of the United States, local resistance to new facilities is growing. Power grids are straining under the load, and environmental regulators are pushing back.

An October 2025 Microsoft financial report noted rising "community opposition, local moratoriums and hyper-local dissent" to many such projects. Alongside peers including Meta Platforms Inc. and Alphabet Inc.'s Google, Microsoft has embarked on a massive build-out of server farm infrastructure to support its cloud computing and AI businesses. Yet, like others, the world's largest software company is facing pushback. In October, it nixed plans for a Wisconsin data center after residents and elected officials opposed its construction, Bloomberg reported.

Elsewhere, plans for centers are triggering protests, environmental impact reviews and grid capacity debates. In space, there are no neighbors and no zoning laws. Solar power is constant — 24 hours a day, 365 days a year, with no clouds, no night and no atmospheric loss. Energy from the sun is 30% more intense than at ground level, offering free and limitless power once infrastructure is in place.



Under an agreement with Lonestar Data Holdings Inc., Sidus Space's low Earth orbit satellite LizzieSat, shown here, will support Lonestar's Digital Data Storage Payload. SIDUS SPACE

That constant energy could make orbital data centers ideal for AI training and inference workloads that demand enormous, uninterrupted power. "There's a physics-based elegance to it," Jason Aspiotis, global director of in-space data and security at Axiom Space, told the Massachusetts Institute of Technology's (MIT) Technology Review. "In space, you don't compete with cities for electricity or water. You can radiate heat directly into the vacuum, and solar energy is infinite."

Space also offers potential security advantages. With data stored above the atmosphere, cyberattacks, natural disasters or physical sabotage become exponentially harder. Subsea fiber-optic cables, on the other hand, which carry 95% of global data traffic, are vulnerable to both physical breaks and geopolitical manipulation. Laser-linked constellations on orbit could create a secure, self-contained network beyond the reach of terrestrial interference.

"Data stored in space is accessible regardless of on-the-ground challenges and provides a secure connection regardless of borders, natural disasters, cut cables, power blackouts or wars," Lonestar chairman and founder Chris Stott told Apogee. "It's the ultimate way to secure data — out of reach, but accessible when needed."

WITH DATA STORED ABOVE THE ATMOSPHERE, CYBERATTACKS, NATURAL DISASTERS OR PHYSICAL SABOTAGE BECOME EXPONENTIALLY HARDER.

THE BIG BET: AI ON ORBIT

AI is the accelerant behind this new frontier. Training large language models like ChatGPT or Gemini requires petawatt-hours of energy and warehouses of graphics processing units (GPUs). A petawatt is 1 trillion kilowatt hours. The IEA estimates that AI-related electricity use could grow by 160% by 2030.

Space-based computing could help relieve that burden — and, paradoxically, speed it up. By processing satellite imagery, sensor data or AI workloads directly on orbit, companies could cut latency and reduce the costly backhaul of raw data to Earth. "Processing data in orbit reduces the need for extensive bandwidth and alleviates bottlenecks," Kepler Communications' Ryan White, director of software and digital design, explained on the company's website. "On-orbit computing minimizes latency, which enables faster insights and actions."

There's another reason tech giants are looking skyward: AI's insatiable hunger for electricity. Training and running large language models, image generators and autonomous-system algorithms consume staggering amounts of power — sometimes rivaling that of small nations. Goldman Sachs projects that global data center electricity demand will climb 165% by 2030, driven largely by AI. Each new generation of chips — like Nvidia's H100 and H200 processors — delivers greater performance but also draws far more energy and generates more heat.

A Starcloud-1 satellite was aboard a SpaceX Bandwagon-4 rideshare mission that launched in November 2025. The satellite carried an Nvidia H100 GPU, the first data center-class graphics processing unit to operate in space. SPACEX

That surge in demand is colliding with a strained power grid. Utilities are struggling to meet the needs of hyperscale facilities, delaying projects and raising prices. In Virginia, a joint legislative report in December 2024 predicted a doubling of the state's power demand over the next 10 years, driven primarily by data centers. Increases in the projected energy demand have "raised concerns about whether enough infrastructure can be built to keep pace," the report said.

Space, by contrast, offers unlimited solar energy. A single square kilometer of solar array on orbit can generate several times more power than the same surface on Earth, free from clouds and nightfall. For companies betting their future on AI, that promise of clean, continuous energy is irresistible. "In space, we don't need permitted land ... we don't need battery storage because we have 24/7 solar power," Starcloud's Johnston told potential investors in Riyadh.

Chris Stott, chairman of Lonestar Data Holdings Inc.

Musk's SpaceX, whose Starlink satellites already blanket space with internet coverage, is quietly planning to integrate graphics processing unit clusters into future satellites. Musk said on the social media platform X in October 2025 that upgraded Starlink V3 satellites — each roughly the size of a Boeing 737 — could double as orbital data nodes to build data centers. Powered by Starship — SpaceX's next-generation superheavy launch system — these satellites eventually could form a solar-powered AI network spanning Earth's orbit and, later, the moon.

Alphabet's Project Suncatcher, announced in November 2025, takes a similar approach. Google plans to launch prototype satellites carrying its custom Tensor Processing Units (TPUs) in 2027, testing how AI models function in microgravity. "Our new research moonshot, Project Suncatcher, envisions compact constellations of solar-powered satellites, carrying Google TPUs and connected by free-space optical links. This approach would have tremendous potential for scale and also minimizes impact on terrestrial resources," Google senior director Travis Beals wrote that month in a Google Research blog post.

Lonestar is similarly poised for on-orbit testing, teaming up with another company to launch and evaluate in-space data storage and processing in low Earth orbit (LEO). Potentially, Lonestar is eyeing data centers on the moon and in cislunar space, generally the region between Earth and the moon — or what Lonestar's Stott calls "the ultimate secure Fort Knox solution ... due to the physical distance and delayed tolerant network."

"This will be the most secure place to store data for resiliency purposes," he said.

Bezos has joined the chorus. Addressing an audience during Italian Tech Week on October 3, 2025, the Amazon and Blue Origin founder predicted "gigawatt-scale" data centers in space within 20 years. "We have solar power there 24/7," Bezos said. "No clouds, no rain, no weather. We'll be able to beat the cost of terrestrial data centers."

If that sounds optimistic, that's because it is. The economics remain daunting. Launching a kilogram into orbit can cost tens of thousands of dollars, and space-based data centers must haul heavy shielding, cooling systems and networking gear.

Yet those costs are dropping fast. SpaceX's Falcon 9 has slashed launch prices by 90% compared with two decades ago. The company's Starship, once operational, would reduce them further — to about $100 per kilogram for payloads of 100 metric tons, possibly by the mid-2030s, according to statements by Musk and analysts' projections. At that price, operating costs of orbital data centers could approach those of terrestrial facilities on a per-kilowatt-year basis.

Companies like Starcloud believe they can achieve 10 times the energy cost savings over a data center's lifetime. "Instead of paying $140 million for electricity, you can pay $10 million for a launch and solar," Johnston told TechCrunch in December 2024. Still, the upfront costs are staggering. Under an agreement finalized in November 2025 with Florida-based Sidus Space Inc., Lonestar's six-satellite LEO network is expected to cost $120 million.

Then there's the issue of heat. Without air or water, cooling electronics in vacuum conditions requires enormous radiators to dissipate thermal energy. Starcloud's engineers are designing radiators the size of football fields for what eventually would be a massive, multigigawatt orbital data center. "Cooling is by far the biggest challenge we are solving," Johnston told the "Thinking On Paper" podcast in March 2025. With no convection or conduction, "everything needs to be dissipated with infrared, like black body radiation," which drives "very large, low-cost, low-mass deployable radiators."

The vacuum of space may be rich with sunlight, but it's also flooded with radiation. High-energy particles from the sun and cosmic rays can fry conventional computer chips within months. To survive, systems must rely on radiation-hardened hardware, which is vastly more expensive and less powerful than Earth-based processors.

Axiom Space is experimenting with commercial off-the-shelf chips adapted for radiation tolerance based on lessons from human spaceflight. Other companies, such as Lonestar, have touted the potential benefits of housing data centers in lava tubes beneath the moon's surface to shield them naturally.

Maintenance presents yet another hurdle. "Fixing problems in orbit is far from straightforward," Dr. Domenico Vicinanza, a data science expert at Anglia Ruskin University in the United Kingdom, warned in an April 2025 BBC article. "Even with robotics and automation, a big hardware failure might require a human mission, which could mean downtime for weeks or months."

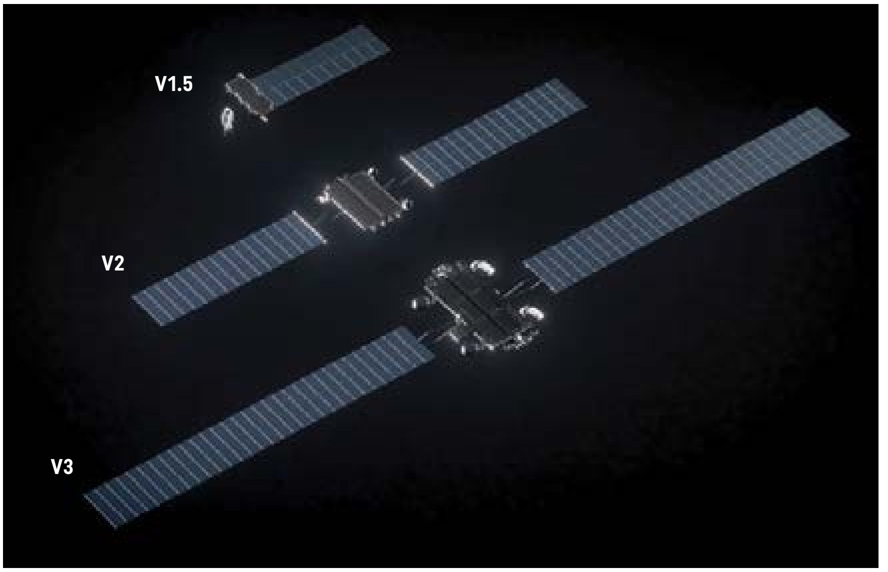
Space debris is another hazard that could sideline transmissions. More than 40,000 tracked objects already orbit Earth. A collision with even a tiny fragment traveling at over 27,000 kph could destroy a satellite and trigger an expanding cascade of debris — known as the Kessler Syndrome — that renders entire orbits unusable.

Security, too, is double-edged. While orbital data centers are difficult to hack physically, they could become prime targets for counterspace technologies — satellite jammers, lasers or even anti-satellite missiles developed by adversaries such as the Chinese Communist Party (CCP) and Russia. In an era of geopolitical tension, storing sensitive data on orbit might provoke more risk than it solves.

ENVIRONMENTAL PARADOX

Advocates argue that space-based data centers could dramatically reduce Earth's carbon footprint. Continuous solar power, no water use and zero land consumption sound like an environmental win. But the reality is more complicated. Rocket launches remain carbon-intensive, releasing soot and aluminum oxides into the upper atmosphere, where they linger for years. Europe's ASCEND study concluded that space data centers will only be eco-friendly if rocket emissions per launch fall tenfold from current levels — a goal still years away.

"We need to make sure that a suitable launch solution can be developed and that the overall structure is as light as possible to minimize the carbon footprint of launch operations," Damien Dumestier, ASCEND project architect at Thales Alenia Space, said on the company's website. "Optimizing payload weight and volume will also be a key challenge."



SpaceX's Elon Musk says that upgraded Starlink V3 satellites, about the size of a Boeing 737, could double as orbital data nodes to create data centers. Starlink V3 satellites will be larger than their predecessors, the V1.5 and V2. SPACEX

A QUIET SPACE RACE

Behind the technical debate lies a strategic one. Data sovereignty — who controls and processes data — has become a geopolitical flashpoint. The European Union's ASCEND program explicitly frames orbital data centers as a path toward "digital sovereignty," freeing Europe from reliance on U.S. hyperscalers like Amazon Web Services, Google Cloud and Microsoft Azure. For its part, the U.S. has likewise remained guarded about sovereignty. "U.S. federal law prohibits U.S. data being stored overseas. It's all about jurisdiction and control," Lonestar's Stott told Apogee. "There is no 'perfect' place to store data on the planet for resiliency purposes."

The CCP, meanwhile, already has launched a dozen satellites as part of a proposed 2,800-satellite "space computing" constellation. Analysts view it as both a commercial and military play: The ability to process Earth-observation data on orbit could offer tactical advantages in surveillance and defense.

The economics of space data centers mirror those of early commercial aviation: high costs, enormous risks and transformative potential. Venture capital is pouring in. Andreessen Horowitz, Sequoia Capital and even In-Q-Tel — the CIA's venture arm — have backed Starcloud.

Former Google CEO Eric Schmidt has invested in launch startup Relativity Space to lower costs for orbital infrastructure. And Bezos' Blue Origin is developing next-generation reusable rockets that could haul multigigawatt data centers into orbit by the 2040s.

A new Microsoft data center sits near rows of houses in Aldie, Virginia. As the data center industry expands its footprint, communities are pushing back. GETTY IMAGES/WASHINGTON POST

Axiom Space's Aspiotis echoes those views. "There is a point in the not-too-distant future where data centers in space are as economical as they are on the ground," he told the MIT Technology Review. "In which case, do we want them on the ground, where they are consuming power, water and other kinds of utilities, including real estate?"

Despite the excitement, experts urge caution. Quentin Parker, director of the Laboratory for Space Research at the University of Hong Kong, says that off-world data center supporters may be "overselling the idea." He notes that space brings its own risks, including radiation, space junk and the consequences of sending more human-made objects into orbit without a solution to the debris problem. Other issues include solar flares that could disrupt data transmissions and the challenge — and expense — of making repairs in space. In addition, some nations are developing jamming technologies that can target satellites and kinetic weapons to take out spacecraft altogether, and in the process cause more debris.

UNLIMITED SOLAR POWER, UNTAPPED REAL ESTATE AND A NEAR-PERFECT VACUUM MAKE SPACE THE ULTIMATE CLEAN ROOM FOR COMPUTATION.

"The terrestrial solutions are still there, and they're still probably a lot cheaper than trying to put anything into space," Parker told CNN in October 2025. "Putting them into space has all sorts of problems associated with it."

Others question the timeline. The ASCEND team projects commercial viability before 2037, assuming breakthroughs in launch efficiency, orbital assembly and cooling. Even Bezos and Musk see a 10- to 20-year horizon before space-based data centers beat their earthly counterparts.

For now, orbital computing remains an experiment — one that blends equal parts engineering ingenuity, financial speculation and planetary necessity. Still, history suggests today's moonshots often become tomorrow's infrastructure. In the 1950s, satellites were fantasy. By the 1980s, they were indispensable. The same could happen with data. As the appetite for AI grows, the case for orbital data centers will only strengthen. Unlimited solar power, untapped real estate and a near-perfect vacuum make space the ultimate clean room for computation.

But it's also a gamble — on physics, economics and humanity's ability to manage the heavens responsibly. "Space is hard, and yes, there are technical challenges, but they are all solvable at a cost that is either equal to or lower than the cost on Earth," Johnston told investors at the FII in Riyadh, adding that breakthroughs around laser communication, orbital debris mitigation and robotic maintenance are turning space-based data centers from a concept into a tangible opportunity. "For the first time, the technology really is there to make data centers in space our reality." ✷

UNEXPECTED EMAIL

Chinese reach out with warning about possible space collision

APOGEE STAFF

A MAJOR GAP in satellite collision warnings appears to be closing somewhat with unprecedented outreach recently by once-silent Chinese space interests.

The Chinese National Space Administration, the country's civilian space agency, emailed NASA in October 2025 about a potential collision that read, "We would like to recommend you hold still and we'll do the maneuver."

The communication was revealed the next day by Alvin Drew, NASA space sustainability director and a former astronaut, during a panel discussion at the International Astronautical Congress in Australia. "That's the first time that has ever happened," Drew said. The revelation was reported by SpaceNews and widely repeated online.

The Chinese Communist Party (CCP) ranks second in space launches only to the United States during the past five years and has more than 5,830 objects on orbit — the majority of them space debris, according to the U.S. Space Force website space-track.org. The U.S. has more than 15,820 objects, most of them active payloads.

Chinese and western commercial satellite operators such as OneWeb and SpaceX also are beginning to share messages, Darren McKnight, senior technical fellow for space tracker LeoLabs, said at a September 2025 space sustainability session. McKnight sees international space groups as a forum for expanding on these first steps toward outreach.

Space Force traffic watchers issue warnings of close approaches on orbit to satellite operators and national agencies, including the CCP. U.S. Space Command said in 2023 that these conjunction data messages never were acknowledged by the CCP. Then, in a 2024 update, the command said the CCP had reached out twice "proactively" on space safety issues.

A Long March 8A rocket carrying internet satellites launches from Wenchang City in China's Hainan province in October 2025. Chinese authorities have been reaching out more often to warn of possible collisions on orbit. ORIENTAL IMAGE/REUTERS CONNECT

Members of a U.S. Army space battalion adjust a mobile integrated ground suite in May 2025 at Fort Carson, Colorado, as part of their work supporting soldiers worldwide.
DOTTIE WHITE/U.S. ARMY

GROWING ARMY SPACE

A separate service branch and improved communications are in the works

APOGEE STAFF

THE U.S. ARMY is moving quickly to expand its space capabilities, from the creation of a separate space branch to improvements in battlefield communications.

The service is getting closer to standing up Army space operations, a plan that has received "overwhelming affirmation" from general officers, Brig. Gen. Donald Brooks, deputy commander of the Space and Missile Defense Command at Peterson Space Force Base in Colorado, said during the Association of the U.S. Army conference in October 2025.

Army leaders also noted that for the first time in its budgeting, the service has included as a top priority counterspace capabilities — described, in part, as countersatellite communications, countersurveillance, and reconnaissance and navigation warfare. Counterspace is one of several mission areas targeted for acceleration under an Army transformation memo from War Secretary Pete Hegseth, military news website Breaking Defense reported. "Calling it counterspace by name is really important," said Col. Pete Atkinson, space division chief at the Army Strategic Operations Directorate.

Meanwhile, the Army is turning to space commerce to help bring about digital modernization under its Next Generation Command and Control (NGC2) program, the website SpaceNews reported. NGC2 is described as a redesign of the Army's enterprise communications backbone, with innovations such as cloud computing, artificial intelligence and space-based connectivity plugged in from the commercial world.

Anduril Industries of Costa Mesa, California, has been awarded a $100 million contract to prototype an NGC2 architecture for an infantry division, working with tech giants Palantir and Microsoft. The Army's vision is to fuse data streams from land, air, sea, cyber and space into a single operational picture, Craig Miller, head of satellite broadband company Viasat's government business, told SpaceNews. Miller said this will require resilient satellite communications, persistent imagery and edge computing close to the fight.

GUARDIANS ON ORBIT?

New report says crewed missions may be necessary

APOGEE STAFF

THE POTENTIAL BENEFITS of human crews aboard U.S. Space Force missions rates consideration in a new think tank report on dynamic space operations, described as methods of increasing versatility, adaptability and maneuverability in the realm.

"Just as human astronauts were essential to the repair of and upgrades to the Hubble Space Telescope and the rescue of several other satellites, Guardians in space may be essential for future Space Force missions," retired Space Force Col. Charles Galbreath wrote in a November 2025 report for the Mitchell Institute for Aerospace Studies. The paper is titled "A Broader Look at Dynamic Space Operations: Creating Multi-Dimensional Dilemmas for Adversaries."

The report's 44 pages covered a broad range of topics, including space combat logistics, avoiding predictable behavior in space, and steps already taken toward the next "revolution in space operations." A brief passage titled "Role of Crewed Missions" said more research is required but suggested that "as humanity's interests in space go further from the Earth, astronaut Guardians may be necessary to execute and secure missions that cannot be accomplished through remote operations."

The Space Force mission is focused on work that Guardians do from Earth, and the service typically dismisses the notion that they will ever function as the characters in "Starship Troopers" of science fiction fame.

Still, as reported by the military news website Defense One, Galbreath elaborated on the suggestion during a virtual Mitchell Institute event, saying, "We can't wake up one day and say, 'My gosh, we need Guardians in space.'" Speaking at the same event, John Shaw, retired U.S. Space Command deputy commander, said the rise of autonomous capabilities in space would seem to diminish the need for human crews.

ABOVE: Nick Hague undergoes astronaut training in Houston, Texas. Hague is a brigadier general in the U.S. Space Force and the first Guardian to launch into space. He is one of two Guardians to take part in civilian missions to the International Space Station.
U.S. AIR FORCE

NEW GLENN, NEW ASSET

Big rocket nears certification for national security launch

APOGEE STAFF

A SUCCESSFUL SECOND LAUNCH, accompanied by its first recovery of a reusable booster, moves the Blue Origin New Glenn rocket forward on its path toward National Security Space Launch (NSSL) certification.

The November 2025 launch from Cape Canaveral Space Force Station in Florida deployed payloads for NASA that will help prepare the agency for Mars exploration and carried out testing of telemetry for Viasat, the satellite broadband company based in Carlsbad, California. Blue Origin, owned by Amazon's Jeff Bezos and based in the Seattle area, joined SpaceX as launch companies that have landed a reusable booster on an ocean platform.

Blue Origin is working with the U.S. Space Force on the final stages of certification to carry out critical national security missions for the Pentagon and for the National Reconnaissance Office. The two-stage New Glenn launcher made its first certification flight in January 2025. The company already has been awarded NSSL contracts as a future heavy-lift provider. SpaceX and the United Launch Alliance also have received NSSL certification.

At nearly 100 meters tall, New Glenn — named for the late astronaut and senator John Glenn — is one of the largest launch vehicles ever built. Its first stage is designed to be reused 25 times — as company Vice President Jordan Charles said, "launch, land, repeat, again and again."

ABOVE: **Blue Origin employees with friends and family watch the liftoff of their company's New Glenn rocket at Cape Canaveral, Florida, in November 2025.**

USA TODAY NETWORK VIA REUTERS CONNECT

APOGEE ILLUSTRATION

THE NEW HIGH GROUND

ARTIFICIAL INTELLIGENCE IS FUELING A GLOBAL RACE FOR MILITARY SUPREMACY IN SPACE

APOGEE STAFF

IN the mid-20th century, the world's superpowers raced to the moon. In the 21st, they're racing for control of the orbital algorithms that may determine who wins — or survives — the wars of the future.

From Beijing to Washington to Moscow, artificial intelligence (AI) is propelling military power on orbit. The United States still commands the largest constellation of military satellites, but the Chinese Communist Party (CCP) is moving "breathtakingly fast," according to U.S. Space Command chief Gen. Stephen N. Whiting. Beijing's new Three-Body Computing Constellation, a network of supercomputing satellites, will process data on orbit using AI models — effectively turning space into a massive cloud network.

For Washington, this is no longer just about rockets or radar. It's about cognition. The U.S. Space Force (USSF) — the newest and most digitally aware service in the U.S. — has made AI the centerpiece of its 2025 Strategic Action Plan, declaring that "superiority will be defined by our ability to integrate with allies and advance real-time analytics and emerging AI technologies to outpace adversaries."

In the eyes of the Space Force, the race has become a contest of code, but other branches are not far behind. At a January 2025 defense summit in Virginia, scientists from the Naval Research Laboratory unveiled a prototype called Autosat — a fully autonomous satellite that can calibrate, navigate and analyze data without human guidance. "We've proven out the principles and are looking for the next step," said Steven Meier, the lab's director of space technology, on the news site Defense One. "We want to get funding to actually build a system and launch it."

Autosat's intelligence grows with every image it sees — airports, roads, buildings — letting it independently recognize objects and patterns. In the next decade, Meier predicts a network of such AI-driven satellites capable of operating without GPS or ground control.

The implications are profound. An autonomous satellite fleet could continue functioning even if cyberattacks or jamming sever communication with Earth. "Advances in autonomous, on-orbit decision-making hold the potential to significantly reduce response times and strengthen the effectiveness of defensive space operations," Krista Langeland of the Rand Space Enterprise Initiative told Apogee. "By diminishing reliance on the SCN [Satellite Control Network], greater autonomy could lessen potential vulnerabilities there and would circumvent any capacity limitations and lack of antenna availability."

In plain English, these machines would think — and react — faster than any human operator, adjusting even for ground station attacks.

As space situational awareness sensors proliferate, more data explaining orbital activity will become available in real time. "A machine can be trained to sift through that data at speeds way faster than anything possible using a human alone," Clayton Swope, deputy director of the Aerospace Security Project at the Center for Strategic and International Studies (CSIS), told Apogee. "This might help spot possible counterspace activities before or as they are unfolding, giving satellites a chance to mount a successful defense."

No competitor looms larger than the CCP. According to the U.S.-China Economic and Security Review Commission,

> **“What trust level is required where I can have one Guardian reviewing 10, 20 or 1,000 space objects with automated help? I don’t know what that number is. It’s the conversation that we’re having.”**
>
> ~ **Seth Whitworth**, Space Force acting associate deputy chief of space operations for cyber and data

Beijing has tripled its satellites in low Earth orbit since 2018, doubled those in geostationary orbit and integrated them into a sweeping system for surveillance, targeting and electronic warfare.

These advances are part of what a 2018 Rand Corp. report identified as “systems confrontation” and “systems destruction warfare” — a CCP doctrine that prioritizes disabling an adversary’s communications and data flow. In a conflict, Chinese hackers would aim to take down networks controlling U.S. satellites, leaving them blind or unable to transmit.

That’s where AI could become the Pentagon’s shield. A new generation of self-healing, self-learning satellites could detect and counter such intrusions autonomously, bypassing jammed ground channels. Unlike Earth-based detection systems, AI offers a scalable way to monitor thousands of nodes simultaneously, in effect turning U.S. satellites into sentient firewalls. The U.S. Navy’s AI-driven space systems, Defense News reported in January 2025, already are designed to “navigate without GPS, communications, and ground control.”

For the CCP, however, AI is not just a defensive tool — it’s a platform for dominance. The Three-Body Computing Constellation, launched in the summer of 2025 with provincial government backing by Hangzhou-based startup ADA Space, includes 12 satellites equipped with onboard AI processors. Each acts as an independent data center.

“China’s approach closely parallels its electric-vehicle strategy — leapfrogging older technologies to lead in next-gen domains,” space researcher Sylwia Gorska of the University of Lancashire (England) told Bloomberg in July 2025. By processing data on orbit, CCP satellites reduce latency and vulnerability to terrestrial attacks while establishing a digital infrastructure less accessible to Western surveillance.

“This marks a major shift in the U.S.-China space competition,” Arizona State University faculty associate Namrata Goswami told Bloomberg. “China is creating asymmetric advantages — autonomous surveillance, environmental monitoring, and military applications less vulnerable to Earth-based attack.”

If the Cold War was fought over nuclear stockpiles, the United States’ next great rivalry is being waged with neural networks. At the Pentagon’s youngest branch, the AI revolution has become institutional doctrine. The Space Force’s 40-page Data & Artificial Intelligence FY 2025 Strategic Action Plan lays out an agenda that could have been drafted in Silicon Valley. Its four Lines of Effort read like a tech startup mission statement:

- Mature enterprisewide AI governance
- Advance a data-driven culture
- Rapidly adopt advanced analytics
- Strengthen government-industry-international partnerships

In practice, this means turning the force’s Guardians into coders and data scientists. Professional military education courses soon will include AI literacy modules. New AI boot camps will train Guardians to use and develop machine learning (ML) models. The plan also calls for Wisdom, a recurring speaker series bringing together tech leaders from the Pentagon, academia and industry, and Momentum, a quarterly publication showcasing applied AI research.

Behind the bureaucratic vernacular lies a simple mission: teach a new generation of warfighters to think — and fight — like digital natives with the best tools at their disposal. “Data and AI are critical for a warfighting service that is purpose-built for space superiority,” Space Force Col. Nathan L. Iven, special assistant to the vice chief of space operations, said in a March 2025 announcement about the force’s AI action plan.

While the Pentagon builds policy, Silicon Valley builds technology. During a Mitchell Institute for Aerospace Studies podcast in September 2025, Primer Technologies CEO Sean Moriarty described how his company — originally incubated by In-Q-Tel, the CIA’s venture arm — helps warfighters navigate the flood of unstructured battlefield data. Primer’s software uses large language models to parse intelligence reports, social media and field logs in real time.

“We want people to start their day where they used to end it,” Moriarty told host Heather “Lucky” Penney. “Our goal is to do the heavy lifting that isn’t strategic so analysts can bring their creativity and imagination to bear from the beginning.”

That ethos — AI as a teammate, not a replacement — echoes across the defense tech world. Primer’s tools help commanders sift through mountains of drone-related data in the counter-UAS (unmanned aerial systems) mission, fusing open-source information with classified feeds to track evolving threats in Ukraine, Israel and elsewhere.

A Guardian observes orbital data at Vandenberg Space Force Base, California. The Space Force aims to increase digital fluency within the Guardian workforce. U.S. SPACE FORCE

By automating discovery and reducing human triage, Moriarty said, “we shift the burden from data collection to intelligence.” In one case, the system reportedly helped a U.S. combatant command detect rebel movements threatening aid workers — a process that once took 50 days was completed in mere hours. “That’s practical AI,” Moriarty said. “Software that works.”

TRUSTING THE MACHINE

Yet as machines grow smarter, some question how much they can be trusted. Space Force officials acknowledge that fully autonomous decision-making — especially in systems capable of lethal or strategic actions — demands caution. “What trust level is required where I can have one Guardian reviewing 10, 20 or 1,000 space objects with automated help? I don’t know what that number is. It’s the conversation that we’re having,” Seth Whitworth, Space Force acting associate deputy chief of space operations for cyber and data, said at the February 2025 Space+AI Summit.

The Space Force is experimenting with human-in-the-loop oversight, where AI conducts the bulk of monitoring while humans retain veto power. But as systems scale up, human attention itself may become a liability. “A tired operator presented with too much data could actually detract from safety,” noted Pat Biltgen of Booz Allen Hamilton, a Virginia-based company that builds advanced technology for government.

AI supremacy in space isn’t just about speed and autonomy — it’s about survival in the face of invisible enemies. A leaked CIA report circulated by media in 2023 asserted that CCP scientists were developing advanced cyber weapons to seize control of enemy satellites during conflicts. An International Business Times article in April of that year said the weapons could render satellites useless for data signals and surveillance during wartime. This was being done as part of the CCP’s core strategy to “seize control of a satellite, rendering it ineffective to support communications, weapons, or intelligence, surveillance, and reconnaissance systems.”

U.S. satellites have since been progressively hardened with AI-enabled cybersecurity. The systems use ML to detect anomalies in telemetry data, predict intrusions and quarantine malicious code before it spreads. One such tool the Space Force hopes to add to its collection would further detect cyberattacks by monitoring satellites’ behavior and telemetry outputs. Cyber Resilience On-Orbit (CROO), the technology by Albuquerque, New Mexico, startup Proof Labs, uses ML/AI to identify anomalous behavior in space. The Space Force anticipates CROO’s delivery, including potential hardware and software options, in 2026.

FASTER ACQUISITION?

For many years, defense innovation followed a predictable pattern: The Pentagon outlined specific needs, contractors developed the requested systems and political leaders acquired the equipment within a budget cycle. AI has upended that model. Now, commercial startups are outpacing military R&D, forcing the government to adapt to the tempo of the tech industry.

"The speed of innovation is no longer set by defense bureaucracy," host Penney said during the Mitchell podcast. "It's set by the market." Companies like Primer, Anduril and Palantir already are fielding dual-use AI platforms that blur the line between civilian and military. The Space Force's plan explicitly calls for deeper collaboration with such firms, emphasizing commercial data integration and shared AI literacy.

"The United States has an extraordinary opportunity to evolve its capabilities without breaking the bank," Primer CEO Moriarty said. "These technologies are already funded by billions in private investment. The key is for government to be a smart consumer."

In other words, the next generation of deterrence may come not from classified labs but from venture capital. As of 2025, more than 11,000 active satellites orbit Earth — triple the number of just a decade ago. With commercial megaconstellations like SpaceX's Starlink and Amazon's Project Kuiper crowding the skies, space domain awareness is a monumental challenge.

The Space Force's Unified Data Library aggregates information from military sensors, private satellites and international partners to maintain a shared picture of orbital traffic. Integrating that data requires sophisticated ML models capable of sifting petabytes of telemetry data to detect anomalies.

"Long gone are the days when one airman could monitor one satellite," the Space Force's Whitworth said. "The question now is how many space objects one Guardian can track with AI assistance?"

The answer: potentially thousands. To manage that scale, the Space Force has begun benchmarking large language models for mission-critical tasks. The aim is to develop a chatlike capability that allows Guardians to query orbital data conversationally — essentially turning an AI app like ChatGPT into a space operations assistant. It's a glimpse of a future where the command console looks less like the 1983 film "War Games" and more like Microsoft Copilot. Despite the automation buildup, most defense leaders insist AI will augment, not replace, human judgment. "AI is there to enhance human performance," Penney said. "You're not replacing people — you're making them better."

In practice, that means software handles the drudgery — data cleaning, pattern recognition, anomaly flagging — while humans focus on strategy.

Still, building trust between humans and algorithms remains a major hurdle. The Space Force is investing heavily in AI literacy precisely because trust must be earned,

The Chinese Communist Party launched a Long March-2D carrier rocket on May 14, 2025, placing an AI-powered space computing satellite constellation into space. XINHUA NEWS not assumed. A Guardian who doesn't understand how a machine reached its conclusion will hesitate to act on it — and hesitation on orbit can mean the difference between collision and avoidance.

"The decision to initiate a defensive maneuver often requires a depth of situational awareness that exceeds what an autonomous single satellite may have available to it," Langeland said. "The development of these autonomous capabilities should therefore begin with a clear assessment of the data and contextual inputs required for effective decision-making and defense."

For all its promise, AI carries inherent dangers. Faulty data can corrupt models. Adversaries can feed disinformation into open-source datasets. And as machines gain autonomy, accountability becomes murky. "Information quality matters an awful lot," Moriarty cautioned. "You have to know the provenance of your data."

When Russia began its invasion of Ukraine in 2022, Western analysts confronted this problem — a torrent of contradictory online claims about troop movements. Primer's system responded by surfacing "contested claims" and flagging inconsistencies for human review — illustrating both the power and peril of automated intelligence.

"You certainly don't want to underestimate an adversary," Moriarty said. "But overestimating one isn't without consequence either." In an era when misinformation travels at light speed, even perfect code can be poisoned by bad input.

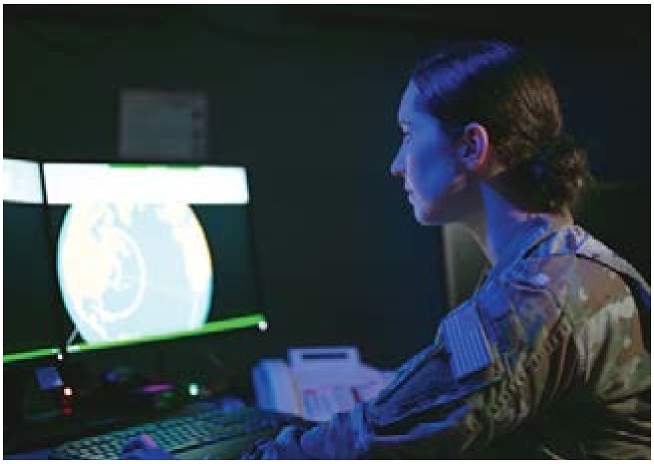
The Pentagon's emerging strategy could be described as deterrence through cognition. If nuclear deterrence relied on mutually assured destruction, AI deterrence may rely on mutually assured detection — an environment where every move is observed, analyzed and anticipated in real time.

Autonomous satellites soon could identify hostile launches or cyber intrusions the instant they occur, triggering countermeasures before human commanders even wake up. Such responsiveness could prevent escalation — or accelerate it uncontrollably. That tension — between control and chaos, autonomy and oversight — is the central drama of the AI space race.

"Decision-making machines need rules of the road just as much as people," CSIS' Swope said. "Without agreed-to rules of the road, whether satellites are controlled by humans or AI-enabled algorithms, it is hard to see significant breakthroughs in space safety."

DIGITAL WARRIORS

Inside the Space Force's data centers, a new generation of digital warriors is taking shape. They are not pilots or astronauts, but coders — Guardians who defend constellations instead of continents. Their weapons are neural networks, their battlefield, the thermosphere. They are trained to think algorithmically, act collaboratively and trust machines as teammates. "The USSF recognized the need for digital fluency within the Guardian workforce, and based on the latest national guidance, the Space Force needs to emphasize AI literacy to employ these tools to solve operational challenges," Iven said.



U.S. Space Force Capt. Colleen O'Hara views data in the Upgraded Early Warning Radar facility at Cape Cod Space Force Station, Massachusetts. U.S. SPACE FORCE

It's likely that fluency will evolve and sharpen. Former Space Force acquisition chief Frank Calvelli predicted that by 2035 most U.S. military satellites will be "significantly more autonomous." The era of joystick-controlled spacecraft will give way to fleets that navigate, analyze and even negotiate orbital paths on their own. "I could really envision 10 years, 15 years down the road, satellites being significantly more autonomous than they are today, like not needing operators, like being able to respond and take actions and do things on their own," Calvelli said during the August 2024 National Defense Industrial Association Emerging Technologies for Defense conference, according to Defense One.

The push toward autonomy in space makes sense, he said, given where the weak link in satellite systems lies, at ground-based control stations that are more vulnerable to cyberattacks. "I believe that from a threat perspective, ground antennas and ground stations are, to me, something that's at risk in a conflict, so I think down the road, you want to take advantage of where the industry is going and really make your constellations as autonomous as possible and get human control out of the loop," Calvelli said.

Meanwhile, the CCP's plan for 2,800 AI-enabled satellites could give it a global surveillance grid powered by in-space computing. Russia, though economically constrained, continues to refine its anti-satellite and electronic warfare systems. The result is an increasingly contested, congested and competitive domain — a digital Wild West at a low Earth orbit speed of over 27,000 kph.

Why does it matter who dominates space AI? Because every other domain — air, sea, land and cyber — depends on it. GPS, communications, missile warning and navigation all rely on orbital systems. Lose space and you lose the war before it begins. "The winner will control the vital infrastructure of modern warfare," Melanie Garson, an associate professor in International Conflict Resolution & International Security at University College London, told Business Insider. "It's not just about satellites — it's about who owns the data highways of the planet." ✷

THE EARLY ORIGINS OF AI

CODE BREAKER SPOKE OF INTELLIGENT MACHINES IN THE '40s

APOGEE STAFF

Nearly 50 years before chess champion Garry Kasparov battled IBM's Deep Blue computer in the ballyhooed man-versus-machine contest of 1996, a British cryptographer and mathematician named Alan Turing was imagining the building blocks of what is now known as artificial intelligence (AI). As early as the 1940s, he predicted that machines one day would play a mean game of chess.

Turing was a World War II code breaker at the famed Government Code and Cypher School at the Bletchley Park house in Buckinghamshire, England. It was the center of Allied code breaking during World War II and a place where team members devised automatic machinery for decryption. Their work culminated in the breaking of the Nazi Enigma code and the development of Colossus, the world's first programmable digital computer.

While working at Bletchley Park, Turing – now considered by many to be the father of AI – talked about the possibilities of machine intelligence by referencing chess. The game was a source of "challenging and clearly defined problems against which proposed methods for problem solving could be tested," according to an Encyclopedia Britannica account. Although Turing experimented with chess programs, he had no computer to run them because stored-program digital computers didn't exist yet.

His musings about a chess-playing computer became public in the 1940s, but the ultimate challenge of man versus machine wasn't realized until 1996, when Kasparov took on Deep Blue. Kasparov, considered one of history's greatest chess players, took the initial match by a score of four games to two. However, Deep Blue staged a comeback the following year and won a highly publicized rematch.

A chagrined Kasparov suggested that Deep Blue had been aided by human assistance, although IBM denied those charges, according to an account from history.com. Kasparov asked for a rematch, but IBM instead retired Deep Blue.

Turing didn't live to see that battle, but he paved the way for it by turning his focus to intelligent machines after World War II. In 1947, he gave one of the earliest public lectures to mention computer intelligence. "What we want is a machine that can learn from experience," he said, according to the Britannica account.

The next year, he introduced many of the key pillars of AI in a report titled "Intelligent Machinery." But he never published the paper, and many of his central concepts later were reinvented by others.

His earlier days didn't portend a world-class visionary. Andrew Hodges, a mathematician at the Mathematical Institute at Oxford University, wrote the biography "Alan Turing: The Enigma," which later was turned into a film. In a 2014 interview with PBS,

An artist's illustration of this Alan Turing banknote was unveiled by the Bank of England in July 2019. Members of the public were asked to "think science" and nominate people from the field. Turing was selected from over 200,000 nominations. AFP/GETTY IMAGES

Chess champion Garry Kasparov, left, contemplates his next move against IBM's Deep Blue computer while Chung-Jen Tan, manager of the Deep Blue project, looks on in New York in May 1997. Although Kasparov took the initial match in 1996, Deep Blue won this rematch.
THE ASSOCIATED PRESS

Hodges pointed out several traits that seemed to reflect the opposite of a budding genius. He stuttered when he talked, for example, and performed so poorly in public schools in the 1920s that he frustrated his teachers.

"I can forgive his writing, though it is the worst I have ever seen, and I try to view tolerantly his unswerving inexactitude and slipshod, dirty work," his English teacher wrote, according to PBS.

Still, he managed to excel at more than science. An avid runner, Turing joined running clubs and won several races. In 1948, according to PBS, his best marathon time was 2 hours, 46 minutes and 3 seconds, which was only 11 minutes slower than the Olympic winning time that year.

The father of the modern computer also dabbled in physics, biology, chemistry and neurology. His most notable work as a computer scientist came in 1936, when he developed the idea for the Universal Turing Machine, which was the basis for the world's first computer. He also developed a test for AI in 1950, the Turing test, that is still in use today.

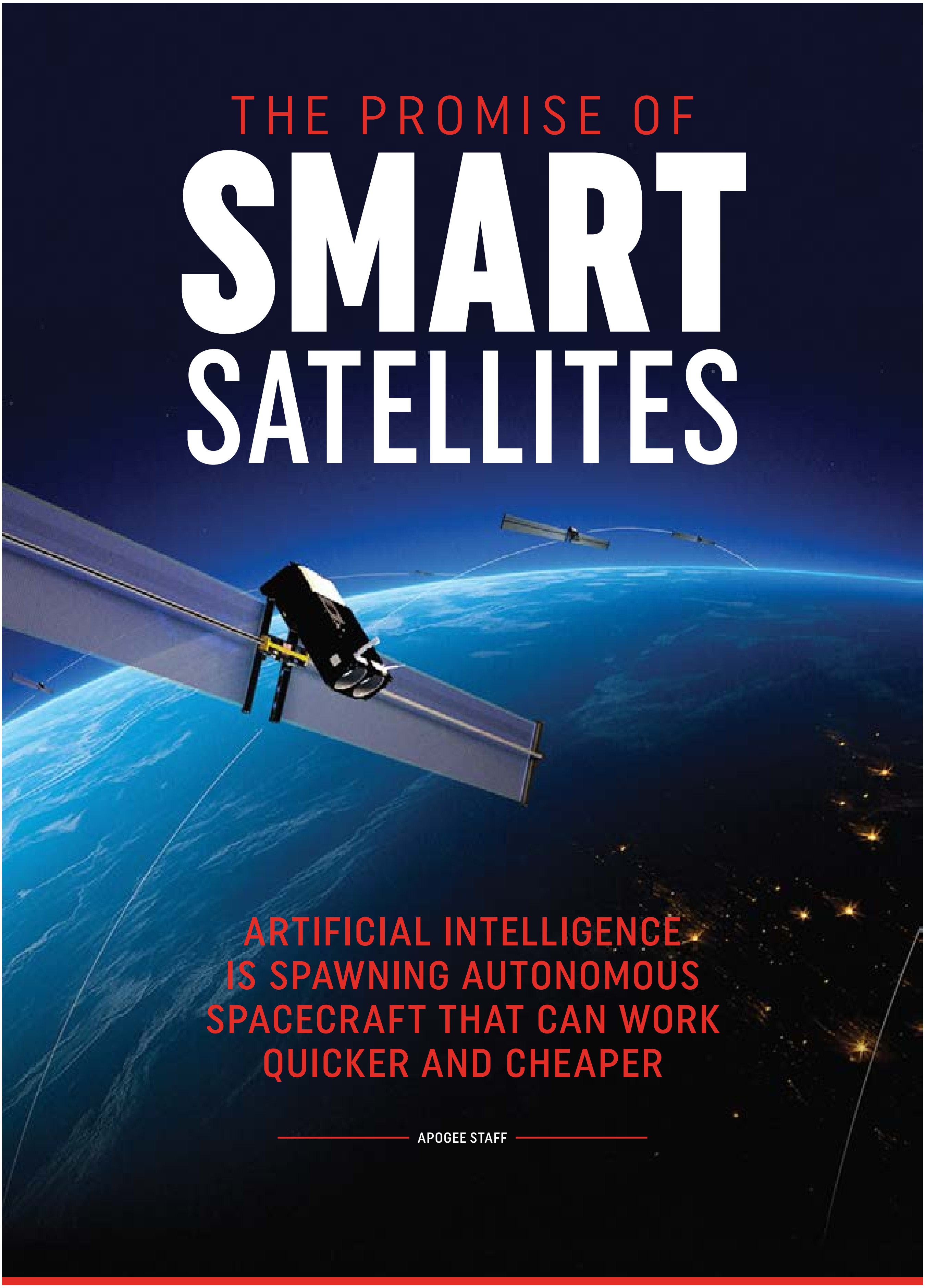
One of his more whimsical pursuits was a fascination with daisies, which also led to a major scientific breakthrough. His 1952 work on morphogenesis became a new field of mathematical biology, providing a mathematical explanation for how things grow.

Cassandra Hatton, director of the history of science at Bonhams auction house, shows a notebook of British mathematician and AI pioneer Alan Turing while standing next to a German Enigma machine, which was the focus of Turing's World War II work as a cryptographer.
THE ASSOCIATED PRESS

Turing took his own life in 1954 at 41. At the time of his death, the public had no idea what he had contributed to the Allied victory, and many didn't know how much he advanced computer science and the fledgling field of AI.

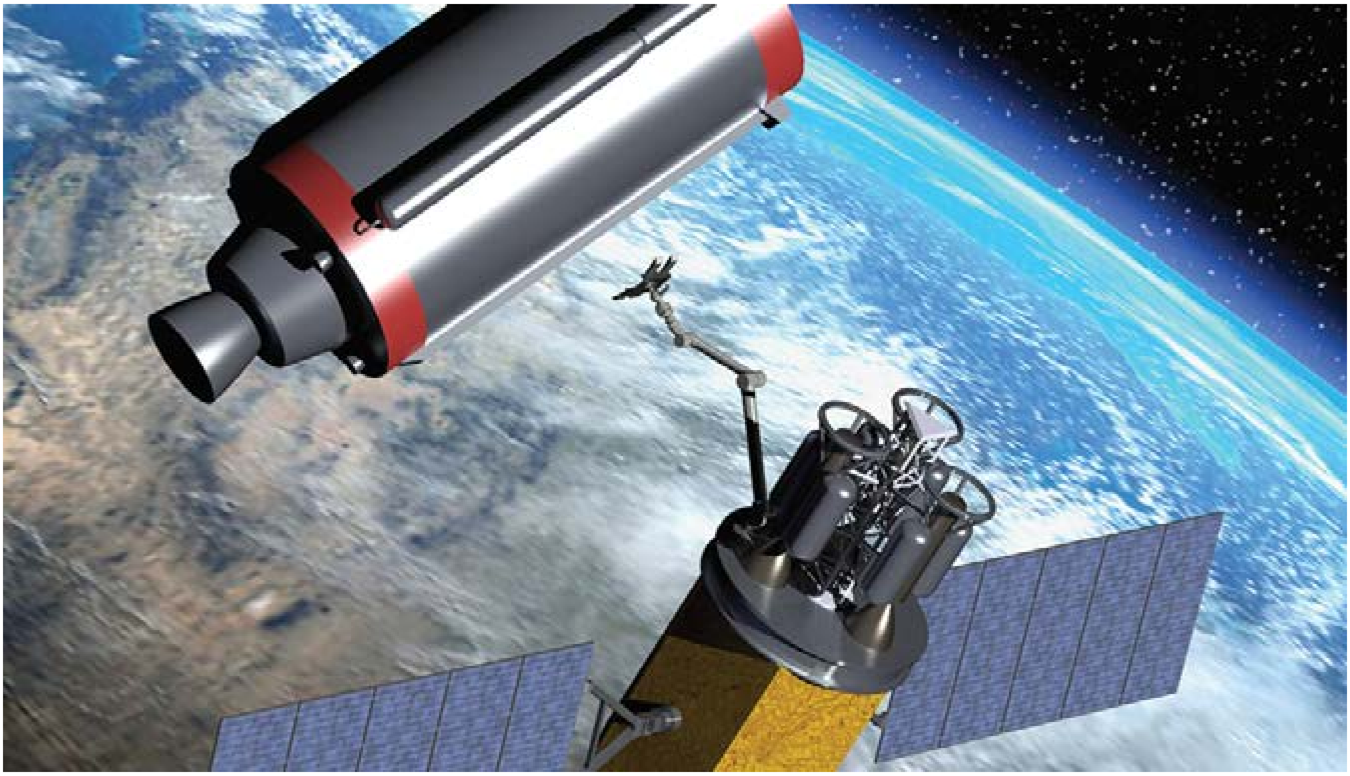
"Alan Turing was clearly a man ahead of his time," reads a June 2012 BBC article. "In 1950, at the dawn of computing, he was already grappling with the question: 'Can machines think?'"

THE PROMISE OF SMART SATELLITES



ARTIFICIAL INTELLIGENCE IS SPAWNING AUTONOMOUS SPACECRAFT THAT CAN WORK QUICKER AND CHEAPER

APOGEE STAFF



Space system guidance and control is one of the artificial intelligence capabilities under study at Stanford University's Center for Aerospace Autonomy Research (CAESAR). CAESAR

Satellites send back information of one kind or another to Earth. They can do their jobs better when they operate independently, free from terrestrial tethers that restrict performance, keeping course and conducting vital tracking and analysis on their own.

Key to accomplishing this is the autonomy afforded by artificial intelligence and machine learning, or AI/ML — the same technology sweeping through everyday life on Earth. Nowhere does AI promise greater transformation than in space defense, where it can inform and speed the decision-making, first moves and reactions that spell the difference in conflict.

"There is no doubt that artificial intelligence will make satellites more effective for national security in various ways," said Simone D'Amico, a professor in the Stanford University School of Engineering who has worked more than 20 years in autonomous spacecraft research and development. One example, D'Amico told Apogee, is the handoff between orbiting satellites known as tip and cue. "Think about detecting a missile launch plan very quickly. Autonomous decision-making will be highly boosted with AI, especially when the interpretation of a lot of complex data is needed in a short amount of time."

Researchers are looking at AI/ML to automate spacecraft functions across the board. Among them: maneuvering, controlling megaconstellations, spotting orbiting objects, tracking debris, identifying and countering anti-satellite threats, detecting targets, and analyzing data. Instead of waiting until it passes a ground station to send down a slug of Earth observation data so someone can make sense of it back here, autonomous satellites can process the data themselves using AI-enhanced onboard computers and just send down what's needed quickly and cheaply.

"The Pentagon is feeling they're getting trucks pull up and just unload all of these haystacks, and they're like, 'My goodness, how do we get the needles out of these things?'" Michael Bartholomeusz, CEO of satellite maker NOVI Space, told Apogee. "AI and machine learning cut through that noise. They transform vast streams of global data into clear, actionable intelligence that can be understood and acted on much faster."

The term AI broadly describes a process meant to mimic human intelligence. Machine learning is a way of achieving AI by identifying patterns. How well it works is determined, in part, by the volume and quality of data used to teach or train the machine. This is a special challenge in space because the most powerful computers don't operate there and because overall human activity and the resulting data are limited compared to terrestrial realms.

United States Space Force Gen. Michael Guetlein, then vice chief of space operations, described this revolution as a military priority during an AI conference in July 2024 sponsored by the Space Force and the U.S. Space Command.

◀ The GENIE constellation platform from NOVI Space will deliver autonomy alongside high-resolution geospatial intelligence, enabling satellites to process and interpret data directly on orbit. NOVI SPACE

The SP240 computer from NOVI Space, about the weight of a can of soup, was designed for so-called low-SWaP environments, where size, weight and power are at a premium. NOVI SPACE

"Clearly, artificial intelligence and machine learning can, should, and will play a powerful role in the coming years," Guetlein said, "including in our efforts to counter emerging threats and preserve the safety and security of our nation, its assets and our allies."

As with many space capabilities, the U.S. is in a race with the Chinese Communist Party to develop AI/ML for space superiority — a contest that extends beyond technology to questions of strategic dominance. Other countries also are pushing ahead with the technology. European countries are investing heavily in on-orbit data processing and AI-driven operations, Japan focuses on disaster monitoring and autonomous satellites, India is applying the technology to resource mapping and climate monitoring, Canada is advancing AI for maritime and satellite tasking, and Israel is applying AI to defense.

NEEDLES FROM HAYSTACKS

Based in Arlington, Virginia, NOVI Space was founded in 2017 and develops AI/ML-driven systems for both defense and commercial customers. The company's GENIE constellation platform will deliver autonomy alongside high-resolution geospatial intelligence, enabling satellites to process and interpret data directly on orbit. The first GENIE satellites were scheduled to launch in early 2026. NOVI already has validated its technology through successful mission operations, achieving Technology Readiness Level 9 — the highest standard for operational maturity, according to NASA's "Small Spacecraft Technology" report issued in February 2025.

In commercial applications, the technology can turn data into decisions, Bartholomeusz said. A satellite could provide a hedge fund or logistics company with daily ship counts in Baltimore Harbor without transmitting gigabytes of imagery. Oil and gas operators could focus on just the perimeter coordinates of a pipeline leak, and farmers could be alerted when specific plots require irrigation — all without reviewing every image frame.

AI/ML also promises to open these capabilities to a much wider market, Bartholomeusz said. "When we developed onboard compute to solve latency challenges for defense missions, we also broke the back of the economic problem," he said. "If you're transmitting bits and bytes of intelligence instead of gigabytes of raw data, you reduce cost by an order of magnitude or more. That opens the door for small and midsized enterprises that previously couldn't afford to use space data. It truly liberates and democratizes access for applications across precision agriculture, food security, safety, maritime operations and infrastructure monitoring."

The technologies that make onboard computing possible, Bartholomeusz said, include radiation-tolerant miniaturized computer chips such as those made by Silicon Valley's AMD, paired with optimized AI/ML algorithms made for environments where size, weight and power are at a premium. NOVI's SP240 onboard computer, for example, weighs about 350 grams, the same as a can of soup, yet vastly outperforms the 26-kilogram guidance computer aboard NASA's

> I think the human should retain the responsibility for strategy, for the high-level objective … exercise ethical judgment, and delegate the routine, the low risk, very quick control loops, especially when it's a split-second task like collision avoidance."

~ **Simone D'Amico**, founding co-director of Stanford University's Center for Aerospace Autonomy Research

1966 Gemini 8 spacecraft. That computer helped guide the first space docking mission and weighed about as much as a 7-year-old child, yet it processed the equivalent of just 4,000 words at a time — about 8 kilobytes of data.

Sifting valuable data from the haystacks also is the goal of a three-year demonstration mission orbited in November 2025 and carrying a computer 100 times more powerful than anything yet launched into space, according to the technology website IEEE Spectrum. The powerful H100 GPU from AI chip giant Nvidia of Santa Clara, California, is traveling aboard the Starcloud-1 satellite and will process data from a fleet of Earth-observing satellites operated by Capella Space of San Francisco, California. A GPU, or graphics processing unit, is an integrated circuit designed to rapidly process large amounts of data in parallel, by breaking it into parts. Starcloud, based in Redmond, Washington, is testing the placement of large data centers on orbit to help limit the acreage and resources they gobble up on Earth as the energy-hungry AI/ML revolution spreads.

Bartholomeusz grouped AI/ML satellite developers into two camps, drawing a comparison to the evolution of mobile phones. "Many companies treat onboard computing as just another feature; NOVI treats it as the foundation," he said. "It's the difference between early 2000s cellphones — which offered limited computing power — and the iPhone or Android smartphones that redefined the device as a true computing platform."

He added, "An iPhone is essentially a compact bundle of sensors and compute, made widely available and affordable, unlocking an entire ecosystem of apps and users. Smart satellites follow that same model — integrating sensors with onboard processing to create an open platform for innovation."

SELF-DRIVING SPACECRAFT

Another terrestrial comparison that helps explain the value of AI/ML in space is automobiles. Specifically, the self-driving kind. Widely accepted standards differentiate the capabilities of autonomous cars and trucks, and these designators — from Level 1 to Level 5 — are working their way into space as well. "It borrows some of the terminology from self-driving cars because we want to do the self-driving spacecraft," said D'Amico, who wears many hats through his work with Stanford. One of them is co-founder and chief science officer with the Stanford spinoff EraDrive Inc. Another is founding co-director of the Center for Aerospace Autonomy Research (CAESAR), a collaboration between D'Amico's Space Rendezvous Lab and the Autonomous Systems Lab directed by fellow Stanford professor Marco Pavone. CAESAR aims to "endow space vehicles with autonomous reasoning capabilities."

Simone D'Amico is founding co-director of CAESAR, which aims to "endow space vehicles with autonomous reasoning capabilities."

Most satellites in use today would be rated Level 3, D'Amico said — operating from a script that's written on the ground and played onboard. Highly micromanaged, Level 3 satellites have limited ability to react to events. At Level 4 and 5, on the other hand, "the AI brain, so to say, is able to learn."

Check out that Gemini docking mission, when a crewed spacecraft connected with a larger Agena rocket, to see how far space autonomy has evolved, he said. "It's really very instructive to see how those operations were conducted back in 1966. Pure manual control by the crew, through the human eye. A probe in a cone, basically, male and female. There was an index bar to align with the Agena target vehicle. Like using a joystick."

In a modern maneuver, as when a SpaceX Crew Dragon docks with the International Space Station, the operation is largely autonomous, a Level 4 with a manual backup. It relies in part on LIDAR, or light detection and ranging — a remote sensing method that sends laser pulses to Earth to measure distances. "The spacecraft uses a number of sensors, from LIDAR to cameras to infrared sensors, for the navigation and the alignment," D'Amico said. "The process is actually controlled by software and algorithms. There are waypoints that the spacecraft has to acquire and maintain in order to proceed with the docking, preprogrammed before

At CAESAR, test beds help evaluate the reliability of artificial intelligence designed for outer space. CAESAR

Researchers from CAESAR can simulate the movements of autonomous spacecraft. CAESAR

approaching the International Space Station."

Today, the docking process also follows international standards, "where any port can dock with any other port ... instead of being a manual one-time event, largely reactive."

One project driving the work of CAESAR is known as ART, or Autonomous Rendezvous Transformer, which is using AI/ML to make satellites maneuver smarter. A goal of the center's work is what D'Amico calls "cognitive spacecraft," capable of taking direction in simple, common language. "Operators will be able to write prompts, so instead of the standard telecommunications that is used in space," he said, "they describe what they would like to see the satellite do — for example, 'Try to approach and repair that unfamiliar tumbling object' — and all the rest is done by AI with minimal supervision."

CAESAR was established with support from private sector affiliates Redwire, a space infrastructure company based in Jacksonville, Florida, and Blue Origin, the launch company based in the Seattle area and founded by Amazon's Jeff Bezos. The Stanford center is conducting research for both companies — in the case of Redwire, to enable autonomous shape characterization and navigation for unknown space objects, and for Blue Origin, autonomous cooperative rendezvous, proximity operations and docking.

SPACE COMPUTING

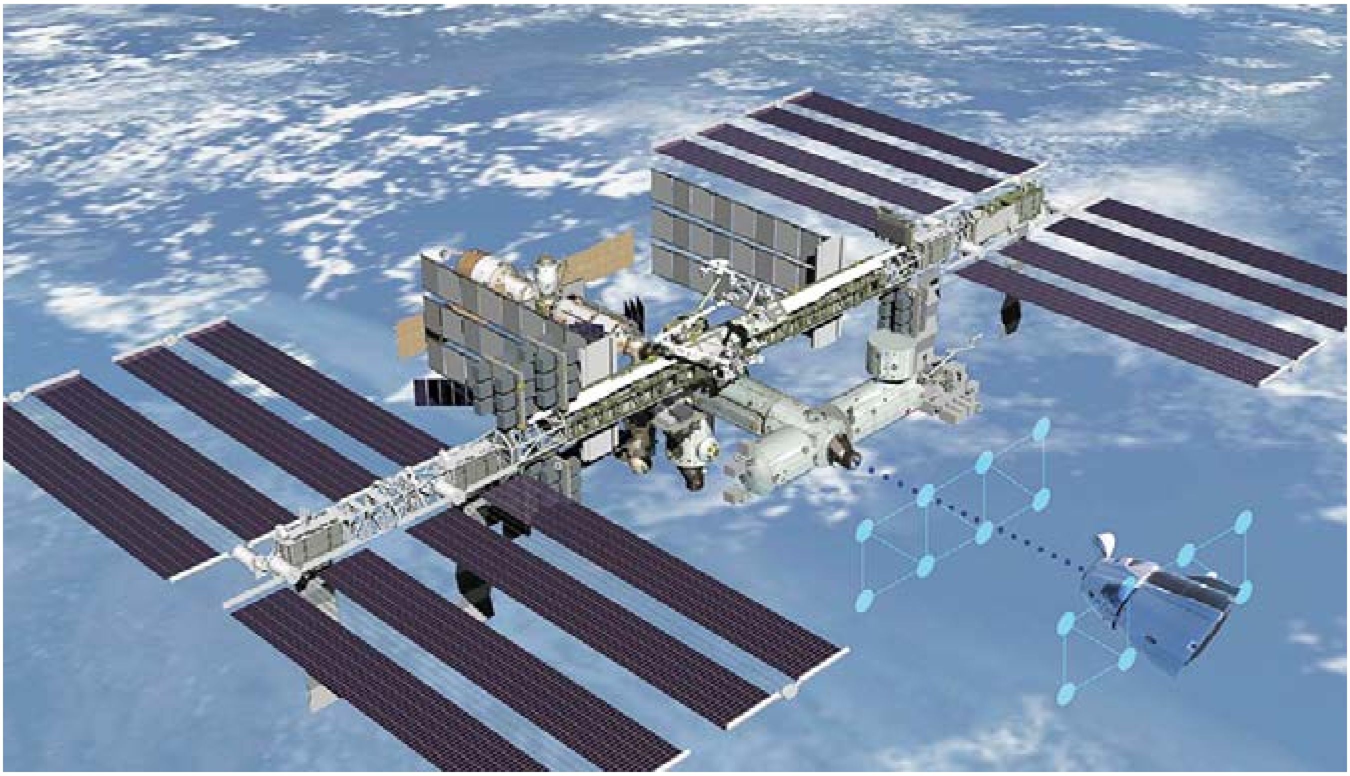
Progress on autonomy in space hinges on the performance of the integrated circuits powering onboard computing. One type, known as GPU, like the device aboard the Starcloud satellite, originally was designed to render video and graphics for uses such as games and is prized for its capacity to handle massive workloads. Another type, called field programmable gate arrays, or FPGAs, features a programmable hardware fabric that allows it to be reconfigured for a specific ML algorithm's needs — an advantage over hard-etched circuits.

D'Amico sees promise in FPGAs, with their lower power demands, programmable logic and capacity to survive longer missions across orbits in a demanding space environment. Still, he said, the future might lie in the broad category known as neuromorphic computing. Unlike traditional chips that use a constant clock and separate processing and memory units, neuromorphic chips integrate these units and use an event-driven approach, firing "spikes" only when necessary to save power and increase efficiency. "They work similar to how our brains work, where basically we have neurons that can be activated depending on conditions and the capability to have a level of dynamic control," D'Amico said.

Like the human brain, AI gets better as it's trained to the task — a process that involves feeding curated data to selected algorithms to help the system refine itself and produce accurate responses to queries, according to a primer from cloud database company Oracle. Typically, when trained AI models deliver consistent results using training and test datasets, the process moves on to testing with real-world data before going live.

Coming up with enough real-world data is a challenge in space, still a frontier of human activity, and especially in space defense. AI training for autonomous car operations, by comparison, benefits from an operational environment that is easily accessible, D'Amico said. When it comes to AI training for space, he said, even the limited data available can be restricted by secrecy classifications. Data is lacking for training on orbital warfare because — for the most part — there isn't any, noted an article in the August 2025 edition of Momentum, a quarterly magazine of the U.S. Space Force. "We don't yet have enough contested environment data in the real world," the magazine reported. "We're not seeing regular adversarial maneuvers, lost sensors, or spoofed signals at scale, but we will."

Synthetic data generated through modeling helps fill the gap in AI training. At CAESAR, this is accomplished, in part, through test beds that function as a surrogate for the orbital environment. "We use robotics, with robotic arms, to move the objects in a scene — an observer satellite, a target satellite," D'Amico said. "It's similar to what happens during the shooting of a movie, where we produce the illumination condition of space using special lamps for direct light from the sun, and for diffuse light that's reflected by the Earth.



CAESAR at Stanford University is conducting research for launch company Blue Origin on autonomous cooperative rendezvous, proximity operations and docking. CAESAR

We can evaluate how well the model that has been trained on pure synthetic data does when deployed in the actual environment. That's the step before deploying it in space."

Another major challenge in training autonomous satellites is that the high-powered computers needed for the job exist only on Earth. "Training models in space is impractical due to server requirements," Bartholomeusz said. "Most models are trained on the ground and then uploaded to the spacecraft. While limited onboard learning is possible, the true focus is on running optimized, power-efficient models within the constraints of space hardware."

OPERATOR TRUST

One factor in applying AI/ML to space defense will be the relationship between the new technology and its human operators. Finding ways to leverage the advantages each brings to the task likely will provide the best results, Space Force Lt. Col. Tanisha J. Saunders wrote in a March 2024 research paper for the Air War College in Montgomery, Alabama.

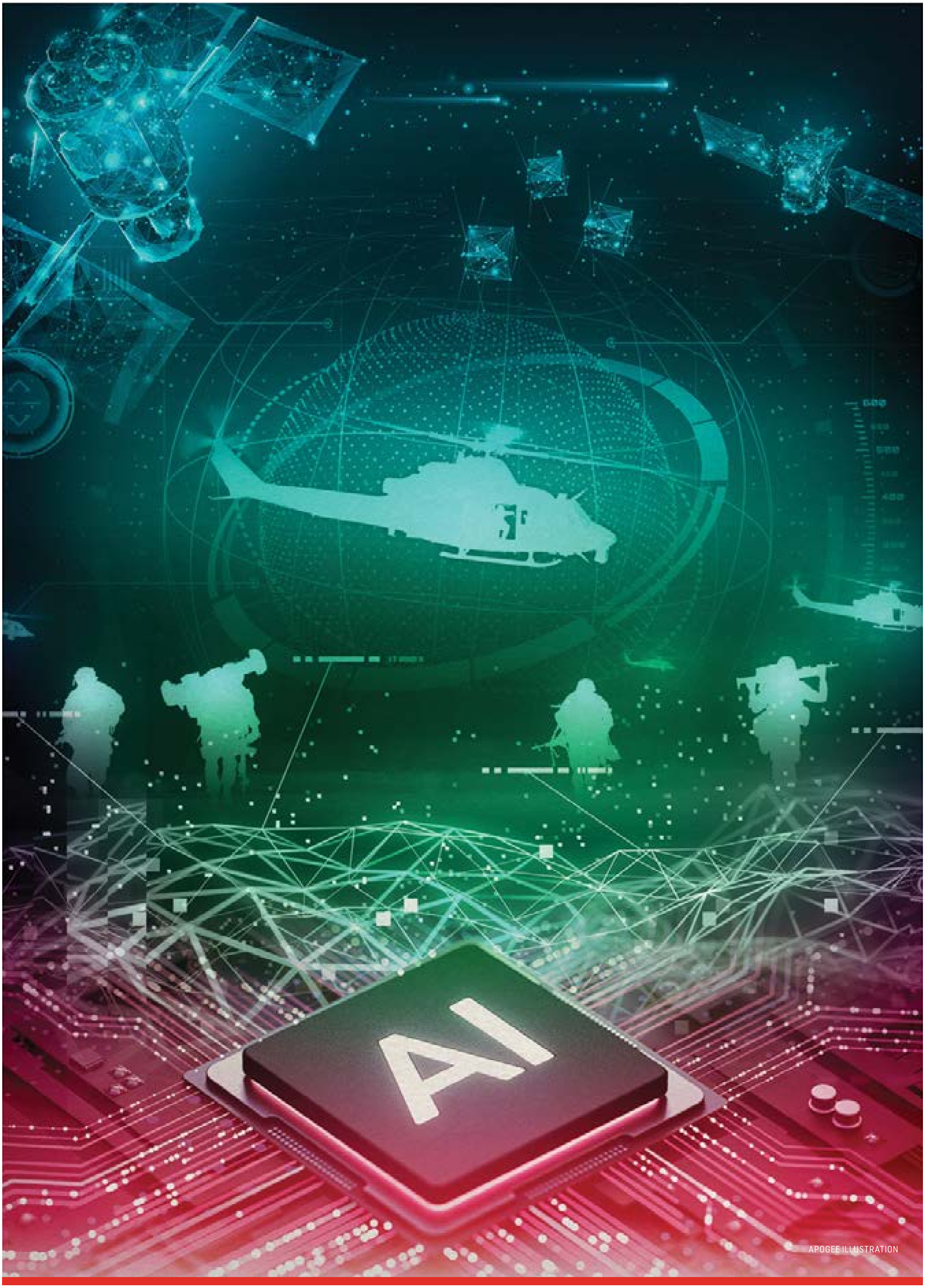
Saunders said, "Machines could cover the areas humans show some weaknesses in, like in rapid data assimilation and analysis, and still enable human counterparts to continue to be successful at processing contextual understanding of dynamic environments to apply military effects." An important first step, she said, is showing operators that the new technology can be trusted, in part by involving them in testing.

It's the path all new technology must travel, Bartholomeusz said. "As with any new tool, trust takes time," he said. "It comes through validation, experience, and the natural ebb and flow of learning." Added D'Amico, "I think the human should retain the responsibility for strategy, for the high-level objective ... exercise ethical judgment, and delegate the routine, the low risk, very quick control loops, especially when it's a split-second task like collision avoidance."

Autonomous satellites will create a host of new possibilities in space, D'Amico said. "Drones in very hostile, unknown environments, far away from us, with huge communication delays. How do you get an underwater vehicle to explore underneath the oceans of, I don't know, Europa? Even closer to us, how do you get a rover to safely explore deep craters or caves under the surface of the moon?"

Another possibility: "A full, autonomous, space-based orbital infrastructure where we provide a kind of intelligence in terms of space traffic monitoring and management. That's something that my company is working on in making the self-driving spacecraft — not only autonomous, but aware of their surroundings so that the satellites can see what's happening around them and react. And share that information with others globally through, literally, a space cloud."

Bartholomeusz sees virtually limitless potential ahead. "AI and machine learning don't just enhance today's missions — they enable entirely new ones," he said. "Satellites could autonomously retask during crises, operate in coordinated swarms, or detect patterns in Earth and space environments that humans would never think to look for. The real promise of AI and ML in space isn't only about efficiency — it's about unlocking missions we haven't yet imagined." ✷



APOGEE ILLUSTRATION

INSIDE THE PENTAGON'S

AI ACCELERATION STRATEGY

NEW RAPID CAPABILITIES CELL AIMS TO TRANSFORM WARFIGHTING

APOGEE STAFF

IN Washington, where bureaucratic gravity can freeze programs before they get off the ground, the Department of War (DOW) has launched one of the fastest-moving initiatives in recent history. In late 2024, amid global anxiety over advances in artificial intelligence (AI), the Pentagon dismantled its year-old Task Force Lima — the team charged with studying generative AI across the military — and replaced it with something far more ambitious and operational: the Artificial Intelligence Rapid Capabilities Cell (AI RCC).

Backed by $100 million in early funding and driven by a partnership between the Pentagon's Chief Digital and Artificial Intelligence Office (CDAO) and the Defense Innovation Unit (DIU) — the body charged with integrating commercial technology with defense systems — the new cell became the centerpiece of a campaign to infuse AI across the military, from battlefield decision-making to human resources workflows. Its mandate is clear: Take the most capable commercial AI systems available — what experts call frontier models — and get them safely and effectively into the hands of warfighters and civilian officials as soon as possible.

"The U.S. and the U.S. private sector, in particular, is at the cutting edge when it comes to artificial intelligence," then-CDAO chief Dr. Radha Plumb said as she introduced the initiative in December 2024. "At the same time, it's important to recognize that AI adoption by adversaries like China, Russia, Iran and North Korea is accelerating and poses a significant national security risk.

"We are taking an all-hands-on-deck approach to ensuring the U.S. continues to lead the way in accelerating [War Department] adoption of these tools," Plumb said.

Her warning reflects a larger geopolitical reality. The Chinese Communist Party (CCP), the U.S. military's pacing challenge, according to Pentagon leaders, has openly embraced the idea of "intelligentized warfare" — its term for conflict in which algorithms drive tempo and decision-making. Russia, likewise, is experimenting with AI-enabled targeting and electronic warfare, and Iran and North Korea reportedly are building autonomous systems and information-operations tools of their own. The Pentagon sees a narrow window to ensure the U.S. stays ahead in an era increasingly shaped by data and algorithms.

Then-Chief Digital and Artificial Intelligence Officer Dr. Radha Plumb announces the formation of the AI Rapid Capabilities Cell, in part to counter AI investment by the Chinese Communist Party and Russia. DEPARTMENT OF WAR

> It's important to recognize that AI adoption by adversaries like China, Russia, Iran and North Korea is accelerating and poses a significant national security risk. We are taking an all-hands-on-deck approach to ensuring the U.S. continues to lead the way in accelerating [War Department] adoption of these tools."
>
> ~ **Dr. Radha Plumb**, then chief digital and artificial intelligence officer

Against this backdrop, the AI RCC is attempting something the Pentagon strives to achieve: moving at commercial speed.

TURNING SILICON VALLEY'S TEMPO INTO MILITARY ADVANTAGE

While Task Force Lima identified the strengths and challenges of generative AI, the AI RCC focuses on putting these insights into action. Its four-part strategy involved a series of experiments to test cutting-edge AI models directly in military and business settings.

Central to this approach were four RCC pilots, each lasting 90 days. Rather than simple demonstrations, the tests embedded advanced generative AI in command centers, logistics sites, legal departments, software production and administrative operations, aiming to prove whether AI can speed up decisions and reduce workloads. Some pilot programs concentrated on military applications like command and control, unmanned system coordination, and predictive logistics, while others targeted enterprise problems such as procurement, human resources, compliance and cyber triage.

In addition, the CDAO announced it would establish secure AI sandboxes — laboratories built with commercial cloud partners — to allow personnel to quickly build and refine tools.

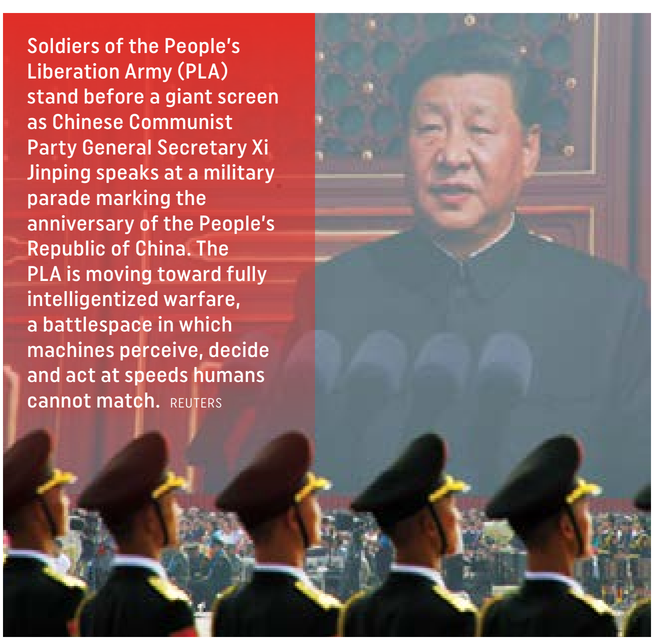
Another initiative sought to incorporate AI tools into the Pentagon's Global Information Dominance Experiments, quarterly multinational exercises designed to test technology in complex, real-world scenarios. Lastly, the initiative set aside $40 million to invest in emerging AI companies, highlighting the Pentagon's commitment to expanding innovation beyond its usual contractors.

Together, these measures represented one of the most ambitious campaigns for adopting AI in any military organization.

CCP'S COMPETING VISION: AI-POWERED WARFARE

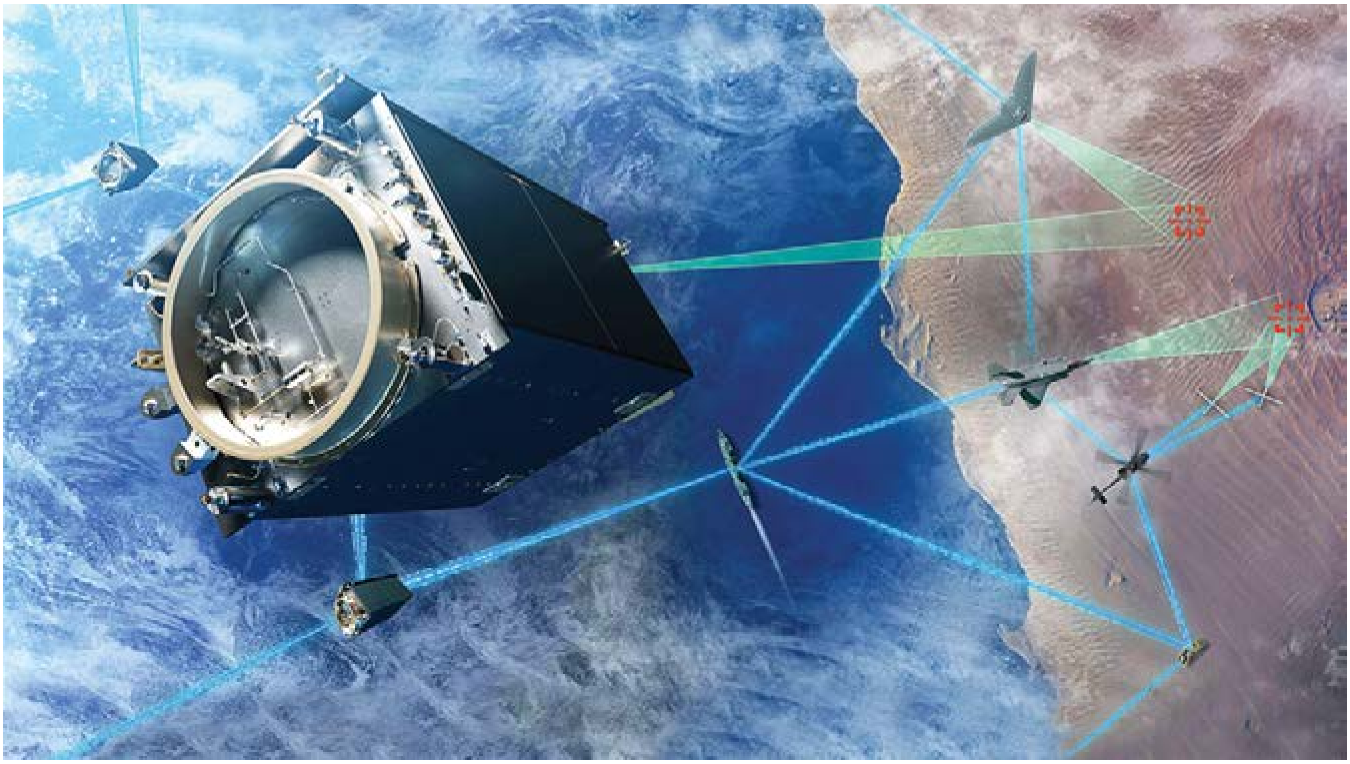
The urgency to infuse AI into systems architecture is magnified by developments in Beijing. According to the March 2025 book "The PLA's Long March Toward a World-Class Military: Progress, Obstacles, and Ambitions," the CCP is prosecuting its own accelerated campaign to redefine future conflict through AI.

Co-author Meia Nouwens, who chronicled Beijing's AI ambitions in a chapter titled "AI and the PLA's New Revolution in Military Affairs: Moving from Weapons Applications toward a Battle Brain," described how the People's Liberation Army (PLA) views AI as central to a "new revolution in military affairs." It is a revolution that ultimately will yield fully intelligentized warfare — a battlespace in which machines perceive, decide and act at speeds humans cannot match. Nouwens is a senior fellow for Chinese security and defense policy at the London-based International Institute for Strategic Studies.



Soldiers of the People's Liberation Army (PLA) stand before a giant screen as Chinese Communist Party General Secretary Xi Jinping speaks at a military parade marking the anniversary of the People's Republic of China. The PLA is moving toward fully intelligentized warfare, a battlespace in which machines perceive, decide and act at speeds humans cannot match. REUTERS

Meia Nouwens, co-author of "The PLA's Long March Toward a World-Class Military: Progress, Obstacles, and Ambitions," discusses the CCP's military modernization at a January 2025 NATO Defense College event in Rome. NATO DEFENSE COLLEGE



Artificial intelligence will play a pivotal role connecting commanders and operators to actionable intelligence as part of the Pentagon's Combined Joint All-Domain Command and Control strategy. In this illustration, an LM 400 satellite with onboard processing transmits data to decision-makers and mission operators. LOCKHEED MARTIN

She reported that PLA theorists argue the velocity and complexity of future defense operations will exceed human cognitive limits, eventually requiring an AI-driven "command brain" to process data, recommend actions and coordinate forces across domains. This digital nervous system would ingest massive streams of sensor, cyber and electromagnetic data; detect anomalies; forecast adversary behavior; issue recommendations; and, possibly, autonomously trigger tactical responses. Humans would remain in control of politically sensitive decisions, but machines would increasingly operate at the tactical edge.

The PLA's interest is shaped by its own institutional weaknesses, Nouwens wrote. The PLA lacks recent large-scale combat experience, and commanders vary widely in quality. Beijing believes AI-enabled simulation and wargaming can compensate for both gaps, using generative models to re-create historical conflicts, explore alternative strategies, and train both officers and algorithms for contingencies the PLA has never faced in real life.

But the path to intelligentized warfare remains turbulent. Nouwens highlights internal concerns about unreliable datasets, cloud vulnerabilities, political pressure that distorts model outputs, and the escalation risks inherent in semiautonomous decision loops. Still, the PLA's ambition is unmistakable: The CCP's civilian AI ecosystem and military-civil fusion policies are converging toward an AI-enabled force designed to compete globally by the mid-2030s.

For U.S. officials, these developments reinforce the stakes. Beijing is not merely modernizing — it also is redefining the speed and structure of command itself. Signs of the CCP's resolve to add AI to its cyber arsenal already have emerged. In mid-September 2025, CCP-sponsored hackers launched a large-scale, AI-driven cyberattack against U.S.-based institutions.

A summary about the espionage by San Francisco, California-based AI researchers Anthropic said the hackers, known as GTG-1002, manipulated the company's Claude Code tool – an AI-powered coding platform – into "attempting infiltration into roughly thirty global targets and succeeded in a small number of cases. The operation targeted large tech companies, financial institutions, chemical manufacturing companies and government agencies. We believe this is the first documented case of a large-scale cyberattack executed without substantial human intervention."

Anthropic said this "case study likely reflects consistent patterns of behavior across frontier AI models and demonstrates how threat actors are adapting their operations to exploit today's most advanced AI capabilities."

The Pentagon's AI RCC is, in many ways, a U.S. answer to AI intrusions, at least at the military level.

BUILDING THE AI BACKBONE

None of the AI RCC's goals is achievable without a robust technical foundation. Over the past two years, the CDAO has been assembling exactly that. In mid-2024, the office awarded contracts totaling $513 million to Denver, Colorado-based Palantir to develop strategic-level data platforms to support the Combined Joint All-Domain Command and Control (CJADC2), an initiative that aims to leverage digital and AI technologies to rapidly deliver intelligence and strategic planning options to commanders.

About the same time, it awarded another $100 million to California-based Anduril to extend its fusion technology across the military. The company received a similar $100 million award from the Army six months later, with the CDAO's support. Anduril's initiative, known as the Edge Data Mesh, aims to provide a decentralized, resilient network for real-time data fusion and processing on the front lines, enabling faster decision-making even in contested environments.

A partnership with Scale AI would provide the scaffolding — labeling pipelines, evaluation tools, quality checks — to prepare training-ready datasets. As of early 2026, these technologies were in development and testing phases.

One of the biggest barriers remains cybersecurity approvals. Traditional Authority to Operate (ATO) processes can take months or years. The AI RCC is rolling out a modernized, risk-based ATO pathway that aims to cut timelines significantly and make continuous deployment of technology more feasible.

CDAO'S INTERNAL SHIFT

The launch of the AI RCC coincided with a major internal restructuring inside the CDAO. This included the creation in December 2024 of a Scaled Capabilities directorate — responsible for moving successful AI and data solutions beyond initial pilot programs and making them available for enterprise and joint-use cases across the Pentagon, according to a DefenseScoop report.

The CDAO also implemented tighter integration between the AI RCC and the Advanced C2 Accelerator, in charge of developing and scaling next-generation command and control capabilities. Additional restructuring occurred during early to mid-2025. Jonathan Elliott, who previously served as director of assurance and assessment at the CDAO, leading the development of new technologies to ensure AI was operationally effective and met warfighter needs, was appointed director of the AI RCC in August 2025.

Also in August, it was announced the CDAO would realign under the Office of the Under Secretary of War for Research and Engineering. The realignment partly was intended to accelerate a departmentwide AI transformation as the DOW seeks to become "an AI-first enterprise," a CDAO announcement said.

"The rapid development in Artificial Intelligence capabilities has brought Generative AI models to the forefront of the current technological landscape," a Pentagon spokesperson told Apogee. "As frontier AI develops, the AI Rapid Capabilities Cell will facilitate rapid adoption by identifying, evaluating and enabling frontier AI pilots, which will allow the DOW to obtain and maintain a strategic advantage."

THE FUTURE IS NOW

Signs of what AI-enabled warfare could look like are quickly developing. During a 2025 Air Force war game in Nevada, an AI-powered planning system helped operators make decisions seven times faster, explore far more tactical options and maintain consistent accuracy.

The goal of the exercise — called Decision Advantage Sprint for Human-Machine Teaming (DASH) — was not automation of command but augmentation. Instead of replacing human commanders with AI, the Pentagon is considering how to support them through virtual assistants that quickly process huge amounts of data — allowing commanders to focus on strategy. The two-week experiment kicked off in April 2025 at the Howard Hughes Operations Center in Las Vegas, Nevada, the first of three DASH exercises for the year.

"This is where theory meets execution; we've spent years defining what decision advantage looks like," Air Force Col. Jonathan Zall, advanced battle management system cross-functional chief, said in an Air Force report about the exercise. "DASH is about delivering it by building software that helps our operators act faster and smarter than our adversaries. As the Air Force continues to iterate, experiment and evolve, the human-machine team will remain at the heart of the department's push for decision advantage."

AI's impact is similarly evident in commercial ventures like sandbox labs for developing new technologies. In December 2025, General Dynamics Information Technology (GDIT) opened its Mission Emerge Center in Springfield, Virginia — a 483-square-meter facility aimed at accelerating development of advanced technology for intelligence and defense missions, including AI and high-performance computing, cyber capabilities and sensor processing. The center also can support other General Dynamics units.

"We can create solutions that we showcase here that are tagged to a sandbox environment that we're building, where the customer can actually see things," GDIT President Amy Gilliland said during a tour with reporters, according to DefenseScoop.

Jonathan Elliott is the director of the AI RCC for the Pentagon's Chief Digital and Artificial Intelligence Office, which is responsible for leading Department of War adoption of frontier AI.

Also in December, Pentagon leadership took a significant step toward widespread adoption of AI with the rollout of Google Cloud's Gemini for Government, the first of several frontier AI capabilities to be housed on GenAI.mil, the DOW's new AI platform. The launch was driven by the AI RCC.

"We are pushing all of our chips in on artificial intelligence as a fighting force," War Secretary Pete Hegseth said in a DOW announcement. "The Department is tapping into America's commercial genius, and we're embedding generative AI into our daily battle rhythm. AI tools present boundless opportunities to increase efficiency, and we are thrilled to witness AI's future positive impact across the War Department."

U.S. Air Force air battle managers participate in the Air Force's first Decision Advantage Sprint for Human-Machine Teaming experiment at the Howard Hughes Operations Center in Las Vegas, Nevada, in April 2025. U.S. AIR FORCE

General Dynamics Information Technology opened its Mission Emerge Center in Springfield, Virginia, in December 2025 to accelerate development of advanced technology for intelligence and defense missions, including AI. GENERAL DYNAMICS INFORMATION TECHNOLOGY

The DOW is training its employees to use GenAI.mil. The learning sessions are designed to build confidence in AI and give personnel instruction to realize its maximum potential. All tools on GenAI.mil are certified for so-called Controlled Unclassified Information and Impact Level 5 to make them secure for operational use. Gemini for Government offers web-grounded natural language conversation and retrieval-augmented generation, reducing AI "hallucinations," or plausible-sounding but false outputs.

Kelly Hammett, director of the Space Rapid Capabilities Office, said potential uses of AI likely will grow from there and may eventually help the Space Force. Discussions are occurring about the potential for AI to help Guardians sift through data to identify satellites, make small adjustments in trajectory and discern threats.

"You have something like 2,000 active satellites that are tracked right now, and in five years you're going to have 10,000. How do you keep track of all that? How do you take all that data and sift through it to figure out what's happening and get a picture of what's changing in terms of threat, environment or conditions?" he told Apogee during December's Spacepower 2025 conference in Orlando, Florida. "That's a use of artificial intelligence that's gaining massive traction" in discussions.

Some AI applications are already in use, such as Project Maven, which relies heavily on machine learning and since 2022 has been managed by the National Geospatial-Intelligence Agency. The DOW's flagship AI program, Project Maven was introduced as a way to help the Air Force comb through thousands of drone and satellite images to identify potential threats. The program was expanded to other services and is expected to begin transmitting 100% machine-generated intelligence to combatant commanders sometime in 2026.

The Pentagon's AI transformation is not optional, military leaders say — it is existential and likely to unfold briskly given the pace of technological change and pressure to stay ahead of adversaries like the CCP and Russia. But while AI likely will play an increasingly dominant role in intelligence gathering and analysis, it could be some years before it expands into offensive capabilities. One reason: the need to verify its findings — and how it arrived there, including its coding, Hammett said.

It's more likely that satellites will include AI to conduct systems evaluations, adjust their orbital paths, and gather and analyze intelligence. With the anticipated proliferation of satellites and growing complexity, "you don't want to send commands constantly to do these small discrete actions," he said.

With the PLA accelerating its own AI-driven modernization, the objective is clear. The AI RCC is the Pentagon's attempt to match commercial speed, harness frontier technology and ensure the U.S. does not fall behind in the defining military competition of the century. Plumb's successor, Dr. Douglas Matty, who took the helm of the CDAO in April 2025, is charting a similar course, aimed at integrating cutting-edge technology across the military while streamlining procurement and implementation.

In testimony in May 2025 before the U.S. House Subcommittee on Cyber, Information Technologies, and Innovation, Matty said: "By harnessing data, analytics and AI, we are empowering our commanders and troops to make faster, smarter decisions.

"We are bolstering our readiness by improving how we maintain equipment and manage resources; and we are enhancing our deterrence by developing new capabilities that increase the speed and agility of the joint force," he said. "All of this contributes to a more lethal, resilient and responsive military, ready to meet the challenges of any threat that comes our way." *

THE DAWN OF SATELLITE INTELLIGENCE

NASA JPL, Ubotica transform real-time Earth monitoring

APOGEE STAFF

NASA's Jet Propulsion Laboratory and Ireland-based Ubotica are testing AI-powered "look-ahead" technology aboard the CogniSAT-6 satellite, depicted above. This innovation enables observational satellites to skip areas obscured by clouds and seek those of particular interest, such as a wildfire. UBOTICA

IMAGINE SATELLITES that can watch, interpret and respond in real time. Firefighters get immediate notification as wildfires ignite along a remote woodland border. Engineers in a bustling city are warned to redirect traffic as a violent summer storm approaches. A ship is alerted as ice drifts into shipping lanes. Seconds and minutes can be critical for response times, but for decades such events slipped by unseen, buried in mountains of archived satellite data and discovered too late to make a difference.

Today, society stands at the threshold of a radical transformation: an era of artificial intelligence (AI) where satellites aren't passive eyes in the sky but dynamic partners to help us see and understand events as they unfold. Among those at the heart of this revolution are two pioneering technologies — Ubotica's Space:AI Layer and NASA's Dynamic Targeting — each reshaping our ability to observe, analyze and act on events as they occur. The term "Space:AI Layer" refers to two emerging concepts in AI and technology. One is a physical intelligence layer for environments where fused sensor data is used to allow physical AI tools (robots, autonomous vehicles) to perceive and cooperate with their surroundings. A second AI-enabled layer is on orbit, composed of data centers and communications infrastructure to provide computing power and connectivity from space.

INTELLIGENT ORBITAL NETWORKS

Under the old paradigm, Earth observation was simple: Satellites mapped the globe in preset patterns, regardless of whether what they captured held value. Every day, fleets of spacecraft amassed petabytes of imagery, much of it rendered useless by clouds or empty landscapes — or containing no events of interest at all.

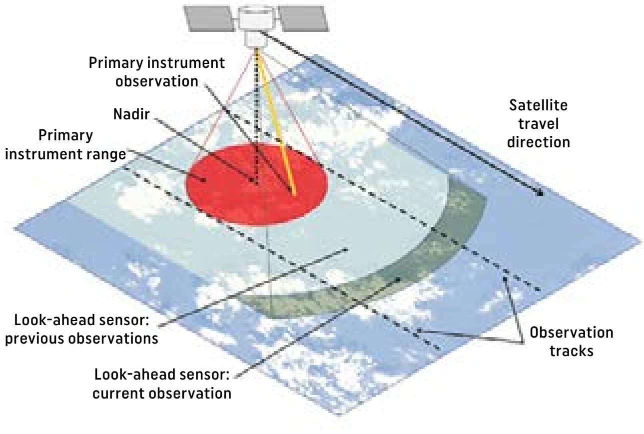
NASA's Jet Propulsion Laboratory (JPL) and Ireland-based Ubotica have developed a technology backed by AI that shifts that dynamic. Instead of using satellites to simply collect raw data, they would interpret it, share insights and adapt their missions to what matters most on the ground. JPL's vision, called Dynamic Targeting, builds on this idea, imagining constellations of intelligent spacecraft functioning like a planetary nervous system, making autonomous decisions and collaborating as a space-based sensing network.

"The idea is to make the spacecraft act more like a human: Instead of just seeing data, it's thinking about what the data shows and how to respond," Steve Chien, a technical fellow in AI at JPL and principal investigator for the Dynamic Targeting project, said on NASA's website. "When a human sees a picture of trees burning, they understand it may indicate a forest fire, not just a collection of red and orange pixels. We're trying to make the spacecraft have the ability to say, 'That's a fire,' and then focus its sensors on the fire."

Instead of using satellites to simply collect raw data, they would interpret it, share insights and adapt their missions to what matters most on the ground.

HOW IT WORKS

The Space:AI Layer enables satellites to process data onboard to shrink the time between observation and understanding. Instead of sending terabytes of raw imagery to Earth for slow analysis, the satellites extract key insights on orbit and deliver actionable intelligence within minutes.



Dynamic Targeting, an AI-driven technology developed by NASA's Jet Propulsion Laboratory, enables satellites to look ahead to avoid clouds or to make a closer observation. NASA/JPL-CALTECH

At the core of this capability is Dynamic Targeting, co-developed by JPL and Ubotica. Breaking away from static imaging routines, satellites equipped with Dynamic Targeting use "look-ahead imaging" to scan areas 40 to 60 degrees ahead of their orbital path — giving themselves a preview of what's coming up, Ubotica's website explains. In just five seconds, onboard AI analyzes the images for anomalies, identifying clouds, thermal hot spots or other events of interest. If something valuable is detected — the glow of a wildfire or a suspicious vessel at sea — the satellite can autonomously reorient itself, adjust its sensors and focus on the emerging threat or opportunity.

This process unfolds in less than 90 seconds. Commands are generated, sensors are reconfigured and high-value data is captured and processed — all before the event slips out of view.

COGNISAT'S MISSION

The leap from concept to reality occurred in July 2025, when Ubotica and JPL tested Dynamic Targeting aboard a CogniSAT-6 CubeSat. The satellite — the size of a suitcase and designed and built by United Kingdom-based Open Cosmos — hosted a payload developed by Ubotica featuring a commercially available AI processor. This wasn't a simulation. It was a live mission, with the satellite processing real data and making real-time decisions on orbit.

During the demonstration, CogniSAT-6 didn't hunt for specific phenomena like fires. That will come later. Instead, its mission focused on an ever-present phenomenon — clouds. Most science instruments on orbiting spacecraft look down at whatever is beneath them. However, for Earth-observing satellites with optical sensors, clouds can get in the way as much as two-thirds of the time, blocking views of the surface. To overcome this, Dynamic Targeting looks 500 kilometers ahead and has the ability to distinguish between clouds and clear sky, Ubotica said. If the scene is clear, the spacecraft captures images of the surface when passing overhead. If it's cloudy, the spacecraft cancels the imaging activity to save data storage for another target.

THE IMPACT OF INTELLIGENT SATELLITES

The potential of Space:AI and Dynamic Targeting is immense. In disaster response, the ability to detect and analyze events like wildfires or hurricanes in real time means emergency teams can work from annotated maps highlighting collapsed infrastructure and isolated populations within minutes, not days, helping focus resources where most needed.

In agriculture, satellites would differentiate between normal seasonal variations and early warning signs of drought, pest outbreaks or disease. Farmers and policymakers would be empowered to make decisions proactively, mitigating crises before they escalate.

Environmental protection could enter a new era. Instead of combing through endless archives for evidence, authorities would reference timely, irrefutable intelligence on illegal mining, logging or fishing operations and track the events as they happen, allowing for effective enforcement and conservation.

Maritime security also would benefit. Dark vessel detection enhanced with AI-driven Dynamic Targeting would allow satellites to scan vast ocean expanses, focusing on suspicious ships approaching critical infrastructure instead of wasting time imaging empty water.

WHAT'S NEXT

With the cloud-avoidance capability now proven, NASA said CogniSAT-6's next test will be to hunt for severe weather — essentially targeting clouds instead of avoiding them. Other potential targets are thermal anomalies like wildfires and volcanic eruptions. The JPL team has developed unique algorithms for each application.

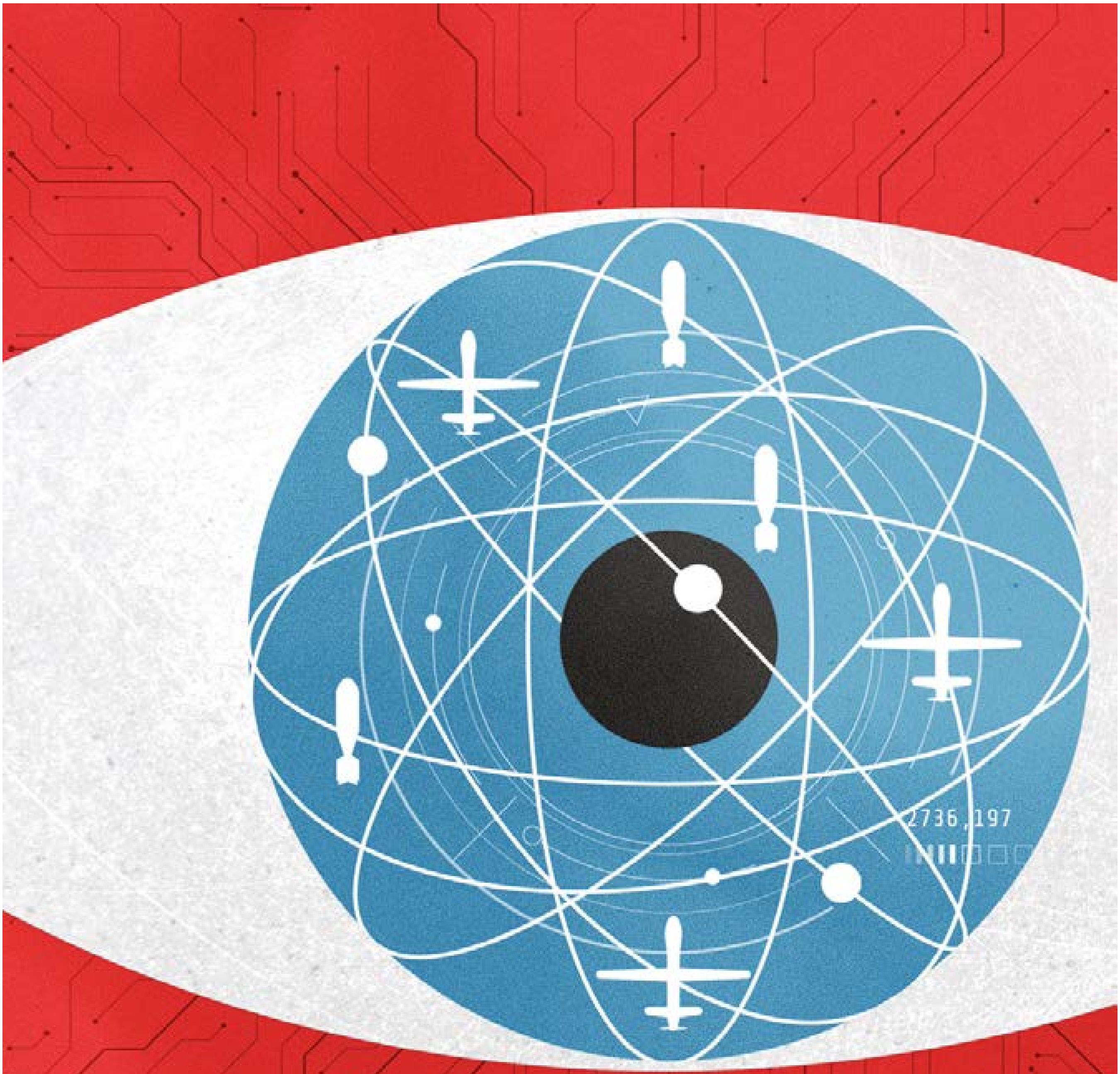
"This initial deployment of Dynamic Targeting is a hugely important step," Chien said. "The end goal is operational use on a science mission, making for a very agile instrument taking novel measurements."

There are several approaches to realizing this goal, including deployment on spacecraft engaged in space exploration. Chien and his colleagues at JPL drew inspiration from their prior work with the European Space Agency's Rosetta orbiter, where they demonstrated autonomous detection and imaging of plumes emanating from comet 67P/Churyumov-Gerasimenko.

On Earth, adapting Dynamic Targeting for radar applications would facilitate the study of hazardous deep convective ice storms, extreme winter weather events that are infrequent and transient — making them challenging to observe with current technologies, NASA said.

By employing specialized algorithms, satellites equipped with look-ahead instruments would identify these dense storm systems, enabling focused radar observation as the spacecraft passes overhead, collecting comprehensive data during brief intervals of six to eight minutes.

Additional concepts include implementing Dynamic Targeting across multiple spacecraft. Image analysis results from a leading satellite could be promptly transmitted to a trailing satellite, which then would concentrate on specific phenomena. This approach could extend to constellations comprising dozens of orbiting spacecraft. A test of this strategy, named Federated Autonomous Measurement, occurred in late 2025.



AI ON THE BATTLEFIELD

REDUCING HUMAN CONTROL RAISES TOUGH ETHICAL QUESTIONS

APOGEE ILLUSTRATION

APOGEE STAFF

Concepts that once conjured up images of sci-fi fantasy — killer robots, autonomous drones and self-correcting satellites — now are within the reach of military commanders. Machines can be trained to process information at speeds far beyond human capacity, creating a thorny ethical debate: If artificial intelligence (AI) can assess threats and predict human behavior quicker than people, when — if ever — should machines be allowed to make lethal, split-second decisions?

Already, over Ukraine, semiautonomous, AI-powered drones are acquiring targets without the help of their human pilots. In the early days of the war, dozens of Ukrainian and Russian drones fell from the sky due to signal-jamming technology that disconnected the pilots from their machines. But Ukraine and Russia now are fielding systems that let drones target tanks and fly toward them autonomously even when that pilot-drone connection is broken, Reuters reported in November 2025. Ukraine says humans still make the firing decisions. "Without the additional [AI] guidance, we simply could not hit it," a 31-year-old drone pilot from Ukraine's 58th Separate Rifle Brigade told Reuters. "Absolutely no way."

The ethical questions of this revolution are many. What if the AI system is operating from bad data and leads to civilian casualties? Who is accountable when that happens? What if ethnic or racial bias alters datasets?

Most military ethicists argue that maintaining human oversight and accountability for lethal force decisions remains a moral imperative. Like with any weapons system, militaries can impose human controls over AI-based decision support systems (AI-DSS). The systems can analyze vast amounts of data, recognize patterns and suggest solutions for military commanders. That doesn't mean humans should — or will — lose control, argues Emelia "Emmy" Probasco, a senior fellow at Georgetown University's Center for Security and Emerging Technology (CSET).

"We have a whole range of controls we can use to contain the risk of certain systems," Probasco told Apogee. "Guns get locked up on bases when they aren't in use. Certain missiles aren't used except under specific conditions and with explicit permission. The Navy's close-in weapons system has an automatic mode that can only be turned on by a few people on a ship and only in certain situations. All of these actions help humans maintain control, but more importantly, they help military commanders maintain control."

While embracing the analytical power of AI, commanders still can determine the amount and quality of human interaction involved in lethal decisions, she said. "You can think of AI-DSS in a similar way [to weapons control measures], except that the types of controls are different," Probasco said. "Instead of locking it up, commanders will have to decide when to use certain models, what the quality and latency of data streams ought to be at various times, and the level and quality of human interaction with the system in different scenarios."

In an April 2025 report titled "AI for Military Decision-Making: Harnessing the Advantages and Avoiding the Risks," Probasco and three co-authors suggested that enthusiasm for AI-DSS on the battlefield "must be balanced with an understanding of their capabilities and limitations to ensure appropriate and effective deployment."

Effective deployment, the authors wrote, requires a well-defined scope for AI use. The systems must have a specific purpose, and operators should not let them process data that is contextually different from what the systems were trained to do, the authors said. "Without well-defined use cases or guardrails, they can confuse operators and lead to misuse," the report states.

THE U.S. MILITARY'S AI ETHICS JOURNEY

When the United States Department of Defense (DOD) started pouring money into AI years ago, military leaders knew they must adapt quickly to this game-changing technology. AI could positively affect everything from logistics to space-based intelligence analysis and decision support in combat, according to a September 2025 report at the private news and resources website military.com.

Without the boundaries Probasco referenced, AI just as easily could undermine U.S. values and even international law, according to the report. So in 2018, leadership at the DOD, now the Department of War, asked the Defense Innovation Board (DIB) to come up with ethical guidelines for military AI use. The panel, consisting of experts from technology, academia and industry, spent more than a year talking to commanders, engineers, policymakers and allies.

The DOD in 2020 then published five core ethical principles for AI use: responsibility, equitability, traceability, reliability and governability.

- **Responsibility** means humans will stay in charge. AI may assist, but people are accountable for how AI is used.

A Ukrainian National Guard member prepares to launch a drone in Zaporizhzhia. She is part of a new all-women uncrewed aerial vehicle group.
THE WASHINGTON POST VIA GETTY IMAGES

- **Equitability** refers to weeding out bias in data and algorithms.
- **Traceability** emphasizes transparency and documentation. The military should keep a record of how a system was built and why it makes certain decisions.
- **Reliability** requires systems to be tested and deemed safe within their intended use, whether that's spotting enemy aircraft or managing supply chains.
- **Governability** means humans should man the "kill switch." If an AI system acts unpredictably, humans must be able to shut it down.

But no international laws ensure that everyone plays by the same rules. As AI warfare evolves, officials worldwide are starting to wonder where the line should be drawn on lethal autonomous weapons systems. Alexander Schallenberg, then Austria's foreign minister, gave this warning at a Vienna conference in April 2024: "This is the Oppenheimer moment of our generation."

He voiced worry that AI-driven warfare could "spiral into an uncontrollable arms race" and that "autonomous drones and algorithm-driven targeting systems threaten to make mass killing a mechanized, near effortless process," according to an August 2025 article in the U.S. Army War College publication The War Room.

The AI ethics challenge extends into orbit, where satellites provide intelligence, communications and reconnaissance in addition to space exploration by the public and private sectors. NASA has developed core principles for AI decision-making in space. Its rules contain six principles. AI use should be fair (eliminate biases); human-centric and societally beneficial; explainable and transparent; accountable; secure and safe; and scientifically and technically robust (defends against data attacks and is based on quality data.)

GARBAGE IN, GARBAGE OUT

An AI-based system, experts agree, is only as good as the data it is fed and the skill of its human operators. The CSET authors argued for continuously updated data for AI systems and for the necessity of a continuous certification cycle for AI-DSS administrators.

"Generative AI, especially in chatbot form, seems so easy to use," Probasco told Apogee. "But if you aren't a trained professional, you may not be able to tell the difference between a truthful answer and a false one or a hallucination.

"Imagine, for example, you don't know how to code, but you've heard you can use tools like ChatGPT to generate code for you. This is great, but then how do you know if the code that was generated is secure? It turns out LLMs [large language models] make usable but insecure code. This is a straightforward example of why we need certified users who can tell when an LLM has made an error."

Industry leaders pursuing AI projects increasingly warn of dangers linked to untrustworthy data. An April 2025 report by Forbes magazine, for example, noted that a recent Salesforce survey of 552 business leaders showed that their trust in the data used to pursue cutting-edge strategies has decidedly fallen over the past two years.

Only 40% of the respondents trusted the reliability of their own companies' data, down from 50% two years ago. Although 63% said that finding, analyzing and interpreting data was key to their jobs, just 54% were confident in their ability to do so.

Executives understand that subpar data collection and curation sullies the reliability of the finished product, industry analyst Andy Thurai said in the Forbes article. "They know it is garbage in, garbage out. So, knowing they are feeding garbage in, would you feel comfortable using the decision?"

Guarding against bias in datasets is one point of worry. A February 2024 report by the Congressional Research Service notes that autonomous systems "may be subject to algorithmic bias as a result of their training data or models. Researchers have repeatedly discovered instances of racial bias in AI facial recognition programs due to the lack of diversity in the images on which the systems were trained, while some natural language processing programs have developed gender bias."

These biases could hold significant implications for militaries. For example, incorporating undetected biases into systems with lethal effects could lead to "cases of mistaken identity and the unintended killing of civilians or noncombatants," the report said.

Many argue, however, that with proper curating and accurate data, AI systems could lead to the prevention of unintended consequences by processing information at greater speeds during battle. Probasco said transparency and a commitment to preventing tragedy can help guide an ethical path forward. "History is littered with tragic military mistakes. AI-DSS will not eliminate mistakes made in conflicts, but we should work hard to make sure AI-DSS reduce the frequency and consequences of mistakes," she said. "Addressing errors can only happen if we study and share knowledge about errors and mistakes. The military has a tradition of using mishap reporting to help identify errors and then turn those reports into knowledge and training. We just need to continue to take hard looks at what works and what doesn't work, whether it's AI or not."

The U.S. has taken a leading role in pushing for responsible military AI use by offering up the Political Declaration on Responsible Military Use of Artificial Intelligence and Autonomy. The declaration was launched in February 2023 at the Responsible AI in the Military Domain Summit at The Hague in the Netherlands. The declaration "aims to build international consensus around responsible behavior and guide states' development, deployment, and use of military AI," according to the U.S. State Department. By the end of 2024, almost 60 nations had signed on. Notable exceptions were the Chinese Communist Party (CCP) and Russia.

> Many organizations are experimenting with AI, and what we learn in the military could benefit companies who are also trying to figure out how to safely deploy AI-enabled systems.
>
> ~ **Emelia "Emmy" Probasco**, senior fellow at Georgetown University's Center for Security and Emerging Technology

THE AI ARMS RACE

No one is waiting for the AI arms race to start. It's already here, so urgency surrounds the idea of resolving ethical dilemmas. Ukraine already is locked in an AI-driven drone contest against Russia. Faced with Russia's numerical superiority in troops and weapons, Ukraine turned to drones early in the war, and Moscow followed. Unmanned aerial vehicles now account for 70% to 80% of the battlefield casualties in the war, according to a March 2025 article by The New York Times newspaper.

The AI contest has led both sides to innovate, such as the adoption of fiber-optic cables to bypass signal jamming. Now, the next phase of drone warfare is taking shape: AI-powered targeting systems allow drones to identify and strike targets with minimal human intervention, even in heavily jammed environments. Warfare is turning into a battle of algorithms.

ETHICS VS. THE NEED FOR SPEED

Even though the proliferation of AI systems sparks ethics debates, DOW officials are pushing for quicker acquisition and development as the CCP and Russia strive for AI dominance. In an April 2025 DOW news release, senior defense officials said they were pushing for more innovation, lethality and readiness in shaping the department's approach to AI.

The White House in July 2025 released the "Winning the AI Race: America's AI Action Plan," which it said would "usher in a new golden age of human flourishing, economic competitiveness, and national security for the American people."

The plan identifies 90 federal policy actions across three pillars — accelerating innovation, building U.S. AI infrastructure, and leading in international diplomacy and security. Key policies include a desire to export U.S. AI technology, promote rapid buildout of data centers, remove onerous regulations to enable innovation and make sure developers don't program biases into their AI software.

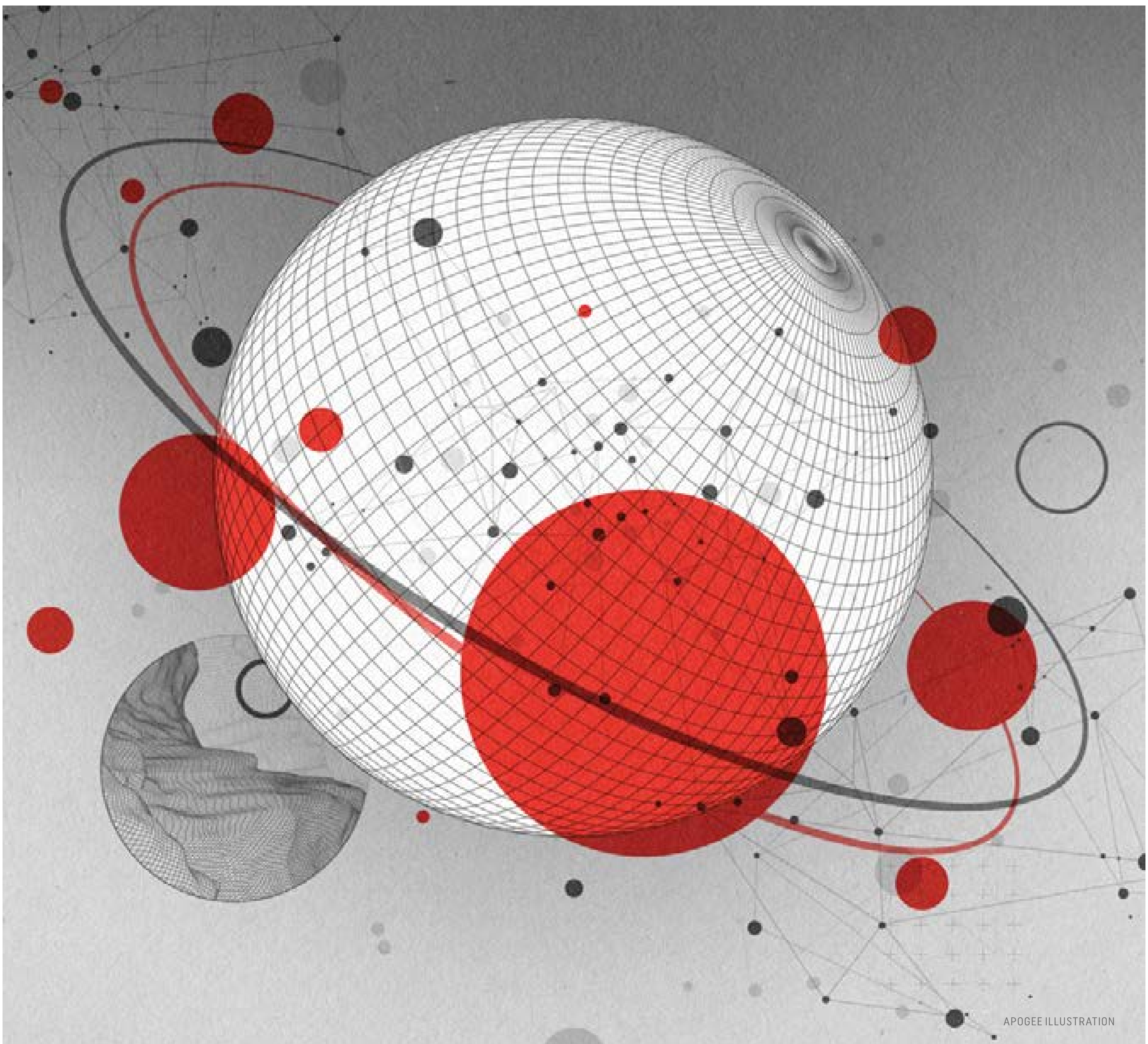
The Russia-Ukraine war provides examples of why this AI push won't slow — precision strikes and simple economics. The primary weakness of Western drones supplied to Ukraine was that Russia's jamming systems were rendering them useless. One popular Western model costs $60,000 to $80,000 per unit, while a Ukrainian first-person-view drone — in many cases built with recycled parts — could cost as little as $400.

As ethicists try to keep up with engineering innovation, Probasco argues for keeping transparency about AI systems at the forefront of the conversation. "Transparency in AI mishap reporting in the military may have a side benefit for society," she said. "Many organizations are experimenting with AI, and what we learn in the military could benefit companies who are also trying to figure out how to safely deploy AI-enabled systems."

Used correctly, AI could provide a fuller battlefield picture and limit unintended consequences, she said. "I especially like the clever applications that take a pretty basic task and just make it faster and less tedious. For example, AI systems that edit intelligence reports to make them shareable with allies and partners [after a human review]. I also see a lot of opportunity for AI-DSS to provide actionable information to help commanders better avoid or mitigate civilian harm." ✷

Predictive Maintenance

How AI can keep satellites on orbit longer and at less cost



APOGEE STAFF

Militaries spend billions of dollars on satellites to relay sensitive information and provide real-time battlefield data, so it's imperative to avoid breakdowns and expensive rescues of wayward orbiting objects. That's why a growing field of engineers, robotics experts and mathematicians are developing AI algorithms to perform what is known as predictive maintenance.

Using tested models that have proven successful with aircraft, experts are using AI to predict a satellite's performance, temperature spikes and future power failures so that one day maintenance can occur before breakdowns, keeping battlefield awareness and communications intact. The goal is to usher in an era of preventive maintenance that extends satellite life and reduces mission failure.

One expert in predictive analytics believes AI will be key to conquering the highest military domain. "We developed a generic, proven [predictive maintenance] model using historical data for aircraft to try to predict anomalies," Abdel-Moez E. Bayoumi, an associate dean and mechanical engineering professor at the University of South Carolina's Molinaroli College of Engineering and Computing, told Apogee. "We found that the model we used for aircraft would also work for satellites as well."

The implications of Bayoumi's work could be profound. Space agencies estimate that there are more than 11,000 actives satellites are on Earth's orbit. They perform civil and defense functions that include weather forecasting, telecommunications and military reconnaissance. To achieve optimal efficiency for satellite fleets, Bayoumi and research scientist Rhea Matthews and their team completed a two-year project in late 2024 designed to predict satellite failures before they occur. The $400,000 project was funded by the South Carolina Department of Commerce in partnership with the Los Alamos National Laboratory and the South Carolina Fraunhofer USA Alliance.

The team analyzed historical satellite data and real-time environmental factors, such as solar flares, which provided insights into satellite performance and improved maintenance decision-making. "With predictive analytics, you can extract the data, characterize the performance and determine a component's lifespan," Bayoumi said on the university's website. "Then a correction can be made since the user can move from monitoring the data to having control for solving the problem."

The team first had to find sources for identifying space weather anomalies. It decided on data from the National Oceanic and Atmospheric Administration and relied on a web-based platform called Seradata for historical information on satellite performance.

"We had hundreds of parameters," so the team performed an analysis on which ones provided the most valuable data, Matthews said at the university's website. "From there, we figured out how these features connected to describe the relationships that we wanted."

The team developed two models. One predicted whether an anomaly would occur on a given day, while another estimated its potential severity. Bayoumi's team then built machine learning models to predict anomalies. The model also estimated remaining useful life and assessed satellite health.

Experts are employing AI to predict a satellite's performance, temperature spikes and future power failures so that one day maintenance can occur before breakdowns, keeping battlefield awareness and communications intact.

"It sensed the type of weather and parameters that could lead to certain anomalies. These were related to the health and performance of the satellite," Matthews said.

The team learned it could develop forecasting models with real-time data if it designed a user-based dashboard. The user interface displayed space weather parameters, current readings and forecasts. Seradata lets users search for specific satellites.

Bayoumi's team provided an overview of their work to NASA and other stakeholders who could benefit from the analysis. A collaboration developed with a space weather expert at Los Alamos. The team's work will include refining

California-based firm Virtualitics announced in November 2025 that it had been awarded a contract from the U.S. Marine Corps to perform AI-powered predictive maintenance on the Osprey MV-22 aircraft.
CPL. MICAH THOMPSON/ U.S. MARINE CORPS

predictive algorithms for accuracy, incorporating additional data, and exploring new applications of machine learning and predictive analytics in satellite operations. "Phase 0 produced a solid framework and prototype that laid a strong foundation for future expansions," Bayoumi said.

Origins of predictive maintenance

Bayoumi has been working on predictive analytics with the U.S. military for years to prolong the lives of aircraft. As director of his university's Center for Predictive Maintenance, he partnered with Clemson University in South Carolina, the Fraunhofer-Gesellschaft research organization and the South Carolina Department of Commerce to produce a virtual reality (VR) demonstration of how the gearbox in the tail rotor drivetrain of an Apache helicopter degrades over time.

The demonstration revealed wear patterns caused by stress on gear teeth, and showed the stress eventually could lead to the component's failure. Bayoumi said this VR tool is a stepping-stone to provide manufacturers with a methodology to detect faults and fix them on the fly or even produce zero-defect products. "We discovered a problem with the gearbox in the tail rotor of an Apache helicopter," Bayoumi told Apogee. "If that problem was discovered before [it failed], we could save $53 million a year for that fleet by addressing a single component."

The experiment showed that grease freely moved from the main gear into the static mast. Leaks in the seal depleted lubricant on the gear mesh surfaces, which led to catastrophic failures. These revelations led to changes in maintenance practices, and a new seal removal tool is now used in the field.

This type of AI-powered analysis could do more than improve safety and save millions of dollars, Bayoumi said. It also could prevent the

"With predictive analytics, you can extract the data, characterize the performance and determine a component's lifespan. Then a correction can be made since the user can move from monitoring the data to having control for solving the problem."

~ **Abdel-Moez E. Bayoumi**
director of the Center for Predictive Maintenance at the University of South Carolina

grounding of a fleet and the tactical disadvantage that would bring. "When you have a gearbox that is essential to that aircraft, you might have to ground that aircraft," he said. "Mission availability could be extremely important because you don't want to lose one of your aircraft."

Bayoumi said the Apache AH-64 helicopter, which first was tested in 1975, is evidence that AI already is extending the lives of military equipment. "The Apache was designed and built

Abdel-Moez E. Bayoumi has more than 40 years of teaching, research and industry experience. He is director of the Center for Predictive Maintenance and a professor of mechanical and biomedical engineering at the University of South Carolina.

in the late 1970s," he said. "They are still flying now because of the repairs. You can extend not only a component, like a gearbox, but the overall structure of the aircraft. You can improve the skin and the structure of the aircraft."

Bayoumi has conducted similar research on the V-22 Osprey, a tilt-rotor military transport and cargo aircraft. The progression of AI research continues with the Marine Corps variant of the Osprey, the MV-22. The Marine Corps in November 2025 announced they had hired California-based firm Virtualitics for a contract to deploy the company's Integrated Readiness Optimization platform to enhance the "sustainment and mission readiness of the MV-22 Osprey fleet," according to a company news release.

The platform uses AI to provide commanders with analytics to forecast maintenance, Virtualitics said in the release. "The MV-22 is one of the most versatile and critical utility assets in modern warfare, and helping its crews sustain operational readiness with trusted AI is exactly what our mission is about," Virtualitics chief revenue officer Rob Bocek said in the release. "By delivering AI to the warfighter, at the edge, where decisions matter most, we're advancing how the Department of War prepares, responds, and maintains superiority in every domain."

A growing field

The implementation of AI and machine learning into predictive analytics will be evident in many facets of daily life, Bayoumi said. From supply chain logistics to cancer diagnoses and public transit, intelligent machines are increasingly playing larger roles.

Bayoumi points to the COVID-19 pandemic as an example of how AI-enabled processes could prevent costly shortages of medical and personal protective equipment. "What action could be taken ahead of time to be sure you have what you need?" he asked.

Public transportation agencies already use AI to keep trains running. New York City's Metropolitan Transportation Authority (MTA) in February 2025 announced a predictive maintenance program for its subway tracks. Working with Google, the MTA's project aimed to detect potential track defects before they escalated into disruptions for customers.

The TrackInspect prototype integrates sensor hardware with advanced cloud and AI capabilities to detect track problems. Google Pixel smartphones were placed on subway cars to capture vibrations and sound patterns through built-in sensors equipped with a microphone, according to an MTA news release.

The sound and vibration data was sent in real time to cloud-based systems, where artificial intelligence and machine learning algorithms generated predictions on trouble spots. "By being able to detect early defects in the rails, it saves not just money but also time — for both crew members and riders," New York City Transit President Demetrius Crichlow said in the MTA release. "This innovative program — which is the first of its kind — uses AI technology to not only make the ride smoother for customers but also make track inspectors' jobs safer by equipping them with more advanced tools."

New York City's Metropolitan Transportation Authority used Google Pixel smartphones to predict potential track failures on the subway system.
AFP/GETTY IMAGES

Predictive analytics also are shaping habits in the medical field, specifically in the fight against cancer. According to a November 2025 report from the American Journal of Managed Care, AI is on pace to "become the most rapidly adopted technology in health care, whether clinicians are ready for it or not. From ambient scribes transcribing doctor-patient conversations, to AI-powered digital twins replacing placebo arms in clinical trials, AI is being inserted throughout oncology," the report said.

It's a pattern of man embracing machine that shows no signs of slowing in many diverse fields. Virtualitics CEO and co-founder Michael Amori is banking on that in the military sector, saying his new contract with the 2nd Marine Aircraft Wing shows "how explainable AI solutions are transforming aviation sustainment, helping the Marine Corps maintain fleet readiness, reduce downtime, and strengthen mission success at speed and scale." ✷

DEFENSE SATELLITES DEBUT

Russian aggression moves Poland and others to orbit first military spacecraft

APOGEE STAFF

WITH THE WAR IN UKRAINE pushing Poland to accelerate its space defense program, the NATO nation has orbited its first three military satellites. The spacecraft were launched in November 2025 from Vandenberg Space Force Base in California aboard a SpaceX Falcon 9 rocket.

Poland plans to send up three more military satellites in 2026 to boost a fleet that will produce intelligence, surveillance and reconnaissance data for analysis by the military's new Geospatial Intelligence and Satellite Services Agency, Defense News reported.

The satellites were developed by a partnership between Iceye of Finland, a major European satellite manufacturer, and a private offshoot of Poland's state-run defense group PGZ. Iceye has called itself a Finnish-Polish company, and recently, the Polish government has taken an ownership stake in the firm.

Iceye has signed contracts with Finland, the Netherlands and Portugal to deploy military satellites equipped with its signature synthetic aperture radar that can see Earth regardless of cloud cover or time of day.

ABOVE: A synthetic aperture radar satellite made by Iceye of Finland operates over Europe in this illustration. Poland is orbiting a fleet of the satellites for military use. ICEYE

"This is a great day for the Polish Armed Forces and Poland, because they are gaining full independence in radar reconnaissance and imaging," Władysław Kosiniak-Kamysz, Poland's minister of defense and deputy prime minister, said at a contract signing in May 2025. "We are also certain that we are acquiring the absolute best capabilities in the world."

Iceye also has provided radar and satellite services to Ukraine in its war against Russia. Ukrainian President Volodymyr Zelenskyy recently met in Finland with a group that included Iceye and Polish leaders, Kosiniak-Kamysz said.

The Polish satellites were deployed as part of a payload of 108 spacecraft carried by Transporter-15, a SpaceX small satellite rideshare mission. The mission also carried Earth observation satellites for the Italian space company OHB Italia and for U.S.-based Planet Labs.

FROM STRATEGY TO TACTICS

NATO SHIFTS GEARS AS DEFENSE DOMINATES SPACE SPENDING

APOGEE STAFF

NATO MILITARY LEADERS and others attending a summit in Paris said their approach to space defense has shifted from strategy to tactics as prospects increase for warfighting in the domain, according to news accounts from the September 2025 Space Defense and Security Summit.

Maj. Gen. Vincent Chusseau, commander of French Space Command, told the second annual summit in Paris that "things are accelerating very fast," according to Defense News. "Space is a really full operational domain. We talk about warfighting in space."

He provided no details, but Brig. Gen. Christopher Horner, commander of 3 Canadian Space Division, said more than 200 anti-satellite weapons are now on Earth orbit, presenting a "shocking number of capabilities."

One point of discussion was that global space defense spending has exceeded civil space budgets for the first time, according to a January 2025 report by summit organizer and France-based space consultant Novaspace.

Government space investments reached some $135 billion in 2024, with defense spending accounting for 54% at $73 billion, Novaspace said. The report highlights the increasing number of countries ramping up investments in space. While the U.S. continues to lead global government spending on the domain, its share has declined from over 75% in 2000 to 59% in 2024, reflecting rising investments from the Chinese Communist Party and other nations, the report said.

"What you see is that it is now the military domain that is leading," Hermann Ludwig Moeller, director of the European Space Policy Institute, told Defense News during the summit. "This is really clear compared to last year. The language and what is behind the language has shifted."

Government money spent worldwide on space defense, including satellite manufacturing, topped the amount spent on civil defense for the first time in 2024.

PUSHING BACK AGAINST RUSSIA

U.K. USES PARTNERSHIP, DETECTORS TO GUARD SPACE ASSETS

APOGEE STAFF

THE UNITED KINGDOM'S MILITARY is taking steps to protect the nation's space assets against interference by adversaries such as Russia.

The U.K. and United States space commands conducted their first joint military operation in space in September 2025, moving two satellites close together during a rendezvous and proximity operation in geostationary orbit. For about a week, a U.S. satellite checked whether SKYNET 5A, a U.K. military communications satellite, was operating as intended, according to a report from the Royal Air Force. The operation was conducted under Multinational Force-Operation Olympic Defender, a U.S.-led space coalition that also includes Australia, Canada, France, Germany and New Zealand.

"We are now, with our allies, conducting advanced orbital operations to protect and defend our shared national and military interests in space," said British Army Maj. Gen. Paul Tedman, commander of U.K. Space Command.

A few weeks later, the U.K. announced that technology is under development to spot lasers that adversaries may use to dazzle satellites and intercept communications. The U.K. Armed Forces project will help protect satellites that are used for everything from bank transfers and weather forecasts to emergency services and intelligence operations, the government said in an October 2025 report.

The new sensor technology will help identify lasers based in space or on the ground and determine whether they pose a threat to satellites, helping the military protect and defend U.K. and allied space systems and assets.

The moves come as the U.K. is sounding the alarm about Russian satellites stalking and seeking to jam the country's fleet of a half-dozen military satellites. In an October 2025 interview with the BBC, Tedman said for the first time that space interference from Moscow has risen to a weekly occurrence since the Russian invasion of Ukraine in February 2022.

"They've got payloads on board that can see our satellites and are trying to collect information from them," he said. In September 2025, Germany's Defense Minister Boris Pistorius said Russia had been shadowing satellites used by his country's military.

"We are now, with our allies, conducting advanced orbital operations to protect and defend our shared national and military interests in space."

~ **British Army Maj. Gen. Paul Tedman**
commander of U.K. Space Command

Paul Tedman, shown here at a space conference in Miami, Florida, in January 2023, now heads the United Kingdom Space Command as a major general in the British Army. Tedman said Russia is interfering weekly with U.K. satellites. LT. COL. DUSTIN CAMMACK/U.S. ARMY

SEA LINKS FOR INDIA

Biggest comms satellite launched from Indian soil will serve Navy

APOGEE STAFF

LINKS AMONG Indian Navy ships, planes and command centers across the Indian Ocean will get a boost from a satellite orbited in November 2025 — the largest communications spacecraft ever launched from the nation's soil.

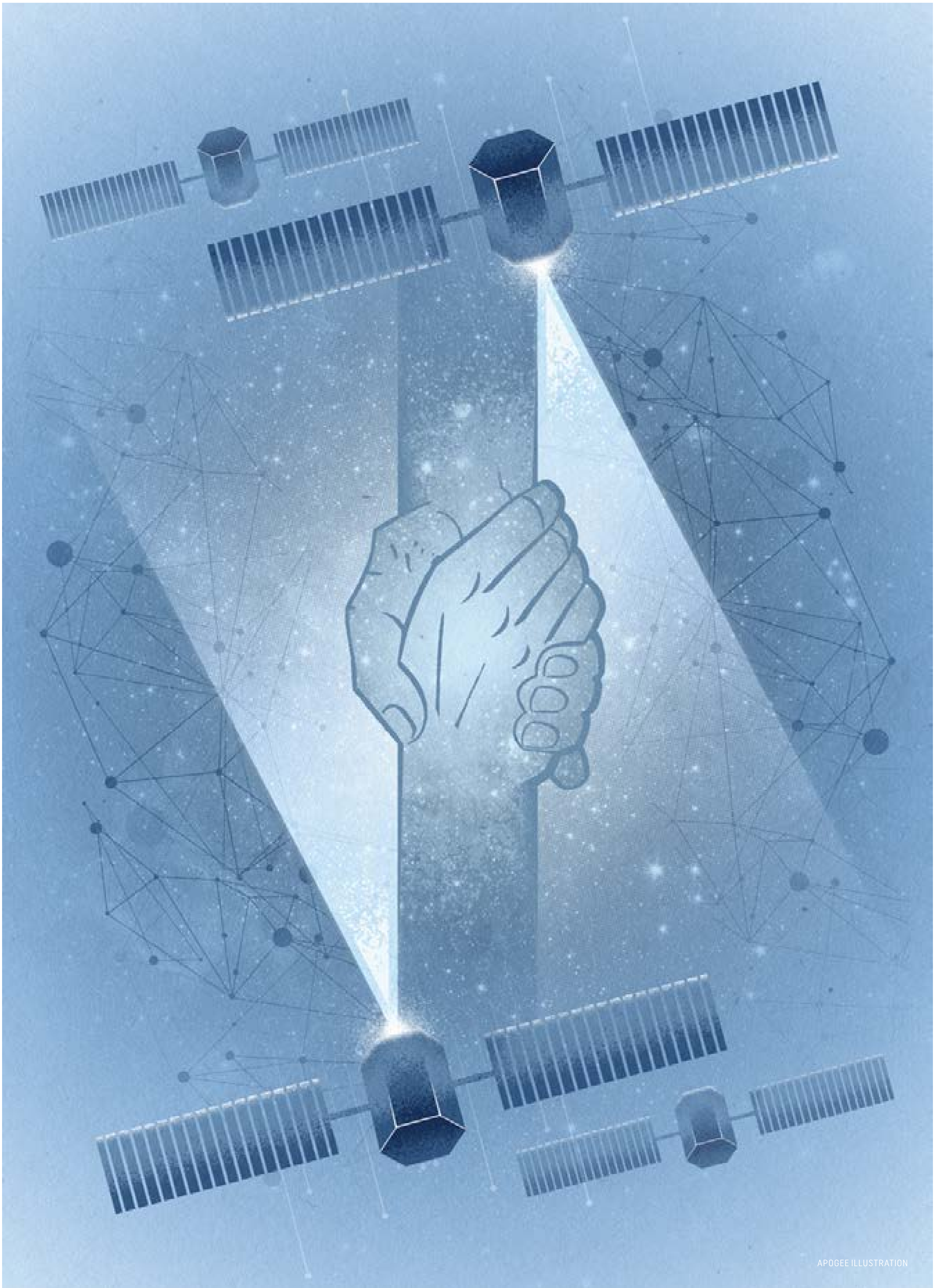
The Indian Space Research Organisation, the nation's space agency, sent up GSAT-7R to replace the aging GSAT-7, launched in 2013 and previously the backbone of India's naval communications, the Times of India newspaper reported.

GSAT-7R, also known as CMS-03, is designed to expand secure communications for the Navy's blue-water operations across UHF, S, C and Ku bands, helping transmit voice, video and data among warships, submarines and aircraft. The satellite will extend the Navy's operational reach across critical maritime regions, the Times reported.

The spacecraft will occupy geostationary orbit at about 36,000 kilometers altitude, hovering continuously over one spot on Earth in a destination popular for reconnaissance satellites and communications craft like CMS-03, space.com reported.

CMS-03 lifted off atop India's largest rocket, the Launch Vehicle Mark-3, from Satish Dhawan Space Centre on the barrier island of Sriharikota in southeast India. Previously, India launched satellites of this size on European Space Agency Ariane rockets from the European Spaceport in French Guiana, an overseas department of France in northeast South America.

India has deployed a satellite to modernize communications with its naval fleet, including the new anti-submarine vessel Mahe. REUTERS CONNECT



APOGEE ILLUSTRATION

TAPPING INDUSTRY FOR AI POWER

TRANSFORMATIONAL TOOL SEEN AS KEY TO SUCCESS IN SPACE DEFENSE

APOGEE STAFF

The head of a fast-growing tech firm has noticed that the promise of rapid advancements in space defense is bringing around some top public decision-makers to deep truths about the free market system.

"I believe that the Department of War and the U.S. government — governments across the world, actually — are finally understanding that there's more private capital out there than there is taxpayer money," Pete Cannito, chairman and CEO of the Jacksonville, Florida, space infrastructure company Redwire Corp., told a space defense conference in December 2025. "And they want to tap into that."

Nowhere is that private capital snowballing like it is in artificial intelligence and machine learning (AI/ML), where just seven major tech companies — including some whose systems form the foundations of AI/ML — were expected to spend more than $300 billion on the technology in 2025. That's equal to the value of Coca-Cola, United Health or Chevron.

Tapping into the advancements fueling this trend has become a matter of policy for the United States government. "America must have the most powerful AI systems in the world," according to America's AI Action Plan, issued by the White House in July 2025. "Achieving these goals requires the Federal government to create the conditions where private-sector-led innovation can flourish."

Air Force Secretary Troy E. Meink, speaking in December 2025 at the Space Force Association's Spacepower Conference in Orlando, Florida, said, "We need this skill set in everything we do or we're not going to be successful." AI/ML skills are emerging across a host of Pentagon initiatives, many of them within the U.S. Space Force — the military's first digital service and the one charged with securing the nation's interests in space.

"In terms of AI, industry is definitely driving the path forward," U.S. Space Force Capt. Drake Williams, who runs an AI prototyping program as an acquisitions manager with Space Systems Command (SSC), told Apogee.

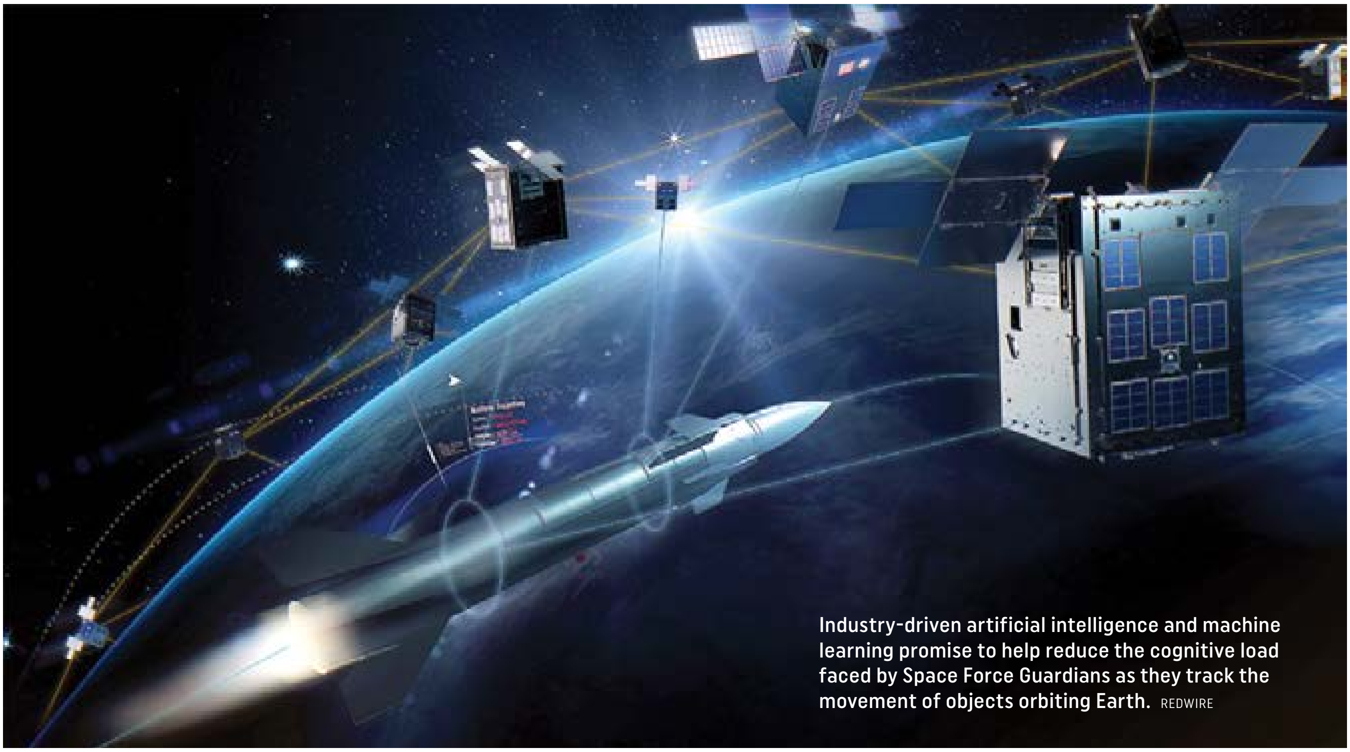
Among the examples: AI/ML capabilities play a growing part in the Space Force's Industry Days, where acquisitions personnel bring in companies to seek help answering identified needs, and in Reverse Industry Days, where companies showcase their developing technology in hopes it might be of use. The service's innovation arm, SpaceWERX, and the Pentagon's Defense Innovation Unit conduct similar outreach to the space industry.

Industry also partners with Space Force and academia at TAP labs — for tools, application and processing — such as the Space Domain Awareness (SDA) TAP Lab in Colorado Springs, Colorado. The lab works on innovation accelerator cycles of two or three months. The latest cohort of companies selected includes Soresu LLC, a Colorado software firm founded in 2025 with just a few employees that leverages AI in orchestrating ground, space and air sensors for autonomous detection of events.

Companies such as Colorado-based Slingshot Aerospace already are bringing AI/ML to SDA — the term that describes an understanding of the realm and of the satellites moving within it. By using AI tools to fuse different data sources, operators can "get actionable information on operationally relevant timelines," Audrey Schaffer, Slingshot's vice president of strategy and policy, told the Constellations podcast in June 2025. "What we're seeing is better exploitation of the data sources that we have."

Data fusion for SDA delivers a better picture of a space object's identity, positioning, movements, behavior and context. The next step, Schaffer said, is doing something with that AI-enhanced data — perhaps using the creative form known as generative AI to evaluate options and make operational recommendations.

Aerospace giant RTX Corp. and its missile-making subsidiary, Raytheon, are working to incorporate AI/ML into new missions such as space-based interceptors, Jeff McCall, Raytheon's vice



Industry-driven artificial intelligence and machine learning promise to help reduce the cognitive load faced by Space Force Guardians as they track the movement of objects orbiting Earth. REDWIRE

president for mission solutions and payloads, told the Spacepower Conference. "For algorithm development, algorithm optimization, light software development, developing fire control solutions for some of the new and exciting missions out there," McCall said during a missile defense panel discussion.

For four decades, Virginia-based Raytheon has been building exoatmospheric kill vehicles that target an adversary's ballistic missiles once they enter outer space. The Space Force in December 2025 solicited proposals for a new generation of space-based interceptors that would take out missiles at an earlier phase of flight. AI technology uses algorithms, a mathematical process for solving a problem using several steps, as its instructions for interacting with training materials to understand what outcome it should work toward.

Florida-based Redwire brings its AI/ML expertise to space defense through products such as the new Acorn 2.0 software, featuring AI-powered digital engineering tools. Acorn 2.0 uses agent-based modeling and AI to solve complex problems beyond the capacity of other modeling tools.

"An agent can be anything you want — a plane, a tank, an unmanned aircraft system, or it can be a satellite or multiple satellites," Dean Bellamy, Redwire's executive vice president for national security space, told Apogee. "I think this is going to allow us to smartly move AI onboard and actually demonstrate virtually how AI would work to an operator and prove it out. I think it's going to be core to how not only Redwire but a lot of our partners build satellites."

AI initiatives by Virginia-based Peraton aim to enhance national security, in part, by creating a relationship between humans and AI. Jessica Kalmanson, Peraton's chief technology officer for space and intelligence, said one priority — the one that "keeps her up at night" — is developing systems resistant to rising attacks from adversaries. "AI in cyberattacks are more and more in the news, and we have adversarial AI and data poisoning. We now have to have systems that think about that," Kalmanson said at the Spacepower Conference. "Can your AI detect when it's being deceived? Can it detect, isolate and keep operating in a degraded state so the operator can keep focusing on the mission to be successful?"

Companies using AI/ML for space defense, as is the case with AI/ML users everywhere, are working from a foundation created by a handful of pioneering research labs and tech behemoths. By some measures, there are eight of them: the U.S. firms OpenAI, Anthropic, Google, Microsoft, Meta and xAI, and the Chinese corporations DeepSeek and Moonshot AI. They are developers of massive, large language models (LLM), based on text, and the foundation models that contain text and other forms of data. "They are the architects of a new kind of internet, capable of generating code, analyzing complex data, and engaging in nuanced, human-like conversations," according to the website Search Engine World. These companies are "pushing the boundaries of what's possible and reshaping how we interact with technology."

Said Williams, "It takes an incredible amount of resources to create a new large language model. It's not something that the government really has the resources or expertise to do, so we've been really leaning on [industry] as we create the engines we can use for our specific use cases."

“There’s a lot of data coming down all the time and we don’t really have the human bandwidth to analyze all of it.”

~ **Capt. Drake Williams**, U.S. Space Force

The Space Force has rolled out a three-level model for leveraging AI/ML, from general to more specific uses. Level 1 is known as enterprise for its widespread, basic application; Level 2 is functional AI, narrowed some to specific activities within the service; and Level 3 is known as mission-specific AI.

Level 1 work draws from the data available through the LLM companies. Through its 2025 Space Force Artificial Intelligence Challenge, the service recently honored a half-dozen teams that created breakthrough products in areas such as onboarding new Guardians, tracking fitness and launch operations. A new Department of War (DOW) web tool called GenAI.mil enables all service members to access these resources to create their own work, whatever their area of responsibility.

Developers can train an LLM to perform a specific function or they can use its ability to communicate in natural language to pull out a piece and create a small language model, one “that you could run off a laptop,” said Bartley Stewart, head of the SSC Chief Digital and Artificial Intelligence Office and Information Dominance Division. “There’s advantages of that approach, especially when you get into things like Level 2 and Level 3 that are operational, where you want to be on the edge.” The edge refers to processing data close to the sensor that is its source, often used to describe autonomous satellites.

One tool for accomplishing these tasks comes from private industry. Ask Sage — billed as a secure, government-grade generative AI platform designed for defense, national security and regulated industries — lets users ask questions and get answers from vast, private datasets using natural language. Ask Sage, based in Virginia and founded by a former chief software officer with the Space Force and Air Force, supports more than 100,000 DOW users, 16,000 government teams and hundreds of commercial companies.

The work of U.S. Space Force Capt. Drake Williams includes standing up a Space Force artificial intelligence hub.

There are many potential mission-specific uses of AI/ML in space operations. “We’ve got a lot of satellites on orbit doing missile warning, weather, GPS activities, space sensing, taking images,” Williams said. “There’s a lot of data coming down all the time and we don’t really have the human bandwidth to analyze all of it. So we use algorithmic sorting to eliminate the things that maybe don’t matter so much and call to the attention of the human operators the things that do matter. Help them sort through different courses of action and present options so we reach this state of decision superiority where we can assess the situation, orient ourselves, make a decision and act — much more quickly than we could if we only have humans in the loop on these processes.”

Barbara Golf, strategic advisor for space domain awareness with the SSC, drove home the challenge of analyzing a growing deluge of data during an SDA panel discussion at the Spacepower Conference. “I’ve got 8,000 commercial sensors coming out of my ears, so I don’t think we have a sensing problem anymore. We’re drowning in data, literally drowning in it … Where do we put it?” The SDA TAP Lab, Golf said, has a backlog of 80 app requests.

Among issues to deal with are the sharing of proprietary code among competing vendors, hosting apps at the secret and top-secret level, and the different platforms required for different types of processing. “There is no one platform to rule them all,” she said.

Today, the major large language models aren’t truly tied to operations in a way that could help with space defense missions. “I don’t think that we trust them to that level yet,” Williams said — not to run, say, constellations of satellite sensors. The service is getting to the point, though, where it can test and accredit LLMs and eventually transfer more responsibility to automated tasks.

Initial prototypes focus on the human-machine interface — enabling an operator, for example, to forgo clicking through all the forms on a graphical interface as is now required to send a command to a system. Instead, with AI/ML, “you could say, ‘Please send a request to view this satellite using this sensor in the next 12 hours.’ You could give the larger language model that natural input, and then it could format that into a machine-readable command.”

The technology also could help discern adversarial activity from normal activity that’s detected by ground-facing Space Force satellites. “They can detect missiles, but they can also detect bright clouds or sun reflecting off of a plane and rocket launches

"Our economy depends on that constant disruption from innovative new companies."

~ **Pete Cannito**, Redwire chairman and CEO

Pete Cannito, chairman and CEO of space infrastructure company Redwire, told a space defense conference that setting standards might be the government's most important contribution to advance artificial intelligence for space defense.

that aren't a threat," Williams said. "That takes quite a bit of skill and training on the job to figure that out. So we use the LLM to basically look at the image of a missile track and determine, 'Is that a missile?' And then start to sort it into the broad categories of missiles so you can understand the threat better."

LLMs help accomplish this by unraveling images into data that consist of 224-character strings of pixels. They're not readable by humans. "Then it can, for lack of a better word, see the image. These data points represent distinctive differences among the many pixels that are being analyzed."

Williams is working to stand up an AI hub within Space Force acquisitions, Stewart said, "so no matter what specific technology industry comes out with, what the next models look like, we can adapt them."

The effort so far consists of a few building blocks. The first is infrastructure and data, ensuring there is computing power that can run the required algorithms on government-accredited hardware and with the right data that's ready to go for the right sources. "Because if you get the latest model, but you don't have anything to give it, it's not very useful," Williams said.

The second building block is talent and the workforce, "making sure we have the right experts in place, making sure the workforce understands how to use these models, if we put them in front of them." The third is partnerships and ecosystem. "That's really having the right connections to industry so we know what's going on. Having the right connections to academia and at the labs and with federally funded research and development centers so that we can all share solutions."

The fourth and fifth building blocks are change management and process reengineering to help speed up the accreditation of new systems, and a responsible AI governance framework "to make sure that we do all these things in an ethical manner."

The push to leverage space commerce notwithstanding, the Space Force's own research contributes to the advancement of AI/ML, too. Stewart tells the story of a respected private vendor who had done business with the government for a long time and "showed me a tool — and it was a good tool. It appeared to do what it was supposed to do. It filled a need we had for Level 2 tooling." At around $500,000, "I don't have any reason to think they were not asking a fair price."

"The very next week," Stewart continued, "there was a Space Force Guardian in a civilian institution who called me up and wanted to show me this tool he had developed. It was an 80% overlap of the tool I had seen previously." Stewart asked the Guardian how long it took and how much it cost. "He said about two weeks ... and about two pizzas." Stewart added, "It wasn't quite as polished, but it was real close to good enough."

In general, though, the role of industry is to do the engineering and build the products, while the role of government is to make decisions, Stewart said, "whether it's a decision around what do we buy, a decision around what company or companies do we go to to procure it, or it's a decision around what do we think the adversary is doing or how do we react or respond? It's all decisions."

AI/ML can help operators reduce what's known as cognitive load. "How long do you have. ... How much are you thinking about? How much can you hold in your memory?" Another factor is information certainty, using AI/ML to fuse a number of inputs to be surer about a decision. "Simplifying them, combining them, so now what the human decision-maker has to

Agatha from Slingshot Aerospace employs artificial intelligence for space domain anomaly detection and characterization. SLINGSHOT AEROSPACE

Aerospace giant RTX uses artificial intelligence and machine learning to improve the design, development and testing of products — and to make them smarter, easier to use and more capable. RTX

make a decision based on isn't as large, isn't as complicated," Stewart said. "You're doing better. You're really making a difference."

Another role for government in its partnership with the space industry — perhaps its No. 1 role — is setting the standards and architecture for all players to follow, said Redwire CEO Cannito. "Because they're really the only ones who are in a position to get everybody to play together." Standards are needed for systems engineering, digital engineering, advanced modeling and simulation, "to make sure that all that stuff can work together, seamlessly, because that's really where the power comes from," Cannito told the Spacepower Conference.

Exercising this power also serves another goal of government, Cannito said: Leveling the playing field for the small startup companies where so much innovation resides. "Standards are absolutely critical to that," he said, "because if you build these monolithic closed systems and you don't publish the standard and then you find this innovating group of young professionals in the garage who have the next killer app, and they say, 'All right, we're ready to plug in in this one area because we do this better than everybody else.' Sometimes you have to bypass that product just because it doesn't fit in your architecture. That's a real missed opportunity, not only for the user not getting the best capability but for our economy. Our economy depends on that constant disruption from innovative new companies."

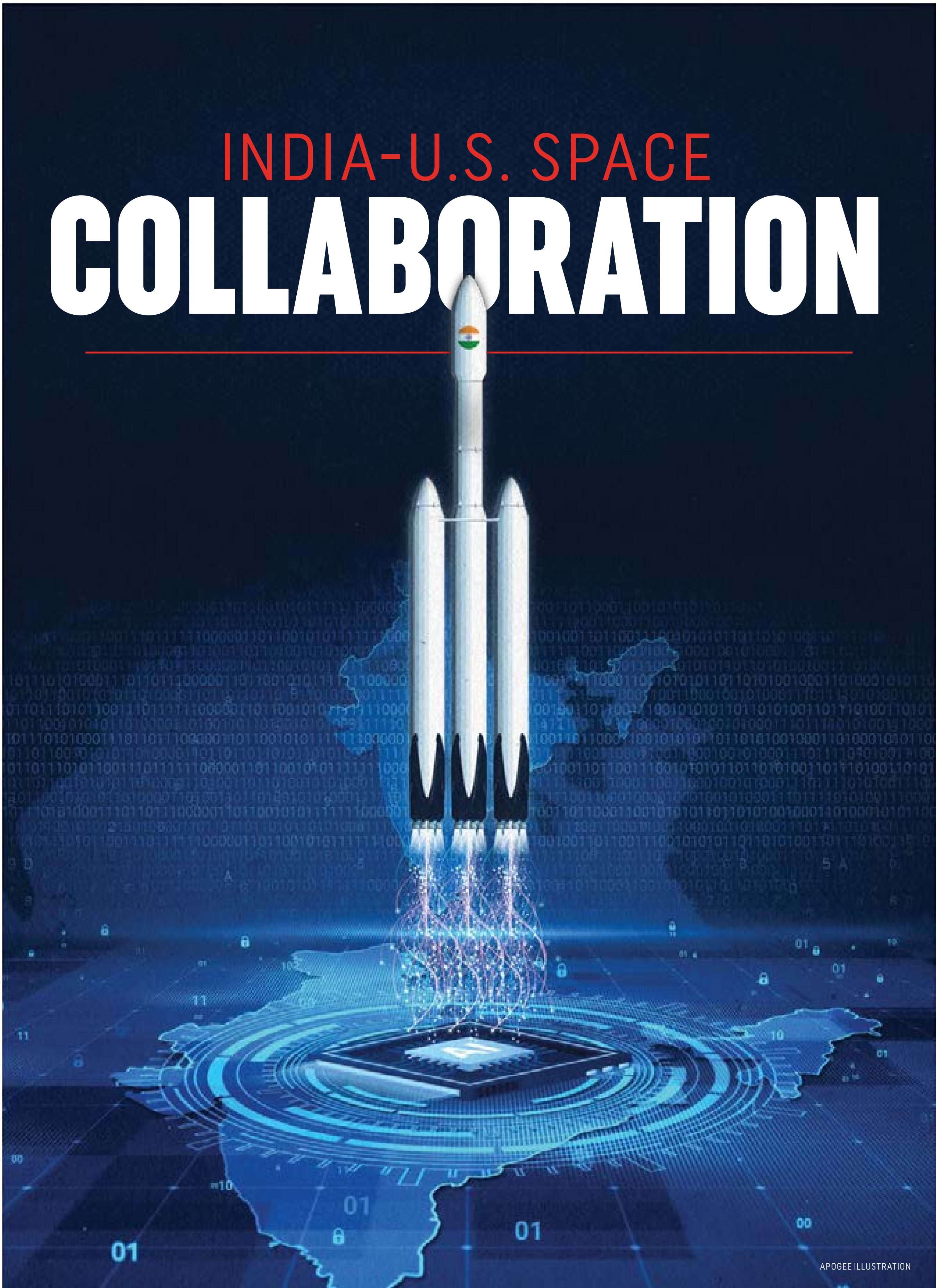
Stewart with SSC echoed the need for the acquisition system to protect small businesses — and to balance this against the need to keep down costs. "If we can get tools so cheap that we save the taxpayer a bunch of money, but by doing that we're driving the small, innovative companies out of business, it's not really a good value to the taxpayer because at the end of the day, our mission is to secure and defend space. If we degrade our industrial base's capability to support the defense of space, then we haven't done a good job."

At the same time, the military must ensure the highest levels of reliability for systems using AI/ML. "I think it's definitely different for commercial versus military," Williams said. "The military has a unique mission; we're talking about lives on the line, and mistakes are costly when the military makes them. So the standard has to be much, much higher. I think the leadership stance now is, 'We understand that we're going to need to implement AI into operations, to keep up with our competitors. But we have to do it very carefully and we have to take each step incrementally and fully test things out.'"

AI/ML capabilities aren't end goals in themselves but a means of reaching them, Stewart said. "We'll often talk about 'AI Tool and Die' ... basically, a machine shop where you make other tools. ... Not necessarily using AI to do the thing, but to develop the algorithm to do the thing. That's where a lot of the power is." This transcends the use of AI/ML for simply reducing toil and taking over mundane tasks. "The capacity for developing tools is super strong."

Added Williams, "AI is itself not inherently a priority. Space Force has its priorities. ... We're just evaluating how do we get to our number 1, 2, 3 priorities? How does AI help us get after those faster?" ✷

INDIA-U.S. SPACE COLLABORATION



APOGEE ILLUSTRATION

A PERSPECTIVE FROM EMERGING FRONTIERS ON SHARED CHALLENGES, THE AI EXPLOSION AND FUTURE OPPORTUNITIES

COL. MANDEEP SINGH RAI/INDIAN ARMY

AS leading nations in space, India and the United States have shared a legacy of collaboration since the formation of the Indian National Committee for Space Research in 1962, when India launched its first sounding rockets from Thumba with U.S. support. The enduring partnership expanded through pathbreaking projects like the Satellite Instructional Television Experiment using NASA's ATS-6, followed by the Indian National Satellite System.

Although India's nonalignment policy and tilt toward the Soviet Union briefly stalled cooperation, post-Cold War ties have revived significantly. The year 2004 marked a renaissance moment for India when two professional societies crafted the plan for providing opportunities to rebuild strategic partnerships in the space sector. The decision to establish the Civil Space Joint Working Group in 2005 led to joint ventures in the following years. It focused on lunar exploration, satellite navigation and Earth observation, including Chandrayaan-1, NISAR (NASA-ISRO Synthetic Aperture Radar), Mars exploration and India's participation in the Artemis Accords.

As prime players in the New Space era, both countries are charting a new frontier under the Initiative on Critical and Emerging Technologies framework, strengthening collaboration across civil, security and commercial sectors. During Indian Prime Minister Narendra Modi's U.S. visit in February 2025, the framework was rebranded as Transforming Relations Utilizing Strategic Technologies to advance cooperation in space, in addition to defense, artificial intelligence (AI), semiconductors and biotechnology. Strengthening their collaborative footprint in space, two Indian Space Research Organisation (ISRO) astronauts began training at NASA, which paved the way for the maiden joint India-U.S. mission to the International Space Station as part of Axiom-4. The July 2025 launch of NISAR was geared to significantly advance capacities in disaster management, climate change monitoring and infrastructure assessment across the globe.

India's Defence Minister Rajnath Singh attends the Artificial Intelligence in Defence exhibition in New Delhi in 2022. HINDUSTAN TIMES VIA GETTY IMAGES

A proposed Space Innovation Bridge under the India-U.S. Defense Acceleration Ecosystem aims to foster India-U.S. startup partnerships in satellite technology and space situational awareness. The growing space cooperation in defense deepens with India's participation in the U.S. Space Command's Global Sentinel exercises and ongoing missile technology export reviews to support commercial satellite launches, reinforcing their role as prominent players in the growing space economy.

A temporary structure with an AI theme greets attendees at the Durga Puja festival in Kolkata, India, in September 2025.
HINDUSTAN TIMES VIA GETTY IMAGES

Insight into the space economy

The latest estimates in The Space Report from the nonprofit Space Foundation peg the global space economy at $570 billion. In 2023, the United States had the largest space budget by far, yet its share of the global space budget decreased from more than 75% in 2000 to 60% in 2023. The Indian space economy is currently valued at about $8.4 billion, constituting a 2% share of the global space market. India envisions scaling the space economy to $44 billion by 2033, including $11 billion in exports, amounting to 7%-8% of the global share. Notwithstanding the budget constraint, ISRO, with a budget that is less than 7% the size of NASA's, has demonstrated distinguished accomplishments, such as the lunar exploration Chandrayaan-3 mission and SpaDeX, an ISRO twin-satellite mission launched in 2025.

The outlook for the space economy through 2040 by the Organisation for Economic Co-operation and Development, a global policy forum, reflects that the transformation of the space sector needs partnerships across countries to address mutual challenges, developing contracts for commercial and public missions to ensure a safe space environment. Also, the space economy for both nations is crucial and thrives on collaboration, innovation and a collective vision. Amid evolving trade challenges, the need for a cohesive and collaborative strategy becomes even more compelling to advance the shared space ambitions of the U.S. and India.

Minimal tariff effects

The 2025-26 Union Budget in India reduced the customs duties on ground installations and satellite launches, along with goods for the manufacturing of launch vehicles, lowering the input costs and enhancing manufacturing and exports. India strategically shielded its space sector from tariff-related disruptions, maintaining resilience against escalating global trade tensions, according to Pawan Kumar Goenka, chairman of IN-SPACe, or the Indian National Space Promotion and Authorization Centre. Goenka said substantial reductions in tariffs on satellite launches, ground infrastructure and launch vehicle components have positioned India's space industry with a distinct competitive advantage in global sourcing. While minor procedural challenges persist concerning the import of certain components, Goenka emphasized that India's space sector remains largely unaffected by the tariffs affecting other industries. Space tech industry experts applauded the resilience over these shocks and see it as a combination of support, strategic sourcing, strong policy and expanding global partnerships.

As with any interdependent ecosystem, the space sector is vulnerable to cascading impacts across its value chain, ranging from procuring raw materials to fabricating radiation-hardened components, which poses a risk of detrimental effects for national space agencies and private enterprises. Escalating costs associated with government-backed initiatives, such as the Mars mission and NISAR, threaten to delay projects even further, which compounds existing challenges. At the same time, economic pressures risk diminishing startup competitiveness, constraining access to capital and ultimately slowing the momentum of transformative innovation within the global space economy. However, given that both India and the U.S. value space partnership, there is a strong need to shield it from any indirect

AS SPACE 2.0 RAPIDLY EVOLVES AMID UNPRECEDENTED TECHNOLOGICAL DISRUPTION, AND WITH AI EMERGING AS A FORCE MULTIPLIER, BOTH INDIA AND THE U.S. MUST ADOPT AN APPROACH THAT IS BOLD, ADAPTIVE AND FUTURE-READY.

tariff shocks through diplomatic engagements, exclusive exemptions, readjusting trade, and technological frameworks.

AI and space: missed opportunities

The space sector is witnessing a seamless fusion of AI and space technology, making strides in groundbreaking advancements in mission planning, autonomous navigation, astronomical dataset analysis, robotics and Earth observation. However, several untapped opportunities in space continue to exist for both countries where AI can be leveraged, particularly in energy solutions for space missions and space mining technologies.

In addition to the existing subsystems of the satellite, future satellites will be equipped with advanced computing and built-in AI infrastructure — such as graphics processing units and algorithms — to provide intelligence on the fly. To enable this, power remains a crucial design factor. Beta radiation from isotopes like tritium and nickel 63 can be alternatives for overcoming the power challenges in AI-enabled satellite design. NASA plans to use this breakthrough in ultrahigh energy density batteries for diverse future applications, including deep-space missions, CubeSats, autonomous power systems for spacecraft and satellite communications networks. A promising avenue for collaboration lies in the development and sharing of technology for AI-enabled deep-space missions, with energy potentially 100 times greater than that of conventional lithium-ion batteries over a 20-year lifespan.

Robots were on display at the India AI Impact Summit in February 2026 in New Delhi. The summit was billed as the world's largest AI event with about 250,000 people participating. AFP/GETTY IMAGES

AI has emerged as a key enabler for an ambitious area of space mining. While ISRO's current focus remains on lunar and Martian exploration, India, as a signatory of the Artemis Accords backed up by its strengthening AI ecosystem, is well-positioned to explore the growing area of asteroid mining. India has proven it can develop cost-effective space technologies (showcased through the SpaDeX mission and Aditya L1 solar mission), advancements in propulsion, material science and robotics. Combined with a robust space research pool and AI talent, these strengths provide a solid foundation for space mining capability. Developing advanced algorithms on existing hyperspectral and telemetry data, while integrating Chandrayaan and NASA's OSIRIS-Rex datasets, is a unique opportunity for creating predictive AI models for prospecting asteroids. Both countries also can explore intelligent mining solutions and in situ resource utilization to optimize processes for extraction and refining through the development of next-generation radioisotope thermoelectric generators that use heat as a source of energy. As global interest in asteroid mining intensifies, driven by its race toward rare minerals, India with the U.S. must gain strategic advantage by working bilaterally as key players in this next frontier of AI-enabled space exploration.

Conclusion

The trajectory of India-U.S. collaboration holds immense strategic and technological value in the global security landscape and in the Indo-Pacific. Fostering a vibrant and resilient space ecosystem that drives innovation, deepens collaboration and builds a sustainable value chain is no longer optional but imperative. As Space 2.0 rapidly evolves amid unprecedented technological disruption, and with AI emerging as a force multiplier, both India and the U.S. must adopt an approach that is bold, adaptive and future-ready. ✷

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AI DRIVES OPERATIONS IN SPACE

APOGEE STAFF

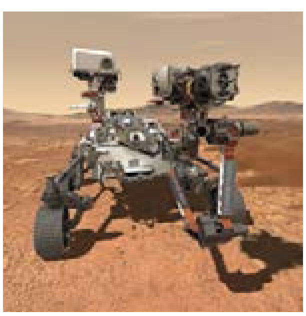
The use of artificial intelligence (AI) in space has grown exponentially from the space shuttle days (1981-2011), when it focused on basic automation, system checks and data processing to improve safety and operational efficiency.

AI now plays a crucial role in satellite collision avoidance, space exploration, enabling autonomous operations, and managing vast amounts of data from satellites and space telescopes. AI's future role in space is expected to grow both in use and complexity. Here is a graphic representation.

3

Astrobee free-flying robots aboard the International Space Station. The cube-shaped, AI-powered robots — Bumble, Honey and Queen — work autonomously to help astronauts take inventory, document experiments and move cargo.

Astrobee robot Bumble NASA



88

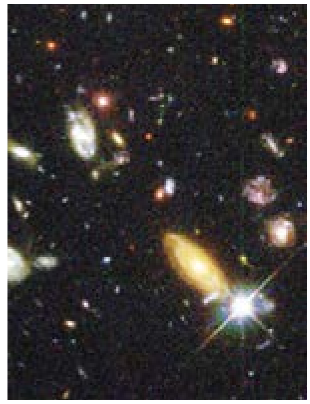
Autonomous driving operations directed by the Mars Perseverance rover's AI-powered AutoNav system.

Perseverance rover
NASA/JPL-CALTECH

301

New exoplanets identified since 2021 by NASA's ExoMiner AI system, which distinguishes real exoplanets from false positives in data collected by space telescopes.

Artist's concept of the hot sub-Neptune exoplanet TOI-421.
NASA, ESA, CSA, DANI PLAYER (STSCI)



98%

Accuracy in classifying galaxies through Morpheus, an AI-driven data-scanning tool used by astronomers and developed by researchers at the University of California, Santa Cruz.

Galaxies seen in a portion of the Hubble Deep Field image.
NASA, ROBERT WILLIAMS AND THE HUBBLE DEEP FIELD TEAM AT THE SPACE TELESCOPE SCIENCE INSTITUTE

9,021

Starlink satellites on orbit as of November 19, 2025, equipped with AI to avoid collisions, according to astronomer and astrophysicist Jonathan McDowell and SpaceX.

50,666

Starlink satellite collision avoidance maneuvers from June to November 2024, according to regulatory filings and media reports.

144,404

Starlink collision avoidance maneuvers from December 2024 to May 2025.

Starlink satellite SPACEX

$2.36 billion

Value of the global AI in space operation market in 2025, per data analytics firm Fortune Business Insights.

$11.35 billion

Projected global AI in space operation market by 2032.

NASA astronaut Anne McClain, a U.S. Army helicopter pilot and combat veteran, unpacks the first of three Astrobee robots, Bumble, at the International Space Station in April 2019. NASA