AIAA

Technologies Transforming Aerospace

Produced in partnership with AIAA by:

BRYCE TECH

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Contents

Introduction

Technology advancements have transformed aerospace over the last decades. Satellites once the size of a school bus are now the size of suitcases, commercial aviation is more fuel efficient and safer than ever, reusability and operational improvements have decreased launch prices and increased capabilities. We are now standing at an inflection point, with novel technologies that will permeate every layer of the aerospace supply chain over the next 10 to 20 years – increasing efficiency, enabling more missions with fewer resources, and transforming what is possible.

AIAA's *Technologies Transforming Aerospace* study draws on insights from the AIAA community to identify emerging technologies capable of disrupting the status quo, advancing the aerospace ecosystem, strengthening nations' strategic postures, and expanding the horizons of human exploration.

The technologies highlighted in this report will shape aeronautics and space over the next decades. These technologies will:

- Expand what is possible: hypersonic propulsion, quantum computing and sensing, space nuclear power and propulsion
- Improve operations and economics: alternative aviation fuels, electric aircraft, fully reusable space launch
- Enhance mission safety and performance: high-temperature materials, pilotless aircraft
- Amplify design capabilities: AI-aided advanced design and engineering, in-space manufacturing

AIAA conducted a survey of its 33,000+ members and combined the results with detailed interviews with senior technology leaders from across industry, government, and academia to identify innovations and technologies that will impact aerospace between 2025 and 2045. AIAA worked with BryceTech, an analytics and engineering firm, to analyze the results, ranking technologies based on their impacts, feasibility, use cases, and potential barriers.

To provide a deeper understanding of the type of impact each technology will have, survey respondents scored each across four potential impact areas:

Economic: technologies that will change the economics of the aviation and space industries, creating new markets, significantly lowering cost, transforming the value proposition, or dramatically improving operational efficiency.

Disruptive: technologies that will drive change in performance or alter the nature of the current aerospace ecosystem, disrupting the status quo.

Societal: technologies that enhance daily life or influence sustainability, workforce, or public engagement to advance how the public perceives the industry.

Strategic: technologies that set the national aerospace industry apart from international competitors, enhance national security, infrastructure, or technological leadership.

In spotlighting these ten technologies, we glimpse the beginnings of a brighter, more resilient aerospace era – one that will elevate the global air and space ecosystem and empower the innovators within AIAA to shape the future of aerospace.

> *"These technologies converge across both the air and space domains. They have the potential to reshape how society interacts with aerospace in the next 20 years."*
>
> – Clay Mowry, AIAA CEO

Technologies Transforming the Aerospace Industry

AIAA's *Technologies Transforming Aerospace* forecast identified ten technologies as most likely to shape aeronautics and space over the next twenty years. Presented in alphabetical order, these ten technologies offer a glimpse of the future to come.

AI-Aided Advanced Design and Engineering

From faster iteration to improved simulation: AI tools supercharge design and engineering, helping people deliver better tech at higher speed and lower cost.

Alternative Aviation Fuels

Keep the planes. Swap the fuel. Alternative aviation fuels, particularly sustainable aviation fuels (SAF), offer a pathway to net-zero carbon emissions by 2050 without redesigning existing aircraft.

Electric and Hybrid Aircraft

From downtown helipads to inter-city routes, electric and hybrid aircraft are redefining what's possible with quieter, cleaner, and more affordable air transport options.

Fully Reusable Launch

We don't toss out our cars after a trip to the supermarket. Why do it with rockets? Fully reusable launch vehicles will upend the cost equation of getting to space, opening new opportunities for commerce, national security, and exploration.

High-Temperature Materials

At the cutting edge of flight, heat is the challenge. Advanced high temperature materials protect advanced systems from extreme heat while enabling higher performance.

Hypersonic Propulsion

A new era of speed is dawning in aerospace. Hypersonic propulsion is poised to turbocharge air travel and unleash unmatched speed and range for modern defense.

In-Space Manufacturing

No civilization has ever expanded without learning how to build where it explores. Manufacturing in space transforms exploration from brief visits into sustained presence and more ambitious missions.

Pilotless Aircraft

For cargo and passengers alike, pilotless aircraft replace human limitation with machine precision, unlocking safer operations, lower emissions, and scalable air transportation.

Quantum Computing and Sensing

Exploiting the quirks of quantum mechanics, quantum technology promises to exponentially increase our existing computational capabilities and unlock the potential of the quantum world, transforming how we understand our own.

Space Nuclear Power and Propulsion

From lunar resource mining to dramatically reduced transit times to Mars, space nuclear technologies create possibilities that simply do not exist with today's means of powering spacecraft.

AI-Aided Advanced Design and Engineering

From faster iteration to improved simulation: AI tools supercharge design and engineering, helping people deliver better tech at higher speed and lower cost.

What is it?

AI-aided advanced design and engineering applies artificial intelligence (AI) and machine learning to enhance the design and engineering process for complex systems such as aircraft, spacecraft, and associated infrastructure. These technologies enable engineers to quickly explore innovative design trade spaces and identify more efficient or effective designs.

AI will serve as a powerful partner in the engineering process, integrating with and extending engineering tools and methodologies. Examples include quickly filtering design options in model-based systems engineering, and integrating processing simulation and digital twin data to identify potential weaknesses. It can also help aggregate and organize engineering, simulation, and test data into a living and traceable digital archive, sometimes called a digital thread, across the product lifecycle. Finally, it helps explore more possibilities, reduce mistakes, and make smarter choices. The result is engineering processes that take less time, enable development at a lower cost, and improve system safety and reliability.

What are the impacts?

- **Economic:** Reduce development time and cost, increasing innovation, and enabling more efficient, higher-performance products
- **Disruptive:** Shift engineering from a slow iterative process to a rapid, data-driven one that can upend cost models, timelines, and increase competitive advantage
- **Societal:** Change the role of an engineer as AI develops to be a partner, and accelerate development of safer, more affordable, and more sustainable technologies
- **Strategic:** Shorten technology development timelines to maintain edge, connect missions to the engineering process, and help detect vulnerabilities in systems and infrastructure

Pathway to Realization

Human-AI Collaboration
Effective collaboration will unlock AI's full potential while supporting accountability and expertise

Digital Infrastructure
Mature, secure, standardized architectures allow AI to learn more effectively

Physics-grounded
Embedding physical laws enables trust and adoption for safety-critical engineering programs

Enablers

Barriers

Trust
AI-aided engineering must be proven to produce safe and reliable designs

Data Availability
Engineering data are often scarce, fragmented, or classified

Workforce Adaptation
Shifting from traditional methods challenges skills, training, culture, and processes

2045

In the short-to-medium term, AI-aided advanced design and engineering will likely evolve from a supportive tool into a core industrial capability. Building on the current state, AI will continue to augment human engineers by accelerating analysis, simulation, and design. AI may become embedded across the full engineering lifecycle, linking design, manufacturing, testing, operations, and disposal through continuously learning digital twins. Ultimately, trusted AI may enable partially autonomous design and optimization, delivering faster development, lower costs, and generating an industrial competitive advantage at the global level.

Use Cases

Near-term: AI tools will increasingly be used to augment an engineer's work. Augmentation will be driven by cost and schedule pressures, with AI used where risk is lowest, focusing on data quality, model validation, and workforce augmentation.

Longer-term: AI is increasingly embedded in engineering education and across the engineering lifecycle. Digital twins continue to mature, with AI systems learning more from flight and operational data and regulatory regimes adapting to AI-generated data. Use of AI likely broadens from the system level to the architecture level, resulting in faster, integrated development of constituent elements.

Future-forward: AI-aided engineering approaches at least partial autonomy, proposing systems and architectures with minimal human intervention. Organizations and even nation-states that master integration of AI for engineering and design gain advantages that inform economic growth and national security capabilities, translating into global technological leadership.

The Tech Stack

The AI-aided design and engineering technology stack can be viewed as an artificial engineering assistant at the system level, with AI-enabled tools and components in the tiers below them.

Tier 1
System
Artificial engineering assistant (suite of tools used to support AI-aided advanced design and engineering technologies)

Tier 2
Subsystems
Digital twins
Model-based systems engineering tools
Physics-informed models

Tier 3
Assemblies
Large language models
Physics-informed neural networks
Design and surrogate models (codes used to make the tools work)

Tier 4
Components and Parts
Transformer architectures
Optimization algorithms
Training frameworks
Data organization
Libraries
Computer-aided engineering kernels

Tier 5
Hardware and Materials
Engineering data
Processors
Memory and data storage

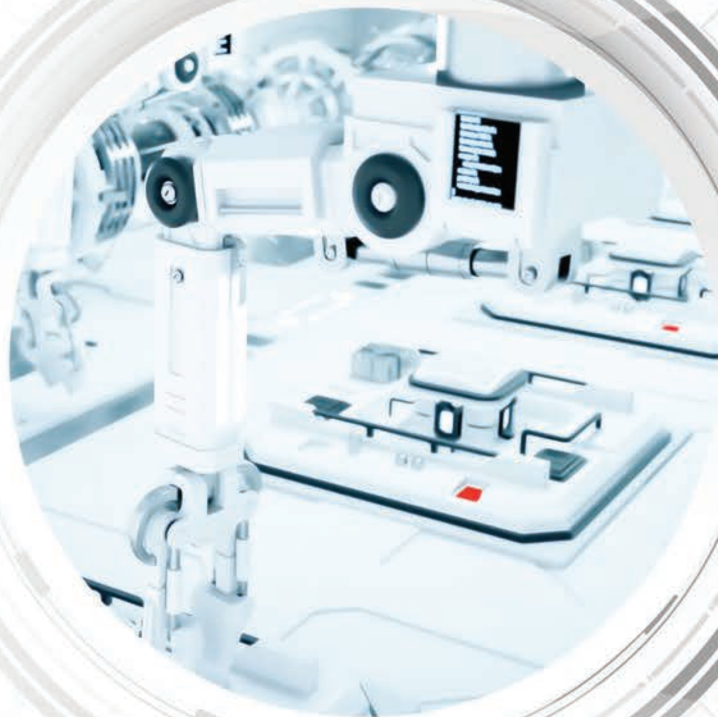
The Developers

Government and commercial organizations are motivated to develop and mature AI-aided engineering tools for the potential to make critical systems and architectures safer, more affordable, and more sustainable.

The leading developers of AI-aided advanced design and engineering are software companies, with support from a mix of government agencies and other technology firms. Companies are using digital models of entire systems to manage resources and schedules. Sometimes called “digital engineering,” this work became a foundation for how complex systems are conceived. Prominent computer-aided engineering software players have been rapidly integrating AI into engineering tools, resulting in a culture that sees AI as intelligent design partners. Advanced AI research is also being pursued by AI companies with a focus on powerful reasoning and optimization models that can aid in engineering disciplines.

$10s of billions
AI-enabled design and engineering tool market size

150+
Start-up companies developing AI-enabled design and engineering tools



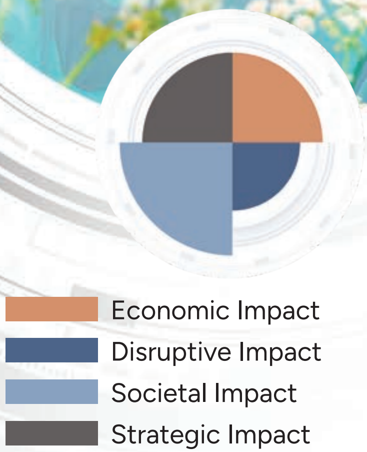
Alternative Aviation Fuels

Keep the planes. Swap the fuel. Alternative aviation fuels, particularly sustainable aviation fuels (SAF), offer a pathway to net-zero carbon emissions by 2050 without redesigning existing aircraft.

What is it?

Over 360 airlines (representing 80% of global air traffic) have committed to net-zero CO_2 emissions by 2050. SAFs are the alternative fuels set to transform the emissions impact of air travel in the next decades. SAFs are jet fuel's more eco-friendly twin: they look the same, act the same, but come from renewable sources like biomass, waste, or even captured carbon instead of crude oil.

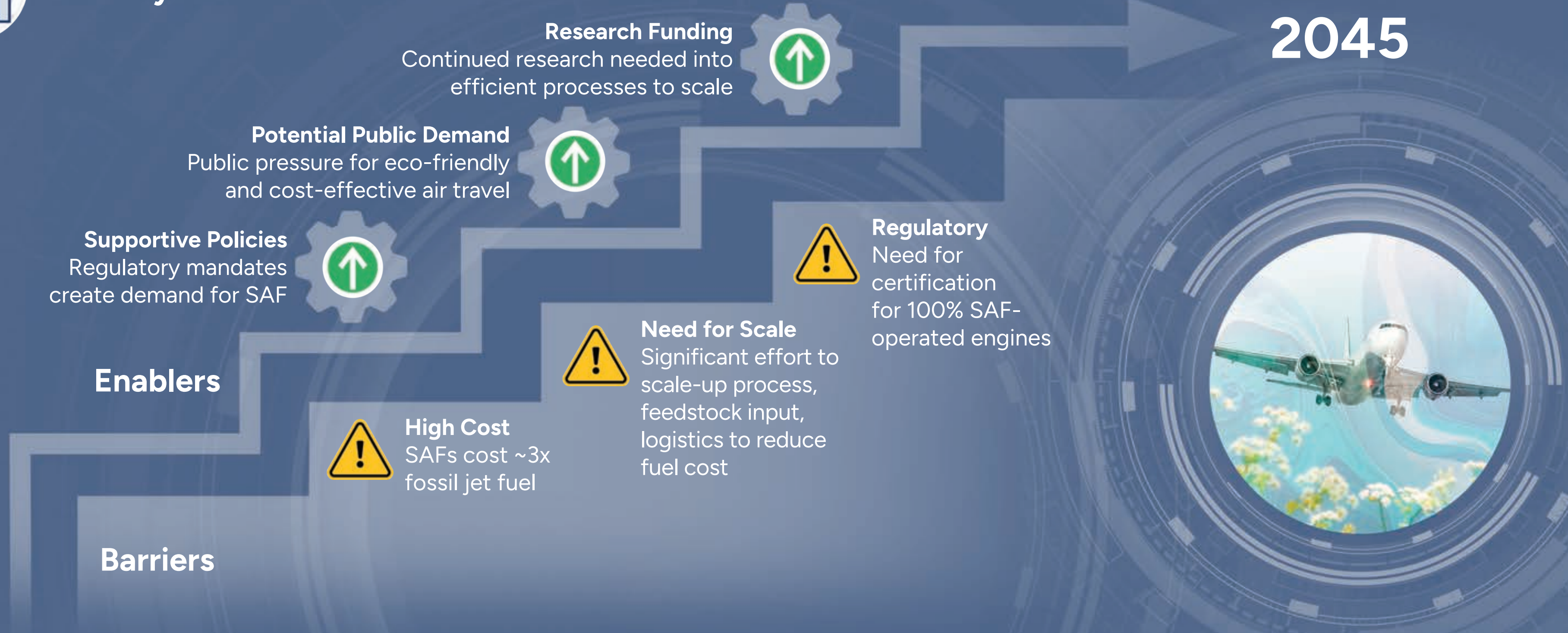
As "drop-in" fuel replacements that can be blended with or completely replace current jet fuel in existing aircraft engine technologies, SAF impacts are unlikely to be seen directly by the public. However, SAF has the potential to reduce greenhouse gas emissions by up to 94%, helping airlines achieve their net-zero targets. Other alternative aviation fuels are in development, including hydrogen, but the pathway for implementation of those technologies is likely beyond the 2045 horizon.



What are the impacts?

- **Economic:** More eco-friendly aviation without the cost of redesigning aircraft
- **Disruptive:** "Drop-in" quality of SAF allows for smooth transition to new fuels
- **Societal:** Potential to reduce environmental impact of air travel, helping airlines achieve net-zero CO_2 commitments
- **Strategic:** Allows for transition to domestically produced biofuels in place of imported fossil fuels

Pathway to Realization



Currently there are eight certified technology processes for producing SAF that are being tested by airlines. The International Air Transport Association (IATA) has adopted a phase-in plan to test and implement 100% unblended SAF with minor technical developments such as SAF compatible seals.

Use Cases

Near-term: SAFs are compatible with existing aircraft and fueling infrastructure, and governments are already mandating SAF blends. The EU requires SAF blending levels starting at 2% in 2025 and rising to 70% by 2050.

Longer-term: While SAF blends are currently capped at up to 50%, 100% SAF flights have already been demonstrated, with Emirates flying an A380 fueled with SAF in 2023.

Future-forward: Hydrogen promises to be a long-term alternative fuel for aviation; research will continue to demonstrate technical advances required for hydrogen.

The Tech Stack

The tech stack for an operational SAF is composed of subsystems typical of aircraft, the "drop-in" quality of SAF means minimal changes to existing aircraft fuels systems and engines. Tier 5 in this case includes producers of biomass that are typically not included in the aerospace ecosystem.

Tier 1
System

Aircraft

Tier 2
Subsystems

Jet turbine engine (minimal changes needed)

Tier 3
Assemblies

Combustor

Fuel distribution system

Turbines

Tier 4
Components and Parts

Sustainable aviation fuels

Tier 5
Hardware and Materials

Biomass, municipal solid waste, agricultural residue

Natural gas

Power

The Developers

One hundred and seventy-eight airports are currently distributing SAF, with global production of SAF doubled to 1 million metric tons (Mt) from 2023 to 2024 and were expected to reach 2 million Mt in 2025. Despite its production growth, SAF currently only represents 0.7% of global jet fuel use. Since 2010 in the US, more than 100 companies have announced development of SAF production facilities, with $14.4B in investment. Aircraft and engine manufacturers are partnering with those companies and other researchers to test higher percentage SAF blends in existing aircraft. Furthering the development and testing of this technology, several engine developers have been testing 100% SAF-powered engines for future use. Testing and regulatory approval is being achieved for using SAF blends in military aircraft. Beyond SAF, researchers in academia and industry are developing hydrogen combustion technologies for aircraft.

>100
Companies developing SAF production facilities in the US

$14.4B
Investment in US SAF production facilities

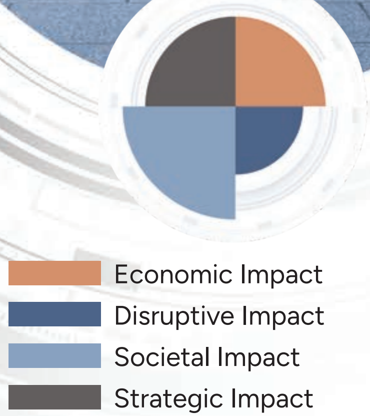
Electric and Hybrid Aircraft

From downtown helipads to inter-city routes, electric and hybrid aircraft are redefining what's possible with quieter, cleaner, and more affordable air transport options.

What is it?

The flight path for zero emission aviation includes clean fuels and electric aircraft. Electrification efforts are occurring on two fronts: vertical take-off and landing (VTOL) advanced air mobility (AAM) concepts and modernization of current conventional take-off and landing aircraft.

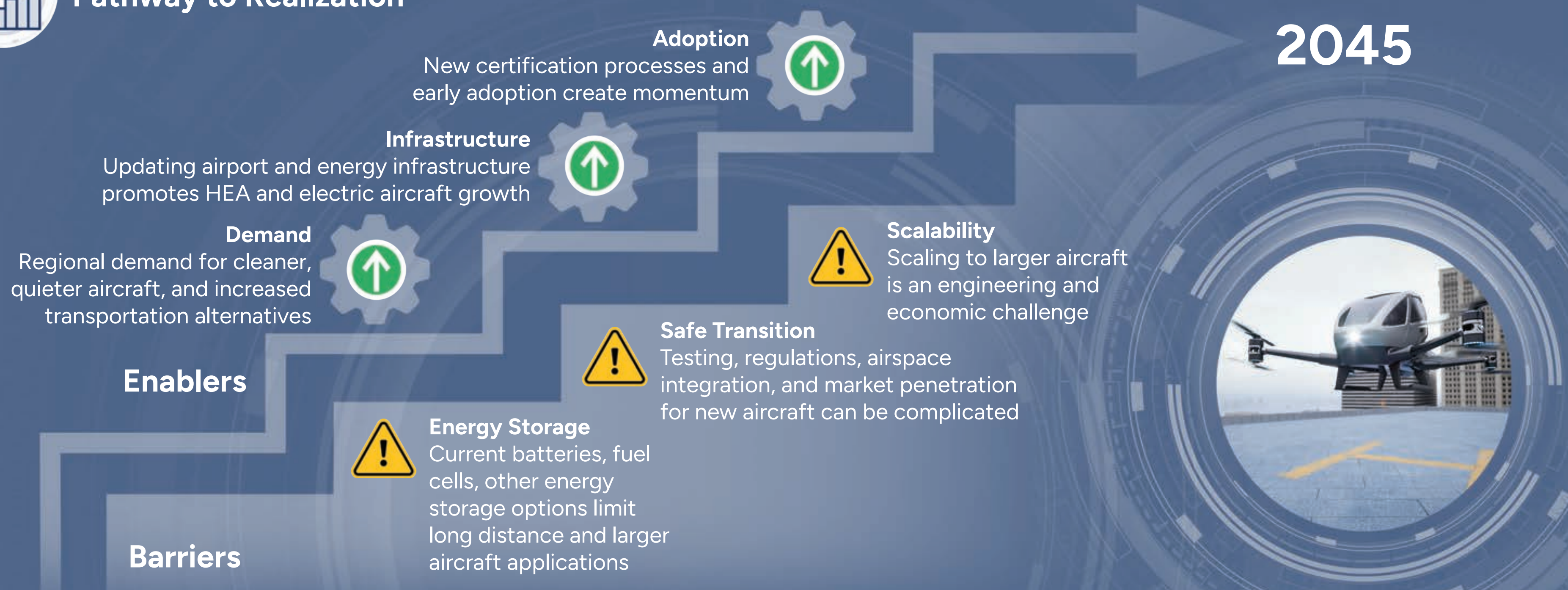
Hybrid-electric aircraft (HEA) use a mix of fuel combustion and electric power for propulsion, managed by an onboard computer to maximize efficiency. They can dynamically swap power sources in flight, such as using batteries during take-off and landing to power loads and reduce noise. Electric aircraft use batteries, fuel cells, or other energy storage exclusively for all phases of flight. Due to current energy storage limitations, most commercial aviation electrification efforts are focused on very short-haul and regional routes.



What are the impacts?

- **Economic:** Reducing jet fuel cost for short-haul flights, enabling more cost-effective regional flights, potentially increasing demand and activity at smaller, more distributed airports
- **Disruptive:** Initial strong impact on regional aviation, with the long-term potential to disrupt transportation networks and airport infrastructure
- **Societal:** Cleaner and quieter operations near airports and over population centers, shift in airport use and/or production of energy
- **Strategic:** Improved flexibility, logistics, and operational energy resilience

Pathway to Realization



Introduction of piloted HEA and fully electric aircraft for small regional and training aircraft is expected to emerge later this decade. A shift to small regional HEA with 30–70 seats may occur during the next ten years with battery improvements, testing, and certification. Limited penetration into some markets served by regional airlines may take place toward the 2040s through hybrid-turbine architectures. Progress will depend on three equally important developments: improved technologies including batteries, fuel cells, and motors; certification and regulations; and large-scale investment in airport infrastructure to enable rapid charging and long runways for electric take-off of larger airframes.

Use Cases

Near-term: Development of piloted HEA and electric vehicles carrying 10–20 passengers expected to continue, with some potentially entering commercial service to support regional air routes.

Longer-term: With additional development in energy storage and advanced materials, time to introduce new aircraft among fleets, and growing acceptance from small-scale demonstrations, larger aircraft capable of carrying 30–70 people and significant cargo loads will be introduced. Autonomous HEA and electric systems may also emerge.

Future-forward: By 2045, HEA and electric aircraft could be operational across many short- and medium-haul routes, delivering quieter operations, lower emissions, and reduced operating costs, even as conventional engines continue to dominate long-range aviation.

The Tech Stack

HEA require an augmentation of the traditional aircraft tech stack with integrated hybrid-electric components and energy management systems. All-electric aircraft replace the propulsion subsystem with energy storage and electric motors.

Tier 1
System

Hybrid and electric aircraft

Tier 2
Subsystems

Propulsion

Power

Tier 3
Assemblies

Batteries, fuel cells, and powertrains

Fuel tanks and distribution system

Tier 4
Components and Parts

Hydrocarbon fuels

Sustainable aviation fuels

Battery cells

Anodes and cathodes

Fuel cell membranes

Tier 5
Hardware and Materials

Hydrogen, lithium, manganese, cobalt, nickel, cadmium, lead, neodymium, samarium

Potentially emerging chemistries: graphene, sulfur, hybrid electrolytes

The Developers

Worldwide, HEA and fully electric aircraft are in an intense R&D and early-demonstration phase, with a few hundred projects underway and several dozen serious developers. On the public-sector side, NASA's Electrified Powertrain Flight Demonstration (EPFD) program, along with European Clean Aviation programs, are targeting megawatt-class HEA and electric demonstrators for 2030–2035 entry into service, supporting large-aircraft research. The current global electric aircraft market is estimated to be about $10–12B with projections into the tens of billions of dollars by the early 2030s. Together, these metrics point to a crowded, global pre-commercial phase where many concepts will likely consolidate, but where the underlying technological and investment momentum is clearly accelerating.

300+
Electric aircraft projects globally

200+
Electric aircraft start-ups worldwide

Fully Reusable Launch

We don't toss out our cars after a trip to the supermarket. Why do it with rockets? Fully reusable launch vehicles (RLVs) will upend the cost equation of getting to space, opening new opportunities for commerce, national security, and exploration.

What is it?

Historically, launch vehicles have used multiple expendable stages, each consisting of engines and tanks (i.e., boosters), to shed empty mass as fuel is consumed. This approach allows the remaining vehicle to accelerate more efficiently to orbit.

Efforts to build fully-reusable launch vehicles date to the late 1960s. The Space Shuttle demonstrated a reusable orbiter and solid rocket boosters; however, refurbishment requirements drove high costs. Since 2015, fly-back and later reuse of first stage boosters has been demonstrated. This simpler, partially-reusable design approach has proven far more successful in reducing complexity and launch expense, and new providers are introducing partially reuseable systems. Moving forward, fully-reusable second stages and payload fairings (the aerodynamic shell that protects the spacecraft during launch) aim to lower launch costs further. Research is also underway to develop a reusable single-stage-to-orbit (SSTO) system, an integrated spaceplane that does not shed stages, which could further evolve the economics of spaceflight.

What are the impacts?

- **Economic:** Dramatically lower launch costs and payload-return capability will help close business case for markets like in-space manufacturing and tourism
- **Disruptive:** Inexpensive rides to orbit could revolutionize satellite constellation design and deployment strategies
- **Societal:** Lower launch cost could enable growth of new consumer services like satellite to smartphone service
- **Strategic:** Enabled satellite constellations provide strategic benefits; lower costs opens new possibilities for responsive space and exploration missions

Pathway to Realization

Enablers

Investment
Significant funding can drive materials breakthroughs

Complementary Hardware
Last-mile transport tugs and in-space infrastructure, including refueling, will widen use cases

High Launch Cadence
Frequent launches and large payload backlogs amortize development and refurbishment costs

Barriers

Materials
Challenges developing lightweight, robust re-entry heat shielding

Reduced Capacity
Recovery hardware, extra propellant for fly-back/landing and stronger structures reduces size or number of payloads carried

Reliability
Demonstrating consistent performance across multiple flights requires extensive data and process maturity

2045

The next major step in rocket reusability is recovering second stages and payload fairings, which will require advances in lightweight, heat-resistant materials to survive re-entry intact. Future SSTO vehicles offering same-day reuse and airplane-like operations also will require propulsion breakthroughs as well as development of in-space refueling capabilities.

Use Cases

Near-term: Vehicles supporting ultra-low-cost satellite deployment and replenishment, along with payload retrieval, return, and recovery from low Earth orbit (LEO).

Longer-term: Vehicles providing transport to in-space destinations, rapid point-to-point cargo delivery, and increased cadence of payload return from LEO.

Future-forward: Vehicles with airplane-like operations for highly responsive payload deployment and return, and point-to-point passenger transport.

The Tech Stack

In the near term, RLVs will require integration of reusable upper stages and cargo bays with existing reusable first stages and associated recovery infrastructure. SSTO RLVs will require new propulsion systems integrated into lightweight, high-strength vehicles possibly equipped with wings and landing gear.

Tier 1
System

Fully reusable launch vehicle

Tier 2
Subsystems

Highly throttleable, multiple-restart propulsion
Thermal control
Precision powered flight control
Landing subsystem

Tier 3
Assemblies

Non-ablative heat shielding
Lightweight fuel tanks and associated plumbing
Aerodynamic control surfaces
Avionics
Landing gears/struts

Tier 4
Components and Parts

Mechanical parts and structures
Fluid and propulsion parts
Thermal control parts
Miscellaneous precision components
Software/firmware modules

Tier 5
Hardware and Materials

High energy propellants
Advanced, heat-resistant composite or ceramic materials
High strength, lightweight structural materials

The Developers

Upwards of 50 companies around the world are developing vehicles with at least partial reusability. These include developers in the United States, Europe, Japan, India, and China. One company has achieved routine first stage reusability with its heavy lift rockets and is working on full reusability for its in-development super-heavy-lift vehicle, currently undergoing flight testing. Other companies are achieving milestones toward partial and full reusability, including aiming minimal to no refurbishment between launches. The European Space Agency, is also pursuing full reusability and has contracted with companies for design work on a reusable upper stage.

50+
Companies developing partially or fully reusable launch vehicles worldwide

4
Partially reusable launch vehicles in service

High-Temperature Materials

At the cutting edge of flight, heat is the challenge. Advanced high temperature materials protect advanced systems from extreme heat while enabling higher performance.

What is it?

High-temperature materials solve a common problem for hypersonic flight, space nuclear power, atmospheric reentry from space, and next-generation high-performance engines: management of temperatures that push the physical limits of existing materials, typically well above 2,000˚F. This puts ever-increasing demands on scientists to come up with new materials that combine heat tolerance with ultralightweight and high strength, attributes which are often at odds.

The materials getting the most attention from researchers fall into three categories: superalloys, including refinements of existing titanium-based alloys and NASA's GRX-810; ceramics, primarily in the form of ceramic matrix composites; and advanced composites such as carbon-carbon. These materials can be used for high-performance jet and rocket engine components; nuclear power and propulsion fuel, structural, moderator, and refractory materials; airframes and leading edges for hypersonic vehicles; and robust, non-ablative heat shielding for atmospheric reentry from space, a key challenge in the quest to make launch vehicles fully reusable.

What are the impacts?

- **Economic:** Components made of new heat-resistant materials will lower aircraft and rocket operating costs by lasting longer and reducing fuel consumption
- **Disruptive:** Ultra-high temperature capable materials will enable reusable spacecraft, higher-energy missions, and faster, more frequent access to space through dramatically improved performance
- **Societal:** High efficiency engines enabled by new components could increase aviation accessibility and sustainability
- **Strategic:** Heat-resistant materials enable capabilities of strategic importance for precision strike and lower cost reusable launch

Pathway to Realization

2045

Enablers

Reducing Cost
Implementation of manufacturing strategies designed to reduce costs and produce materials that are light, strong, and heat-resistant

Advanced Development
AI-powered digital design and simulation tools are key to designing viable materials

Investment
Government and commercial funding is advancing research and testing on heat-resistant aerospace materials

Barriers

Integration
Ceramic composites and similar materials don't easily bind or work with existing metal systems

Resiliency
Many advanced materials are good at carrying load but poor at stopping cracks once they start

Policy
Producing new aerospace materials raises environmental concerns that can be reduced through mitigative and supportive policies (e.g., cleaner production, recycling mandates)

Pushing the design and engineering of the next generation of super alloys, ceramic, and advanced composites will require creativity and innovation, including use state-of-the-art computer-aided design and engineering tools, AI, and advanced manufacturing techniques in the production of lightweight, high-strength materials capable of tolerating temperatures higher than 2,000˚F. Examples of these techniques include 3D printing; precursor infiltration, or filling a sponge-like material with the ingredients needed to form something stronger and more durable (e.g., a porous carbon fiber weave infiltrated with a liquid or gaseous resin); and pyrolysis, the breaking down of a substance without burning it.

Use Cases

Near-term: Advanced heat-resistant materials will be used in hypersonic missiles, rocket engines, and reusable spacecraft heat shields, helping vehicles survive extreme temperatures while improving efficiency and reuse.

Longer-term: Lightweight, heat-resistant structural components will be used for space nuclear power and propulsion systems, particularly for heat shielding and nozzles.

Future-forward: Advanced heat-resistant materials enable larger-scale hypersonic air transportation, as well as structures and reentry shielding needed for fully reusable launch vehicles.

Tech Stack

Heat-resistant materials form a layered tech stack, from thermal protection subsystems to assemblies like heat shields, enabled by engineered components. Ultimately, materials like raw carbon or graphite fibers combined with resins ensure performance, scalability, and cost in extreme temperature environments.

Tier 1
System

Aircraft or spacecraft

Tier 2
Subsystems

Airframes & leading edges
Reentry heat shields
Jet and rocket engines
Thermal protection systems
Rocket fairings
Fission systems

Tier 3
Assemblies

Control surfaces
Wings
Engine manifolds
Engine combustion chambers
Engine nozzles

Tier 4
Components and Parts

Wing struts
Turbine blades
Valves
Injectors
Combustors
Thermal panels

Tier 5
Hardware and Materials

Metals: Titanium, nickel, cobalt, tungsten, molybdenum
Super alloys
Ceramics: Silicon carbide, alumina
Composites: Graphite, carbon-carbon

The Developers

Hundreds of organizations worldwide are racing to develop the next generation of heat-resistant aerospace materials, spanning government labs, universities, and private industry. In the United States, breakthroughs are emerging from national research centers like NASA's Glenn and Ames Research Centers, the Air Force Research Laboratory, and the Department of Energy's Oak Ridge and Sandia National Laboratories. University teams frequently work alongside these labs, helping move new materials from theory to application. Industry plays a critical role as well, with companies translating research into flight-ready solutions. All of these organizations are pushing the boundaries of what aerospace materials can withstand, shaping the future of high-speed flight, reusable spacecraft, and extreme-environment engineering.

~8-12
Time in years from development to flight-qualified for heat-resistant materials

~15%
Share of reusable spacecraft landing mass dedicated to thermal protection

Hypersonic Propulsion

Economic Impact
Disruptive Impact
Societal Impact
Strategic Impact

A new era of speed is dawning in aerospace. Hypersonic propulsion is poised to turbocharge air travel and unleash unmatched speed and range for modern defense.

What is it?

Hypersonic propulsion enables vehicles to fly at speeds exceeding five times the speed of sound (Mach 5). Historically, rocket boosters have been the primary form of hypersonic propulsion, used in ballistic missiles, interceptors, and space launch. Rocket engines, however, are inefficient for sustained hypersonic flight through the atmosphere, driving the development of new air-breathing propulsion systems, including scramjets, ramjets, and turbine or rocket combined-cycle engines. Of these emerging systems, scramjets are used in existing hypersonic weapons and the rotating detonation engine (RDE) is the most promising future technology.

A scramjet is an air-breathing jet engine that produces thrust by combusting fuel in supersonic airflow as a vehicle travels at hypersonic speeds. An RDE uses continuously spinning shock waves to burn fuel more efficiently than conventional alternatives, promising higher performance and lower fuel consumption than other hypersonic engine technologies. By squeezing more energy out of the same amount of fuel, they are more effective than conventional options, resulting in longer ranges, larger payload capacities, and higher maneuverability. RDEs are expected to enable smaller, lighter, and more powerful propulsion systems, unlocking sustained hypersonic flight, reusable launch vehicles, and next-generation missiles.

What are the impacts?

- **Economic:** Maximized efficiency, particularly from RDEs, could enable dramatically lower operating costs for hypersonic propulsion
- **Disruptive:** Effective hypersonic propulsion can transform defense and air-travel, by enabling hard-to-intercept weapons and ultra-fast global transportation
- **Societal:** Sustained hypersonic flight, if made affordable, could revolutionize air travel by potentially cutting flight times for long distance routes by more than 90%
- **Strategic:** As a national security imperative, hypersonic propulsion development could enable new strike capabilities for a country's defense

Pathway to Realization

Investment
Push from government to increase funding for testing, system integration, and transition to operational hardware

Sensors
Improved sensing, modeling, and control; integrated systems design and precise control timing

Test Facilities
Long-duration testing facilities with high-enthalpy ground rigs to recreate the extreme heat, chemistry, and flow physics

Enablers

Systems Integration
Efficiently and safely coupling engine with airframe; certification of system

Materials
Developing materials capable of surviving extreme temperatures, pressures, and shock loads over operational lifetimes

Stability
Scramjets can be difficult to ignite and control, and keeping RDE detonation waves steady across a wide range of conditions is difficult

Barriers

2045

While several hypersonic propulsion technologies show real promise, they face major technical challenges, particularly regarding thermal loads. Scramjets have some use in missiles but there is strong demand for next-generation hypersonic engines like RDE. Increasing collaboration between industry and government means that RDEs could begin appearing in military weapons and platforms within the next 10 to 20 years.

Use Cases

Near-term: Hypersonic weapons using scramjets will continue to be developed and refined. RDE propulsion will transition from small-scale engineering models to large-scale hardware. These will likely progress from laboratory and ground-test demonstrations to niche operational use, driven by military applications where efficiency gains justify technical risk.

Longer-term: Applications stretch beyond missiles and rockets into marine engines and drones, especially as RDEs experience gradual maturation through materials breakthroughs, improved control, and system integration.

Future-forward: Research and development, combined with very limited application in operational scenarios, may enable adoption in missiles, high-speed aircraft, and possibly commercial air transportation, advanced space launch, or propulsion systems.

The Tech Stack

Hypersonic propulsion, including RDEs, functions as a subsystem within an integrated hypersonic vehicle. To achieve sustained Mach 5+ flight, these propulsion subsystems require effective thermal management, combustion control, and precise integration with structural components and high-temperature materials.

Tier 1
System

Aircraft or missile

Tier 2
Subsystems

Engine (RDE, scramjet)

Thermal Management

Flight control/avionics

Tier 3
Assemblies

Combustion assembly (Detonation chamber, fuel-oxidizer)

Cooling

Tier 4
Components and Parts

Nozzles and valves

Sensors (temp, pressure, vibrations)

Detonation igniter

Tier 5
Hardware and Materials

High temperature ceramics and other materials

Thermal barrier coating

The Developers

With more than 50 companies worldwide developing hypersonic technologies and weapons, the hypersonic propulsion landscape is highly competitive. Roughly 30% of these are developing RDEs, reflecting demand for efficient, compact, and powerful engines. Both aerospace giants and start-ups are advancing hypersonic propulsion. Beyond commercial companies, US military laboratories are pursuing hypersonic propulsion, including RDEs for use in platforms and weapon systems. For example, the US Navy is researching RDEs as a potential replacement for, or enhancement to, traditional gas-turbine propulsion systems aboard naval vessels and aircraft, while the Air Force is developing reusable hypersonic drone platforms. International collaboration is also underway, with the Harnessing Hydrogen's Potential with Rotating Detonation (H2POWRD) consortium bringing together 18 academic, research, and industry partners focused on developing hydrogen-fueled RDEs for high-performance hypersonic systems. Collectively, these efforts highlight the growing global investment and innovation in hypersonic propulsion.

~50
Companies developing hypersonic propulsion

15
Companies focused on commercial RDEs

In-Space Manufacturing

No civilization has ever expanded without learning how to build where it explores. Manufacturing in space transforms exploration from brief visits into sustained presence and more ambitious missions.

What is it?

In-space manufacturing is the production of goods, structures, components, and systems in orbit or on planetary surfaces for customers in space and on Earth, using a combination of people, autonomous robotics, and digitally-driven processes designed to take advantage of the unique characteristics of space. Building things in space is expected to shift space systems from being launch-limited products to adaptable, upgradable elements, supporting commercial platforms, national security missions, and long-duration human exploration.

In-space manufacturing leverages the unique characteristics of space to support production of mechanical and biological materials for use on Earth, such as the growth of high-purity crystals, advanced semiconductors, pharmaceuticals, and complex human tissues like retinas, whose quality, yield, or functionality can be enhanced in microgravity. It also includes the on-orbit fabrication and assembly of large engineered systems like satellites and other hardware that are impractical or inefficient to launch fully assembled from Earth, as well as manufacturing on planetary bodies to support sustainable surface operations.

What are the impacts?

- **Economic:** Shifts value from launch-limited hardware to scalable, in-space production of high-performance systems and materials
- **Disruptive:** Enables entirely new systems, materials, and biological products, potentially upending existing industrial, logistics, and business models
- **Societal:** Produces more capable satellites, breakthrough medical and materials research, and resilient space infrastructure that improves life on Earth and lays the foundation for a sustained human presence in space
- **Strategic:** Extends industrial capacity beyond Earth, enhancing strategic resilience, technological leadership, and freedom of action in space

Pathway to Realization

2045

Enablers

Transportation
Movement of large amounts of mass to and from space incentivizes in-space production and recycling

Standard Interfaces
Regular transport, standardized interfaces, and abundant energy make sustained operations possible

Autonomy
Continuous, safe robotic manufacturing in space, overcoming distance, latency, and cost constraints

Barriers

High Risk
Launch, operations, and failure tolerance remain extensive

Policy
FDA approval for space-manufactured medical devices, policy questions on ownership rights in space, and planetary protection concerns

Market Uncertainty
Subsidized launches for tech demos to International Space Station (ISS) ending soon, a potential barrier for future start-ups

In-space manufacturing will likely progress from technology demonstration missions to operational, economically meaningful activity through validation, scalability, and integration. The objective during the next two decades will be to shift from launch-dependent missions to autonomous, space-based industrial ecosystems capable of providing products for use on Earth and supporting large-scale manufacturing and assembly of systems and structures in space.

Use Cases

Near-term: Governments, commercial, and academic players continue to focus on de-risking, exploring, and validating additive manufacturing, biomanufacturing, and robotic assembly at a relatively small scale. Emerging space logistics networks likely to support this activity continue to grow, from orbital transfer vehicles to satellite servicing.

Longer-term: These capabilities will be integrated into operational platforms that manufacture, assemble, repair, and upgrade spacecraft and infrastructure in space, reducing dependence on Earth launch and enabling more resilient national security and commercial systems. Products manufactured in space for use on Earth may find markets, driving demand or scaled capabilities.

Future-forward: In-space manufacturing could become an integrated element of space infrastructure itself, extending from low-Earth orbit (LEO) to cislunar space and on the surfaces of other planetary bodies, enabling systems that are designed from inception to be built, repaired, and enhanced to support a persistent, adaptable, space-based ecosystem.

The Tech Stack

In-space manufacturing platforms will vary considerably in design, depending on objectives and level of autonomy. Examples include an autonomous robotic platform or a dedicated element of a space station or surface installation. Uniquely, platforms will produce lower tier products for themselves and other systems, shifting space infrastructure from launch-dependent to self-expanding, adaptive industrial ecosystems.

Tier 1
System
In-space manufacturing platform

Tier 2
Subsystems
Manufacturing and processing
Robotic assembly & handling
Autonomy, control, and digital manufacturing
In-space logistics and material handling
Health monitoring

Tier 3
Assemblies
Robotic arms and end-effectors
Manufacturing heads
Material feedstock storage and transfer assemblies
Measurement and inspection units
Docking, berthing, and payload handling mechanisms

Tier 4
Components and Parts
Mechanical parts and structures
Fluid and propulsion parts
Thermal control parts
Miscellaneous precision components
Software/firmware modules

Tier 5
Hardware and Materials
Feedstocks
Metals, specialty alloys, composites, ceramics
Electronics and semiconductors
Chemicals
Adhesives, sealants, coatings

The Developers

In-space manufacturing is being driven by a mix of commercial start-ups, established aerospace firms, and government space agencies, each targeting different parts of the market. In the commercial sector, companies are advancing in-space additive manufacturing, satellite assembly, and microgravity production of high-value materials and pharmaceuticals. Larger aerospace primes are focusing on supportive capabilities, integrating robotic assembly, servicing, and modular spacecraft concepts into future architectures. Government agencies are funding demonstrations, operating orbital platforms, and setting requirements, while emerging efforts among other spacefaring nations (e.g., UAE) indicate growing global interest. Together, these groups are shifting in-space manufacturing from an experimental capability to an industrial ecosystem addressing engineering, materials, and biomanufacturing needs.

~$3B
Estimated amount of investment in in-space manufacturing worldwide

~80
Companies worldwide developing in-space manufacturing capabilities

Pilotless Aircraft

For cargo and passengers alike, pilotless aircraft replace human limitation with machine precision, unlocking safer operations, lower emissions, and scalable air transportation.

What is it?

Pilotless aircraft operate without a human pilot onboard and are controlled either remotely or autonomously. Pilotless passenger and cargo aircraft potentially offer significant advantages by enabling highly reliable autonomous flight operations that can be networked into the National Airspace System (NAS) allowing continuous real-time system monitoring that improves safety and predictability. In addition, pilotless operation is a feature of many advanced air mobility (AAM) concepts, which feature electric or hybrid-electric, vertical take-off and landing (VTOL), highly automated aircraft for fast, on-demand regional transport of people and cargo, and a rapidly evolving capability for national security and intelligence missions.

By reducing dependence on pilot duty hours, training cycles, and cockpit design requirements, these aircraft will be able to operate more efficiently, at lower cost, and with greater flexibility across airline, cargo, and military networks. These aircraft could deliver substantial positive impacts by lowering operating costs, improving safety through automated systems, expanding air-transport access to underserved regions, and enabling more efficient, reliable, and scalable passenger and cargo mobility.

What are the Impacts?

- **Economic:** Contribute to reduction in operating costs, increase network efficiency, and address pilot shortages
- **Disruptive:** Reshape labor needs, accelerating automation, and enabling new operating models that fundamentally change the nature of passenger and cargo air transport
- **Societal:** Enable potentially safer, more affordable, and more accessible air travel and logistics while prompting broad adoption of increasingly autonomous transportation systems
- **Strategic:** Enhance transportation resilience and improve scalability and responsiveness of both civilian and military air logistics

Pathway to Realization

2045

Enablers

Integration
Modernization of air traffic control (ATC), communications, and procedures

Advanced Avionics
Require greater sensing, computing, and redundancy than traditionally piloted aircraft

Reliability
Reliable performance across all pilot functions, normal through emergency

Barriers

Certification
No existing certification pathway for fully autonomous flight that replaces all human pilot functions

Acceptance
Broad public and operator acceptance supported by proven safety and economic performance will be needed

Contingency Risk
Autonomy must provide equivalent resilience to human judgement and improvisation when avionics fail

The pathway to pilotless aircraft is progressing through increasingly autonomous flight systems. Pilots are currently assisted by partial or conditional automation. From here, systems will be designed to enable remote-supervised operations, ultimately achieving fully autonomous, certifiable performance across all phases of flight. This evolution requires parallel advances in avionics, sensor fusion, secure communications, trusted autonomy, and safe failure modes. Innovations enabling trusted autonomy, in particular, center on highly reliable perception systems, trackable decision-making algorithms, and resilient human-machine oversight that together ensure predictable, transparent, and safe behavior in the NAS.

Use Cases

Near-term: In select cases, aircraft will adopt progressively more capable autonomous subsystems, such as enhanced autopilots; automated taxi, take-off, and landing; and advanced detect-and-avoid functions. Much of the early work will focus on increasing autonomous functions of Uncrewed Aerial Vehicles (UAVs).

Longer-term: AAM developers will continue to mature designs as systems become operational. Autonomy may mature to the point where large cargo aircraft can routinely operate with a single pilot and possibly remote pilot supervision. These flights will be supported by robust safety systems, redundant communications, and integrated airspace procedures.

Future-forward: Piloted aircraft will continue to dominate the skies by 2045, but in tandem with a growing retinue of autonomous and remote-piloted aircraft. These aircraft will operate in a continuously evolving NAS optimized to support a mix of networked and human-monitored automated ATC and aircraft.

The Tech Stack

Pilotless aircraft will resemble their piloted counterparts, with major modifications focused on avionics and flight deck arrangement at the Tier 2-3 levels. The autonomy and flight management subsystem represents perhaps the greatest difference, along with extensive modifications to sensors, trusted autonomy, redundancy, cybersecurity, high-integrity communications links, and greater emphasis on machine-in-the-loop.

Tier 1
System

Pilotless aircraft

Tier 2
Subsystems

Avionics
Communications
Sensors

Tier 3
Assemblies

Detect-and-avoid
Sensor fusion computers
Autonomous engine controls
Remote pilot station interfaces
Redundant flight computers
Cyber-secure C2 links

Tier 4
Components and Parts

AI optimized processors
Reconfigurable integrated circuits
Field-programmable gate arrays
MEMS sensors

Tier 5
Hardware and Materials

Composites and alloys
General hardware

The Developers

Globally, pilotless aircraft development is active but uneven. Cargo- and passenger-focused start-ups located primarily in the US, Europe, and China are developing a variety of AAM concepts, while airline manufacturers largely frame autonomy as crew-assist technology rather than near-term pilot removal. There is significant activity in retrofit and autonomy kits for existing aircraft and uncrewed cargo logistics, where developers are partnering with government to demonstrate and move toward certifiable operations for autonomous cargo aircraft. Defense contractors continue to evolve autonomous aircraft for national security and intelligence applications. The US military has funded several companies to develop a collaborative combat aircraft designed to be integrated into a network of warfighters and equipment, an architecture likely to reach an operational state beyond the 20-year horizon.

~200
Companies developing pilotless aircraft systems worldwide

~$50B
Current estimated investment in military and commercial autonomous aircraft

Quantum Computing and Sensing

Exploiting the quirks of quantum mechanics, quantum technology promises to exponentially increase our existing computational capabilities and unlock the potential of the quantum world, transforming how we understand our own.

What is it?

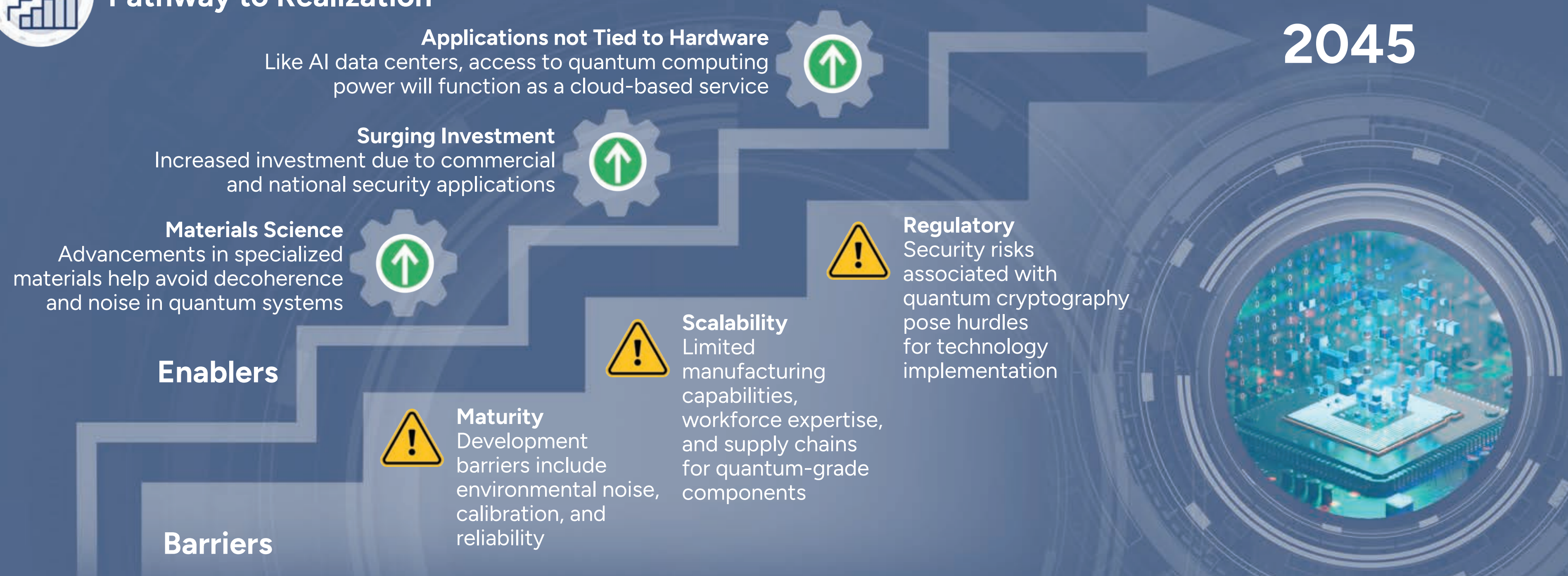
Quantum technologies leverage unique behavior of quantum systems to enable applications that are intractable or cost prohibitive with classical systems. Applications for quantum technology include quantum computing: utilizing superposition, entanglement, and interference to enable novel computing algorithms and quantum sensing: devices that use quantum phenomena to collect and measure physical properties.

Already used in aerospace systems, quantum sensors, like atomic clocks and magnetometers, enable high-precision measurements and applications like GPS-free precision navigation. Current quantum computers have shown promise in optimizing systems and enabling designs for new aircraft and advanced materials. As quantum computers mature, they may improve autonomy algorithms and enhance machine learning.

What are the impacts?

- **Economic:** Exponential gains in computing power and optimization capabilities could dramatically reduce costs and improve operational efficiency
- **Disruptive:** Paradigm-shifting computation could solve currently intractable problems, such as providing accurate simulation of essential molecular processes
- **Societal:** Optimization in emergency response, transportation, and healthcare breakthroughs have the potential to transform day-to-day life
- **Strategic:** Countries with advanced quantum computing and sensing capabilities can become technological leaders, impacting geopolitical dynamics

Pathway to Realization



While in development to become more stable, reliable, and powerful, quantum computing is currently supported by classical computers for research and development (R&D) and will eventually operate as stand-alone systems. Quantum sensing has broad applications that are already transitioning from the lab to the real world. Currently, some high-precision sensors are being used for scientific and laboratory applications, with robust mission-ready systems expected by 2035.

Use Cases

Near-term: Hybrid quantum-classical computing systems are used for research applications, like molecular simulations. Quantum sensing use cases are rapidly growing, with ongoing development and industry adoption of sensors, such as improved atomic clocks, magnetometers, and gravimeters, enabling navigation, biomedical imaging, geophysics, and geological surveying.

Longer-term: As development continues, quantum computing will be used for materials science R&D and specialized optimization. For national security and intelligence, quantum computing may also break some forms of existing data encryption. Quantum navigation and other sensing systems promise to transform autonomous operations, as well as science and intelligence missions. Space missions using quantum gravity sensors are expected in the 2030s, with follow-on commercial sensors maturing before 2045.

Future-forward: Although you shouldn't expect a personal quantum computer on your desk in the next 20 years, quantum computing and sensing have the potential to transform our way of life. Beyond 2045, some see a world with interconnected quantum computers, the computational capability to solve currently intractable problems, and sensing capabilities to help discover life beyond Earth.

The Tech Stack

Like classical computers and sensors, their quantum counterparts sit within system-level information networks. These quantum assemblies, components, and materials exploit quantum physics that behave differently from classical electronics. Qubits, precision optics, and other components must operate in controlled, cryogenic environments to maintain quantum coherence.

Tier 1
System

Information networks

Tier 2
Subsystems

Quantum computer

Sensor payload

Tier 3
Assemblies

Quantum sensor (magnetometer, clock, etc.)

Quantum processing unit

Cooling/cryogenic system

Power system

Tier 4
Components and Parts

Qubits: topological, trapped ion, photonic, and superconducting qubits

Support circuitry

Thermal sensors

Optics, connectors, and cables

Tier 5
Hardware and Materials

Superconductors

Semiconductors

Cryogenic Helium

Copper

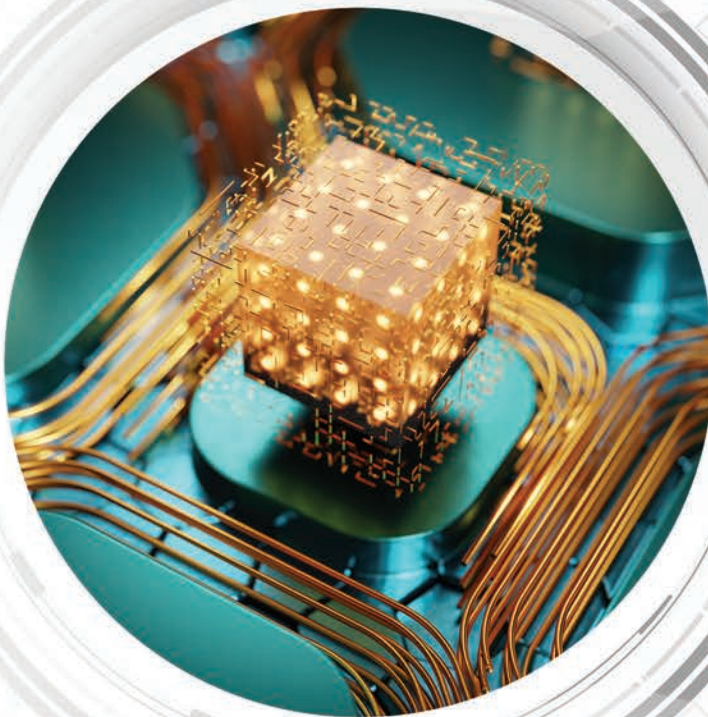
Glass or quartz

The Developers

According to the 2025 MIT Quantum Index Report, over 6,000 companies are working on quantum-based solutions; of these, about 10% are devoted solely to developing quantum technologies, such as quantum computer developers. The other 90% include academia and other organizations, like pharmaceutical companies using quantum-driven drug development, tech giants building quantum computer processors, and auto manufacturers using hybrid quantum-classical computers to research battery materials for EVs. Within the aerospace industry, aircraft manufacturers and large defense prime contractors are also investing in quantum computing and sensing technologies.

6,000+
Companies and research institutions developing quantum technologies, globally

$1.6B
Announced investments



Space Nuclear Power and Propulsion

From lunar resource mining to dramatically reduced transit times to Mars, space nuclear technologies create possibilities that simply do not exist with today's means of powering spacecraft.

What is it?

Reaching other planets demands propulsion systems that are faster, safer, and more efficient while living or mining off Earth will require reliable, high-power energy sources that do not depend on sunlight. Nuclear fission reactors can meet both needs, supplying robust power and propulsion for deep-space travel and off-world operations.

Unlike radioisotope thermoelectric generators (RTG) that have been used on deep space and planetary missions for decades, nuclear reactors generate a natural chain reaction by splitting atoms, fission, providing a pathway to high power that does not rely on large solar arrays and proximity to the Sun. Space nuclear reactors fall into three general categories: 1) nuclear power systems that generate electrical energy for in-space or surface operations; 2) nuclear electric propulsion (NEP) systems, which use reactor-generated electricity to power electric thrusters for in-space propulsion; and 3) nuclear thermal propulsion (NTP), which uses heat from a nuclear reactor to directly accelerate a rocket propellant.

What are the impacts?

- **Economic:** Innovations and improvements to space nuclear systems could impact the terrestrial market for small nuclear reactors
- **Disruptive:** By reducing or eliminating reliance on solar power, nuclear reactors will pave the way for wider ranging deep space exploration and exploitation
- **Societal:** Though debated for safety reasons, nuclear power and propulsion in space could spark public enthusiasm through bold accomplishments
- **Strategic:** Nuclear propulsion helps enable space domain superiority while high power reactors may enable global defensive systems

Pathway to Realization

Commercial Funding
Private firms are developing compact fission and fusion reactors for terrestrial and space markets

Government Funding
Government-funded programs will help advance the technology to operational readiness

Favorable Policies
Government policies promote space nuclear power; certification may ease as launches require it

Enablers

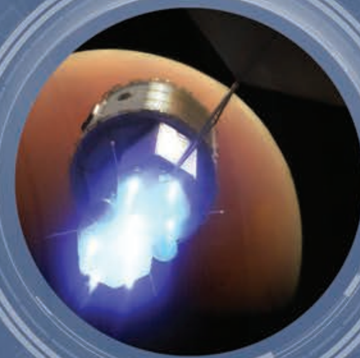
2045

Complexity and Cost
Nuclear reactors are complex and expensive; miniaturizing them for space will be costly

Weight
Nuclear reactors are large, requiring shielding and heat rejection systems that drive up mass

Safety
Potential for nuclear accidents requires additional certifications and engineering costs compared to non-nuclear missions

Barriers



Fission surface power (FSP) development leveraging commercial microreactor technologies to support operations on the lunar surface is a current US national priority. The goal is to deploy a system on the moon by the mid-2030s.

Use Cases

Near term: Operations on the lunar surface as part of NASA's Artemis program will be significantly enhanced by FSP. Small nuclear reactors also can be adapted to power existing electric thrusters to create highly efficient NEP systems for space transportation.

Longer-term: NTP could dramatically increase spacecraft maneuverability and reduce transit times to deep space destinations and enable spacecraft maneuverability without the need for refueling. Nuclear power may be necessary to power systems used in missile defense.

Future forward: Space nuclear power will be a key enabler of future human missions to Mars, both for crew and cargo transportation and to power activities on the Martian surface. Off-planet mining operations could also be powered by nuclear reactors, while NEP or NTP would help transport extracts back to Earth.

Tech Stack

The tech stack for space nuclear power includes the nuclear reactor system for power generation and propulsion; power conversion, heat rejection, power handling, and distribution subsystems; and radiation shielding. NEP marries that technology with electric thrusters, which use electricity to ionize a gas, typically xenon, ejected at high velocity to produce thrust. NTP uses reactor-generated heat to rapidly gasify a liquid medium that is then forced through a nozzle.

Tier 1
System

Nuclear reactor

Tier 2
Subsystems

Power conversion
Reactor control and autonomous fault management
Radiation protection

Tier 3
Assemblies

Reactor core
Primary loop
Safety and control
Cryogenic propellant plumbing (NTP)
Thruster elements (NEP, NTP)

Tier 4
Components and Parts

Radiation-tolerant electronics
Heat-tolerant structural materials
Moderator and reflector materials
Shielding materials
High-performance valves, pumps and turbomachinery

Tier 5
Hardware and Materials

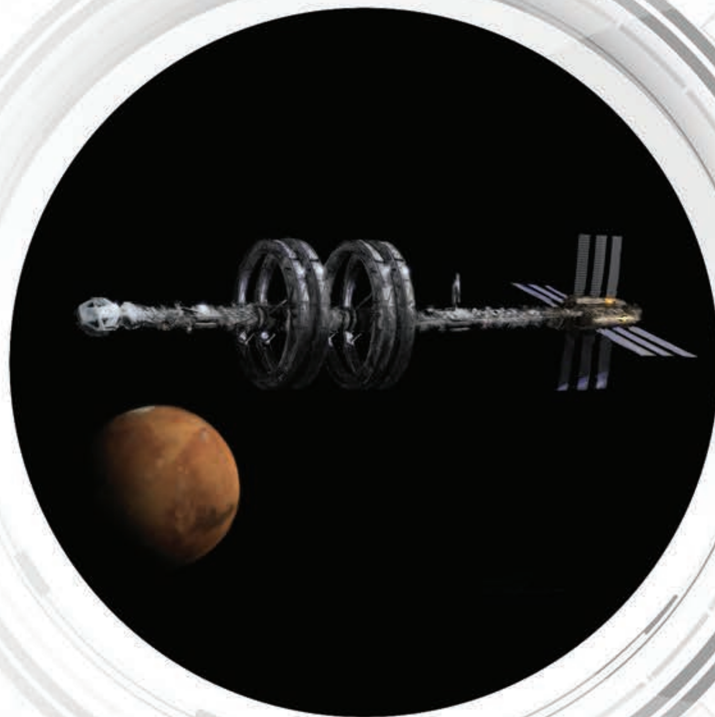
Nuclear materials
Metals and alloys
Graphite and moderator materials
Ceramics and special materials
Coolants, gases, corrosion inhibitors

The Developers

Government and private sector entities are funding development of space nuclear power and propulsion. In 2022, NASA and the Department of Energy's Idaho National Laboratory awarded FSP design contracts to three industry teams. NASA in January 2025 awarded a contract to further refine its FSP design. Meanwhile, the Advanced Electric Propulsion System (AEPS) thrusters for NASA's lunar orbiting Gateway could eventually be coupled with a nuclear power source to create an NEP system. Several companies have reportedly raised investment capital to develop space nuclear power systems, and others are seeking investors for an NTP system.

>$200M
NASA spending on FSP-related technologies since 2000

~15
Companies worldwide developing reactors for space applications



Just Missed the Cut

Beyond the ten technologies featured in this report, respondents pointed to several others they believe could dramatically shape the next twenty years. While these six did not rank among the very highest in projected economic, societal, strategic, or disruptive impact, experts still viewed them as too important to overlook and worthy of special recognition.

Collaborative autonomous aircraft. Collaborative autonomous aircraft are helping to redefine air operations by replacing lone vehicles with tightly coordinated teams that think and act together. By sharing sensor data, distributing decision-making, and dynamically assigning roles in real time, this approach allows the vehicles to adapt to changing environments, distribute tasks, and remain resilient even when individual elements fail.

Direct-to-device satellite communications. Direct-to-device satellite communications aim to connect everyday consumer devices, like smartphones, directly to satellites without the need for specialized ground equipment. By extending coverage, this capability enables messaging, emergency services, and data connectivity in remote, rural, or disaster-affected areas. Advances in satellite payloads, spectrum sharing, and network integration are making it possible for space-based systems to interoperate with existing cellular standards.

Functional materials. Functional materials are engineered to respond to their environment or perform specific tasks such as sensing, actuation, energy storage, or thermal management. Examples include shape-memory alloys that change form with temperature, piezoelectric materials that convert mechanical stress into electrical signals, and multifunctional composites that combine strength with electrical or thermal functionality. Functional materials can reduce system complexity, weight, and power requirements, enabling smarter, lighter, and more adaptive systems across aerospace applications.

Large structure additive manufacturing. Large structure additive manufacturing is helping to transform aerospace by enabling the rapid fabrication of large, lightweight structures for use in airframes, rocket structures, and tooling. By removing the need for costly molds and long supply chains, this approach shortens development cycles and allows designers to incorporate complex geometries and features directly into flight hardware. As these methods mature, large-scale additive manufacturing can become a powerful enabler for more flexible and more affordable aircraft and spacecraft.

Novel aerodynamic designs. Improving aircraft efficiency may require radically rethinking the design of aircraft bodies, which has remained largely the same since the dawn of the jet age. Two promising designs are blended-wing bodies and truss-braced wings. A blended wing body integrates the wings and fuselage into a single surface, while a truss-braced wing design uses slim wings supported by external struts. Both allow for reduced weight and drag while enabling higher efficiency at cruise. These two concepts could reduce fuel use and emissions while improving performance compared to conventional tube-and-wing aircraft.

On-orbit refueling. Fuel capacity is often the biggest factor limiting what spacecraft can achieve. By enabling satellites and space vehicles to replenish propellant after launch, on-orbit refueling can dramatically extend mission lifetimes and operational flexibility. On-orbit refueling may play a key role in sustainable space operations, including satellite servicing, deep-space exploration, and the development of in-space infrastructure.

Conclusion

The next two decades will mark a transformative era for aerospace, driven by rapid advances across propulsion, materials, autonomy, and digital engineering. Innovations such as sustainable aviation fuels, hybrid and electric propulsion, reusable launch systems, hypersonic propulsion, and advanced high-temperature materials will fundamentally reshape how aircraft and spacecraft are designed, built, and operated. At the same time, breakthroughs in AI, quantum computing and sensing, and pilotless aircraft will accelerate development cycles, improve safety, and enable levels of efficiency and performance that are currently unattainable. Together, these technologies point toward an aerospace sector that is more adaptable, resilient, and environmentally responsible than ever before.

As these top innovations mature, their combined impact will extend well beyond the aerospace industry itself, influencing global transportation, national security, and space exploration. Realizing their full potential will require investment, cross-industry collaboration, public education, and thoughtful regulatory frameworks. Ultimately, the innovations outlined in this report will redefine what is possible in air and space over the next 20 years.

About AIAA and BryceTech

AIAA is the largest professional society in the United States dedicated to aerospace engineering, science, and technology. It serves as a central hub for aerospace professionals across industry, government, and academia. Our purpose is to ignite and celebrate aerospace ingenuity and collaboration, and its importance to our way of life. Our promise is to be your vital lifelong link to the aerospace community and a champion for its achievements.

Find out more at: aiaa.org.

BryceTech is an engineering and analytics firm serving government and commercial clients in complex technology domains. BryceTech is internationally recognized for its objective, evidence-based analytic and strategic support, as well as for its authoritative data sets characterizing the aerospace industry. BryceTech expertise includes modeling demand, forecasting space activity, technology scouting, and policy and economic analysis.

Find out more at: brycetech.com.

"Aerospace technologies enable navigation, communication, investigation, and innovation on Earth every day. The future will be defined by radical shifts in performance, economics, and national competitiveness. The AIAA community is uniquely equipped to help shape this future."

– Clay Mowry, AIAA CEO

Appendix A: Detailed Methodology

AIAA contracted with BryceTech to generate a report on the top ten technologies, developments, or innovations that will impact the aerospace sector in the next 10-20 years. The sector includes the aviation and space domains, as well as related research and development. BryceTech developed four categories of potential impact to evaluate the innovations: economic, disruptive potential, societal, and strategic (including prestige, technological leadership, and defense). BryceTech also examined the barriers to realizing these innovations in the next 10-20 years.

To come up with the top ten technologies, BryceTech conducted a structured survey that received 725 responses from members of the AIAA community, asking them to: identify the three technologies or innovations they believe will have the biggest impact on aerospace in the next two decades (individually developed and not guided by a predetermined list); rank them according to impact in each of the four categories described above; identify barriers to realization or implementation; and provide any additional insights they deem relevant.

In addition, BryceTech interviewed more than 20 experts in the field, a mix of senior technologists, executives, and academics, asking a similar set of questions with an eye toward adding depth, color, and context to our survey results.

BryceTech also conducted desk research to validate and supplement interview and survey findings.

With data obtained from the above activities, BryceTech conducted a quantitative analysis to arrive at ranking taking into account how each technology scored in the four categories. After analyzing the list to ensure the technologies were viable within the specified time frame, the rankings were submitted to AIAA for further review and validation.

BryceTech then created profiles of each of the technologies and innovations on the final list, including descriptions, likely impacts, and barriers to implementation.

"Aerospace is standing at a technological inflection point. From low-cost space launch to high-speed transportation to in-space infrastructure – aerospace connects the world in profound ways."

– Clay Mowry, AIAA CEO

AIAA