Raytheon Technologies

Advancing sustainable aviation.

How we're supporting the civil aviation industry's drive to decarbonize

> "Our efforts include groundbreaking work to create new engine technologies, lighter and more efficient materials and more intelligent technology solutions that will work together to help the industry achieve its goal."
>
> **Gregory J. Hayes**
> **Chairman and Chief Executive Officer**

The future of aviation is sustainable.

As we look to the future, the long-term environmental issues posed by climate change are a concern for us all. In 2018, the Intergovernmental Panel on Climate Change reported the importance of the ambition of limiting global temperature rise to no more than 1.5 degrees Celsius above pre-industrial levels. There is no silver bullet that can singularly resolve the climate change problem; instead, the challenge demands a collective response at a global scale. Our Environmental, Social and Governance (ESG) strategy outlines Raytheon Technologies' approach to help address this crisis, leveraging the scale of our company, the ingenuity of our people and our history of rising to meet generational challenges.

Our leadership role in the aerospace industry provides a critical platform, given that aviation is one of the hardest-to-abate sectors in terms of cutting greenhouse gas (GHG) emissions – and that traffic volume is poised to double roughly every 20 years to further connect the world and advance global development. As an aerospace and defense manufacturer, we fully support the civil aviation industry's drive to decarbonize by 2050 and are taking action to reduce emissions through the products we design, develop, manufacture and support.

By 2050 we aspire to partner to achieve industrywide net-zero carbon emissions in civil aviation. To support the industry's goals, we aim to directly address 30% of air transport carbon dioxide (CO_2) emissions through the engines, aircraft systems and services in our 2050 civil fleet, relative to 2015 technology levels and the associated emissions baseline.

We are developing a broad portfolio of solutions, based on a number of different technologies, to help advance the air transport industry's commitment to reach net-zero by 2050. In addition, we are collaborating with stakeholders across the value chain to support the development and use of sustainable aviation fuels (SAFs) and other technologies that improve overall aircraft fuel economy.

On the path to decarbonize aviation

Raytheon Technologies takes pride in the role it plays in connecting people and cultures. As a longtime aerospace manufacturer, we take seriously our responsibility to provide safe, fast, efficient and economically viable ways for people to fly to meet one another. Our storied tradition of innovation in aviation began with Pratt & Whitney's inception in 1925, followed by Collins Aerospace in 1933. Just as our founders sought to bring life to a new industry with cutting-edge technologies, today Raytheon Technologies is creating the future with higher performing and more sustainable aerospace solutions.

Sustainable development is vital for the future of the aviation industry. Key aviation industry organizations such as the International Air Transport Association (IATA) and the Air Transport Action Group (ATAG) fully recognize that the aerospace industry must play a critical role in ensuring global temperatures do not increase more than 1.5 degrees Celsius. The aerospace industry faces many complex challenges to meet this goal. As ATAG's Waypoint 2050 report outlines, air transport is one of the hardest sectors to decarbonize due to a lack of off-the-shelf technologies that provide energy solutions meeting the speed and distance requirements for aviation.

The aerospace industry currently contributes around 2% of global CO_2 emissions. However, given the projected growth of air traffic demand, the industry predicts its carbon emissions will more than double by 2050 relative to 2019 levels if technology does not improve and get adopted. Raytheon Technologies and our business units Pratt & Whitney and Collins support the ATAG "Fly Net-zero" commitment to achieve industrywide net-zero carbon emissions in civil aviation by 2050.

The future of sustainable aerospace hinges on multiple, distinct technologies – some of which are just emerging. As breakthrough aerospace technologies are developed, their safety must be rigorously tested before they enter into service. This maturation process will take time, which is why Raytheon Technologies has a broad portfolio of solutions at varying levels of maturity to help reduce GHG emissions in the aerospace sector now and in the future.

Our road map to 2050

How we're supporting the air transport industry's net-zero commitment.

INDICATIVE MILESTONES

		2035	2050
ENGINES AND AIRCRAFT SYSTEMS	Continuous engine efficiency improvements and additional advancements	Develop hybrid-electric turboprop propulsion technology with potential fuel savings of 30%.[1] Launch hybrid-electric GTF engine with 25% potential additional fuel burn reduction.[1]	Launch advanced cycle engines that reduce fuel burn by potentially 33% over 2015 baseline with 100% AAF including hydrogen.[1]
ENGINES AND AIRCRAFT SYSTEMS	Aircraft system improvements	Optimize the design of aircraft components and equipment to minimize weight and maximize energy efficiency, reducing fuel burn by 3% per flight.[1]	Optimize the design of aircraft components and equipment to minimize weight and maximize energy efficiency, reducing fuel burn by 8% per flight.[1]
AIRLINE, AIRPORT & AIR TRAFFIC OPERATIONS	Aircraft trajectory and ground operations improvements	Develop next-generation technologies for air traffic and ground optimization, leading to 5% emission reductions on average per flight.[1]	Develop next-generation technologies for air traffic and ground optimization, leading to 8% emission reductions on average per flight.[1]

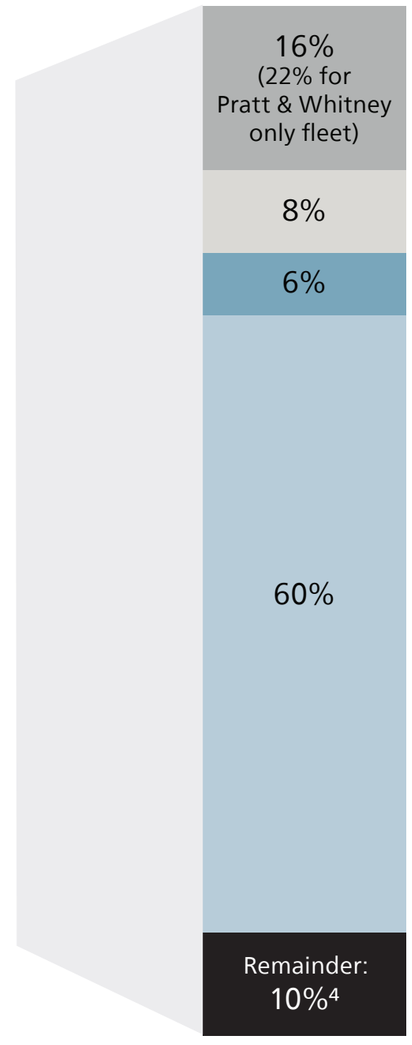
Driven by Raytheon Technologies

Supported by Raytheon Technologies

VALUE CHAIN PARTNERS	Sustainable aviation fuels (SAF), and other alternative aviation fuels (AAFs), airframer efficiency improvements and operations improvements from other players	Support energy industry value chain partners to achieve: 2035: 30% SAF availability	Support energy industry value chain partners to achieve: 2050: 85% SAF/AAF availability
VALUE CHAIN PARTNERS		Airframers and other value chain partners enhance aircraft design to reduce drag and weight and improve overall vehicle fuel economy.	Technologies for air traffic optimization and infrastructure improvements from other value chain partners.

Estimated fleet impact

Aggregate emissions reductions from 2050 civil fleet with Raytheon Technologies aviation products relative to an inventory baseline with 2015 technology levels[2,3]



1 Improvements measured over a baseline with 2015 technology levels.

2 Values represent Raytheon Technologies' estimates for civil fleet net CO_2 emissions relative to a 2015 technology baseline using GHG Protocol for Project Accounting methods for our fleet of engines and systems. We adopted a 2015 technology baseline consistent with ATAG Waypoint 2050, which is a vision of net-zero aviation that is widely adopted by the industry. Several new, significantly fuel efficient aircraft, including Airbus A320neo and Boeing 737 MAX, were introduced after 2015 and have been and continue to be adopted by airlines to replace older aircraft as well as to grow their fleet to serve traffic demand.

3 Forecasting method adds direct emissions from aircraft engines to indirect emissions from non-engine related equipment mass, aerodynamic drag and secondary power extraction. As detailed guidelines for fully analyzing emissions for the aviation industry do not yet exist, the methodology used in the future may evolve with industry standards.

4 Potential solutions for reducing the remainder include further enhancing the advancements noted above to further reduce emissions or employing market-based mechanisms.

Engine and aircraft systems

Continuous engine efficiency improvements and additional advancements

2035 milestones

Develop a hybrid-electric turboprop propulsion technology with potential fuel savings of 30% compared to the 2015 baseline.

Launch hybrid-electric GTF engine with 25% potential additional fuel burn reduction over 2015 baseline.

2050 milestones

Launch advanced cycle engines that reduce fuel burn by potentially 33% over the 2015 baseline with 100% AAF including hydrogen.

Aircraft system improvements

2035 milestones

Optimize the design of aircraft components and equipment to minimize weight and maximize energy efficiency, reducing fuel burn by 3% per flight compared to the 2015 baseline.

2050 milestones

Optimize the design of aircraft components and equipment to minimize weight and maximize energy efficiency, reducing fuel burn by 8% per flight compared to the 2015 baseline.

Improving engine efficiency

Every 20 seconds, a Pratt & Whitney GTF™ engine powered aircraft takes off from one of our 58 airline customers, producing 16% lower CO_2 emissions and delivering 50% less nitrogen-oxide (NOx) emissions compared to prior-generation best-in-class engines, namely the IAE V2500 turbofans from 2015 levels. The GTF engine builds on a long track record of innovation and efficiency gains at Pratt & Whitney – a 70% improvement in fuel efficiency since we introduced the JT8D in the 1960s. This engine is the industry's best-in-class for single-aisle applications. Our engineers revolutionized the traditional jet engine architecture, adding a gear system in between the fan in the front and the turbine in the back, so that the fan and the turbine can spin at their optimal speeds for improved efficiency. This geared architecture enables reduction in the number of engine stages and airfoils, providing industry-leading efficiency, weight and environmental benefits to the engine. The GTF engine is the only geared propulsion system in service that is delivering industry-leading sustainability benefits.

Since entering into service in 2016, this technology has saved operators 600 million gallons of fuel and avoided nearly 6 million metric tons of CO_2. Our engineers are determined to drive additional incremental emissions reductions. To that end, this past December we announced a newer model that will be available in 2024, the GTF Advantage™ engine, that will improve the reduction in fuel consumption and CO_2 emissions to 17% versus the 2015 baseline. We are also ensuring that the GTF engine will be compatible with 100% SAF, to further reduce engine emissions.*

At the same time, Collins is improving the efficiency of turboprop aircraft propulsion with advanced propeller systems. In 2019, Collins announced a new center in France to develop enhancements for existing propellers, new systems for future turboprop, and disruptive technologies for next-generation aircraft, while also helping to reduce cycle times for customers through increased automation. The center optimizes propeller designs that improve aerodynamics and reduce weight, fuel consumption and noise.

Further improving the efficiency of aircraft engines will require innovation across several areas, including:

- Enhancing P&W's geared turbofan architecture, with higher gear ratios that enable larger diameter fans and smaller diameter, higher pressure ratio turbomachinery to further increase engine efficiency.
- Introducing materials that can operate at higher temperatures, such as ceramic matrix composites (CMCs) that operate beyond the melting point of today's best nickel superalloys.
- Using advanced manufacturing to produce more effective cooling circuits that can keep key parts of the engine hot section below critical temperature thresholds.
- Reducing propulsion systems weight through the use of advanced materials such as composites to produce lighter-weight fan blades, fan cases and nacelles.
- Adopting advanced nacelle and exhaust technologies and design methods that reduce noise, weight and drag.

Introducing hybrid-electric propulsion

Hybrid-electric aircraft propulsion systems pair a conventional aircraft engine with an electric motor and drivetrain. The engine and motor power balance is coordinated by advanced control systems to work together in parallel to optimize the efficiency of the propulsion system throughout the flight envelope. We estimate that our advanced GTF with hybrid-electric technology will provide efficiency improvements that enable a 25% reduction in CO_2 emissions by 2035, relative to 2015 baseline technology.

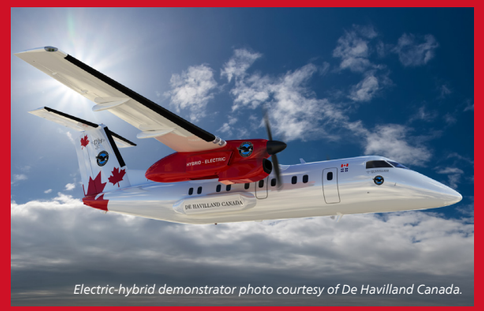
We are working across our business units and innovation teams to make hybrid-electric propulsion a reality for the next generation of commercial engines. We are uniquely positioned to lead aerospace in electrification in commercial aviation through the combination of Collins' expertise in aviation electrical systems and Pratt & Whitney's propulsion system manufacturing and integration capabilities.

Initiatives within the hybrid-electric space include:

- The Collins, Pratt & Whitney and Raytheon Technologies Research Center (RTRC) partnership with NASA, Penn State University, Georgia Tech and Howard University to develop hybrid-electric propulsion technologies.
- A $163 million Canadian Dollars Pratt & Whitney project supported by the governments of Canada and Quebec to develop a regional aircraft-scale hybrid-electric demonstrator, together with Collins and De Havilland Aircraft of Canada. With this demonstrator, we are targeting a 30% fuel efficiency improvement compared to today's best turboprops, with flight testing planned for 2024. (See "From gas to hybrid-electric: A demonstrator collaboration.")

From gas to hybrid-electric: a demonstrator collaboration

Stakeholder collaborations are a key ingredient in the sustainable aerospace future. Consider the work Pratt & Whitney and Collins have undertaken in collaboration with De Havilland Aircraft of Canada Limited, the Canadian government and the government of Quebec. Together, these organizations are working on a hybrid-electric demonstrator with a De Havilland Dash 8 regional aircraft that could significantly reduce emissions from fuel consumption.



Electric-hybrid demonstrator photo courtesy of De Havilland Canada.

The demonstrator will replace one of the aircraft's conventional gas turbine engines with a hybrid-electric propulsion system that pairs a 1MW electric motor with a 1MW internal combustion engine, for a total of 2MW propulsive power. A production aircraft with two hybrid-electric engines has the potential to reduce fuel consumption by 30% for short haul flights. The project will target testing a demo engine in 2022 and flight testing a full hybrid-electric flight demonstrator in 2024. This demonstrator is a key milestone on the path to development of a commercially viable hybrid-electric aircraft.

Developing hydrogen-fueled propulsion

While significant innovation and infrastructure investments must occur before hydrogen-powered aircraft become a reality, a hydrogen-powered engine could be game changing for sustainable aviation, as it produces zero carbon emissions during the combustion process. **Raytheon Technologies has the full portfolio of technologies needed to enable hydrogen-based propulsion solutions, including:**

- Electrical systems and fuel and thermal management systems from Collins.
- Gas turbine, combustion and advanced materials expertise from Pratt & Whitney.
- Advanced architecture concepts and fuel cell technologies being studied at the RTRC.

Hydrogen-burning engine concepts are not new for Pratt & Whitney, which first demonstrated a hydrogen-burning aircraft engine in the 1950s. Current concepts are more advanced, bringing meaningful improvements in overall engine efficiency through various means, including leveraging the cryogenic temperatures of the fuel as a heat sink for the aircraft. We also have collaborated with our partners in Japan to undertake low-NOx combustion of hydrogen, a critical step toward ensuring this technology has an important role to play in aviation decarbonization.

Pratt & Whitney has been selected by the U.S. Department of Energy (DOE) to develop novel, high-efficiency hydrogen-fueled propulsion technology for commercial aviation, as part of DOE's Advanced Research Projects Agency-Energy (ARPA-E). The Hydrogen Steam Injected Intercooled Turbine Engine (HySIITE) uses liquid hydrogen combustion and water vapor recovery to achieve zero in-flight CO_2 emissions, while reducing NOx emissions by up to 80% and reducing fuel consumption by up to 35%. The HySIITE engine will burn hydrogen in a Brayton (thermodynamic) cycle and use steam injection to dramatically reduce NOx. Via an innovative semi-closed system architecture, HySIITE aims to achieve thermal efficiency greater than fuel cells and reduce total operating cost to be comparable with "drop in" SAF.

Additionally, as an alternate to cryogenic hydrogen fuels, our team at RTRC is working on engine concepts that are powered by intermediate hydrogen fuels such as ammonia, which bring the benefits of hydrogen propulsion in a more transportable fuel. (See "Ammonia could fuel the future of sustainable flight.") For fuel cell propulsion architectures, we are leveraging Collins' strong expertise in fuel cells for space and sea applications and RTRC's background in fuel cell research to develop fuel cells for power generation.

We see the potential for these advanced cycles to improve engine efficiency another 10%, which could contribute to address the industry's gap to net-zero carbon dioxide emissions by 2050.

Ammonia could fuel the future of sustainable flight

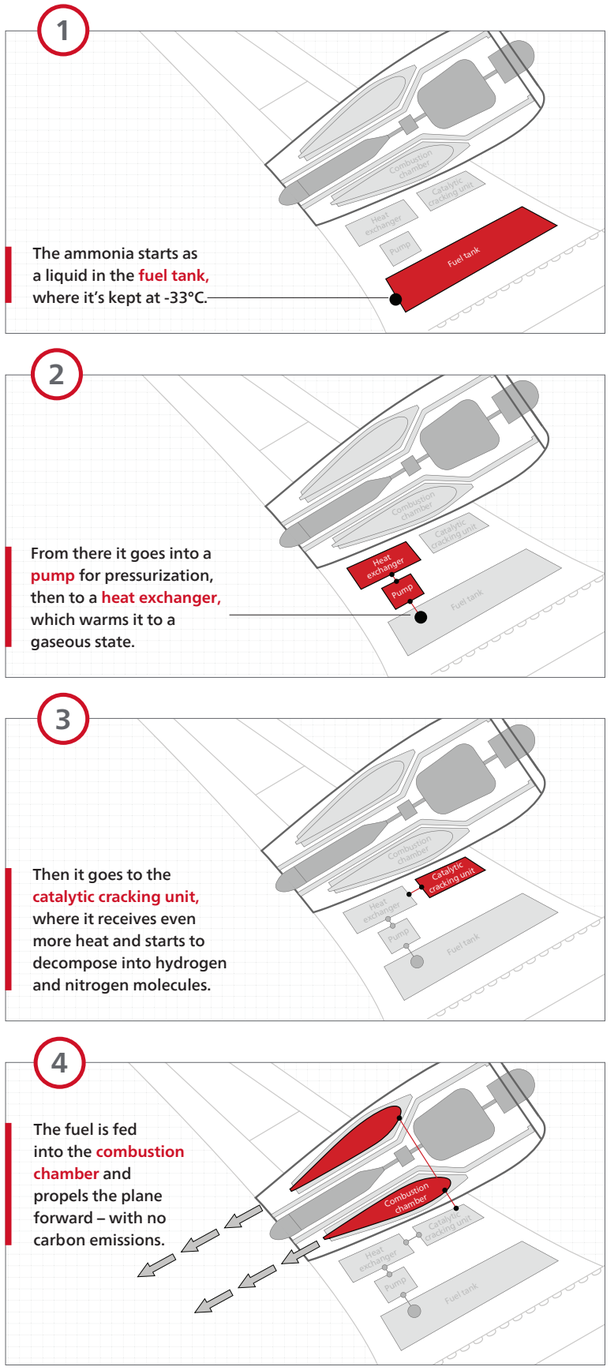
The RTRC is developing a carbon-free propulsion system through a U.S. Department of Energy program.

Under a $2.6 million research grant from ARPA-E, Raytheon Technologies is developing a turboelectric aviation propulsion system that would use ammonia as both a fuel and a coolant – potentially paving the way for the decarbonized future of flight.

Ammonia is a compound of nitrogen and hydrogen, and can be used as a fuel that produces no carbon emissions from combustion. As part of our roadmap to 2050, the RTRC and ARPA-E have partnered to explore the possibilities of ammonia in civil aviation. Although both hydrogen and ammonia produce zero carbon emissions, ammonia has a few distinct advantages as it does not need to be stored nearly as cold (-33°C vs. -253°C for liquid hydrogen). Ammonia is also more energy dense than hydrogen by volume, which translates to less aircraft structural weight and drag.

This program involves designing new systems that can convert liquid ammonia into its desired gaseous state for combustion. As the graphic at right shows, this process would involve a fuel tank to store the liquid ammonia, a pressurization pump, a heat exchanger, a catalytic cracking unit and a combustion chamber within the engine.

Ammonia-powered flight



Aircraft system improvements

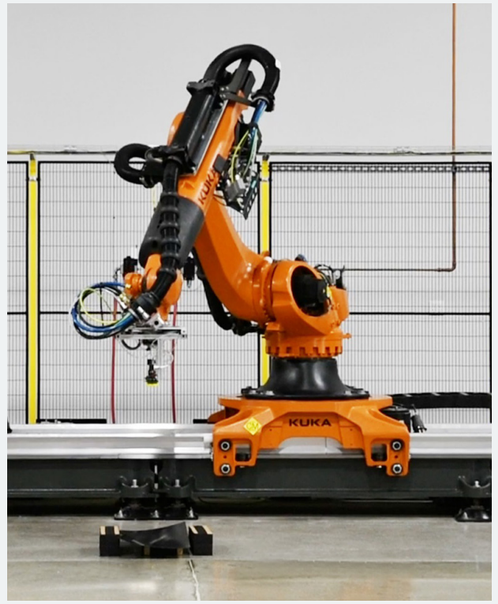
Introducing lighter-weight and more energy-efficient aircraft equipment systems

The weight and energy efficiency of airborne systems and equipment are critical variables that affect fuel burn and emissions for aircraft as a whole. Collins and Pratt & Whitney have focused on leveraging the latest materials and design and manufacturing processes to produce the lightest and most efficient aircraft products ever made, contributing to overall aircraft energy efficiency and helping reduce aircraft emissions.

An aircraft's weight is directly correlated to its fuel burn, payload and range. We estimate that, under cruise conditions, every 1,000 pounds of weight reduction results in a 0.7% fuel savings for an average single-aisle aircraft.

Key efforts across our business units to reduce aircraft system weight include:

- Leveraging advanced lightweight materials, including using composites for structural elements ranging from engine nacelles to cabin seats. For example:
  - **The DURACARB® carbon brake technology from Collins saves about 700 pounds of weight on single-aisle aircraft, along with improved performance and durability.**
  - **We are reducing weight by applying thermoset and thermoplastic composites to aerostructures, as well as to mechanical parts such as struts and shafts.**
  - **Advanced composite fan blades and fan cases for next-generation GTF engines enable lower weight with increased durability and operational capability.**
- Leveraging advanced manufacturing processes to make it possible to optimize product weight. Where possible, our engineers leverage technologies such as additive manufacturing and tomolithographic molding (TOMO®) to produce equipment designs that are lighter weight than anything produced with conventional manufacturing technologies, without compromising on safety, quality or reliability.



Innovations in thermoplastics

Collins recently acquired Dutch Thermoplastics Components (DTC), a leader in the development and fabrication of structural thermoplastic composite parts. Thermoplastics composites offer higher impact resistance, unique process possibilities providing reductions in manufacturing cycle time and the need for fewer fasteners, in addition to what could be offered by traditional thermoset composites, such as strength and lighter weight. Further, thermoplastic composites are recyclable at the end of their life cycle.

This acquisition underscores our commitment to using advanced materials and processes to address key areas of importance for our customers: weight reduction for fuel savings, reliability improvements and sustainable practices across the product life cycle.

High-temperature materials and manufacturing technologies reduce fuel burn

In 2021, Pratt & Whitney opened a ceramic matrix composites (CMC) R&D facility in Carlsbad, California. The 60,000-square-foot facility is dedicated to the engineering, development and low-rate production of CMC components for aerospace applications.

These innovative ceramic composites are lighter and can withstand higher temperatures, which improves thermal efficiency for gas turbine engines. When ready, these materials will be integrated into military and commercial engines to increase range, improve fuel efficiency and reduce emissions.

In addition to the Carlsbad facility, Pratt & Whitney announced in late 2020 that we would be opening a new turbine airfoil production facility in Asheville, North Carolina. This $650 million facility will use the latest technologies and processes to manufacture the next generation of turbine airfoils.

We are also focused on improving energy efficiency in aircraft equipment. A broad class of equipment, including electronics, avionics, actuation, fuel systems and environmental control systems (ECS), consume aircraft energy in electric, hydraulic or pneumatic form. Reducing equipment energy consumption directly translates into lower overall aircraft fuel consumption and lower emissions. Our efforts to improve equipment energy efficiency include:

- Deploying an electrified ECS for the Boeing 787, one of the clean-sheet-design aircraft in the new century. This system pressurizes and conditions cabin air by using electric power from the engine generators to drive compressors, taking fresh air via dedicated inlets instead of the more traditional approach of taking bleed air from the engine. From engine power extraction to cabin air compression, this concept yields a net efficiency gain and a reduction of fuel consumption.
- Converting hydraulic actuation to electric actuation, improving overall system efficiency and weight, such as in the electric actuation flight control systems on the Airbus A380.
- Improving the energy efficiency of power electronics used in power distribution systems and motor drives through the use of advanced electronic designs and more efficient semiconductor devices.
- Reducing the drag of exterior fuselage components such as nacelles and satellite antennas.
- Investing $18 million to develop "smart" actuation components for commercial airplanes and helicopters in our center of excellence for actuation systems in France. This Collins program is supported through a four-year R&D program grant from the French Civil Aviation Authority. The investment will be used to develop a number of solutions, including a lighter, more compact motorized gearbox; more compact actuator structures with improved thermal management; a full-authority actuator to enable fly-by-wire for all helicopter platforms; AI-enabled prognostics and health management capabilities; and an advanced modular electro-mechanical actuator that can be used across a number of platforms.

Airline, airport and air traffic operations

Aircraft trajectory and ground operations improvements

2035 milestones

By 2035, develop the next-generation technologies for air traffic and ground optimization, leading to 5% emission reductions on average per flight compared to 2015 baselines.

2050 milestones

By 2050, develop next-generation technologies for air traffic and ground optimization, leading to 8% emission reductions on average per flight compared to 2015 baselines.

Trajectory-based operations

Another way to reduce fuel burn and emissions is through trajectory-based operations (TBO), a concept that proactively optimizes and manages flight trajectories instead of continuously reacting to local conditions and traffic conflicts throughout the flight.

Several solutions from Raytheon Technologies work together to unlock the ability to optimize and reliably execute optimized flight trajectories. The combination of these solutions could reduce air transport emissions by 8% on average per flight by 2050 compared with 2015 baselines.

Raytheon Intelligence & Space TBO technologies and developments include:

- The FAA's Wide Area Augmentation System (WAAS), which enhances the Global Positioning System (GPS) and provides precision navigation over North America.
- The next-generation Operational Control System (OCX), which modernizes the ground control segment of the GPS.
- The FAA's Standard Terminal Automation Replacement System (STARS), which is used by air traffic controllers to manage the airspace around the nation's busiest terminal areas, accounting for 100% of U.S. commercial departing and arriving air traffic.
- The Advanced Weather Interactive Processing System (AWIPS), the National Oceanic and Atmospheric Administration/National Weather Service's (NOAA/NWS) weather forecasting data and display toolkit for all entities involved in air traffic operations.

Collins Aerospace TBO technologies and developments include:

- Global air-ground data communications capabilities, such as Controller Pilot Data Link Communications (CPDLC), Automatic Dependent Surveillance-Contract (ADS-C) and ARINC Global Network, and messaging services to enable TBO by providing digital connectivity between the Air Navigations Service Provider (ANSP), the Operations Control Center (OCC) and the aircraft.
- Airborne, weather radar and tailored weather services at the OCC and uploaded to the flight deck to support safe and efficient operations for airline and the flight crew.
- Flight planning and dispatch, fuel analysis, weight and balance, and departure control systems that help with more efficient and predictable flight plans. The recent acquisition of FlightAware significantly complements these offerings with enhanced global situational awareness, predictive technology, analytics and decision-making tools for aircraft operators and millions of passengers
- Avionics solutions including:
  - **Multi-mode GPS receivers compatible with multiple global navigation satellite constellations and augmentation systems, as well as ground based radio navigation aids, providing advanced global navigation and precision landing capabilities.**
  - **Additional technologies, such as the Automatic Dependent Surveillance-Broadcast (ADS-B), integrated surveillance system, adaptive flight display, head-up display, combined vision systems, autopilot and flight-by-wire, ensuring efficient and safe execution of the cleared trajectory, even under marginal weather conditions.**

Airline and airport operations

Raytheon Technologies provides a comprehensive set of cloud-based, connected systems and tools for passengers, airlines and airports to help the air transportation ecosystem operate as seamlessly and efficiently as possible. Enabled by our network connectivity, messaging and data exchange, with continuous innovation in artificial intelligence, machine learning and data analytics, these systems and tools directly reduce emissions associated with ground operations and also support efficient flight operations to fully capture the benefits of TBO.

For example:

Collins provides the ARINC PaxLink™ Passenger Services System, which includes modules ranging from airline network and schedule planning, fuel consumption analysis, crew management, weight and balance, and departure control systems to passenger reservations, check-in and border management at the airport. The system provides safe and efficient ground operations and management of on-time performance and disruptions.

Collins offers the Aviation Resource Management System, which provides flight data monitoring and analysis, logistics and inventory management, maintenance repair and overhaul (MRO) planning and execution management.

Pratt & Whitney offers EngineWise™, which combines industry-leading data analytics, engine expertise and customer fleet experience to build shared insights and engine MRO capabilities. These capabilities ensure asset health and safety as well as efficient airline technical operations to achieve fast turnaround time and reduced material and energy consumption, while maintaining optimum product performance and minimizing unplanned aircraft downtime.

Product use value chain partners

Alternative aviation fuels, airframer efficiency improvements and operations improvements from other players

In addition to developing technologies that are in our control to pursue, we are also working closely with industry partners, including airframers and energy companies, to support the development of other important technologies that are necessary to deliver net zero reductions in CO_2 emissions. These industry partner efforts will deliver the following aspirational milestones:

2035 milestone

30% SAF availability

2050 milestone

85% SAF/AAF availability

2035 and 2050 milestones

Airframers and other value chain partners enhance aircraft design to reduce drag and weight and improve overall vehicle fuel economy.

Technologies for air traffic optimization and infrastructure improvements from other value chain partners.

Enabling the use of alternative aviation fuels

The most common fuel used by commercial aircraft is Jet A, a kerosene-based fuel that meets specific performance and safety requirements. AAFs include SAFs and other alternatives such as hydrogen and ammonia. SAFs are renewable synthetic jet fuels that can be produced by converting biomass feedstock and waste into liquid fuels, or alternatively by chemically combining CO_2 and hydrogen. AAFs are poised to have an immense impact on the aviation sector's path toward net-zero. Several SAFs have been approved within industry specifications (ASTM D1655) to be used as a 50% blend with conventional jet fuel.

Today's pure SAFs offer up to an 80% or more reduction in fuel life cycle CO_2 emissions relative to fossil-fuel based jet fuel, yet SAFs currently comprise less than 0.1% of global jet fuel consumption. Focused investments from industry and governments are occurring to increase global SAF production and reduce cost. The goal is to drive increased availability and use, which ATAG has projected to rise exponentially in this decade.

Pratt & Whitney has been active in SAF testing and certification for almost two decades, and all of our modern engines are currently compatible with the approved 50% SAF blend.

Collins designs and integrates advanced fuel measurement and management systems, as well as other fuel system components, such as fuel controls, pumps, valves and nozzles for nearly every type of engine and aircraft. Today, these systems and components are compatible with approved 50% SAF blends. In collaboration with engine and aircraft manufacturers, Collins is working to ensure compatibility with unblended (100% or neat) SAFs to provide even greater environmental benefit.

Ensuring compatibility with 100% SAF may require testing, requalification or recertification, and in some cases the redesign of components or subcomponents depending on the future standards of 100% SAF. For example, for current fuel gauging systems Collins has developed a densitometer device that directly measures the density of fuel, allowing a 1% fuel quantity accuracy regardless of fuel type. For new aircraft, Collins is developing a pressure-based fuel gauging system that directly measures the pressure of fuel so we can accurately calculate fuel quantity regardless of type.

In addition to our efforts at Raytheon Technologies, the contributions of airframers, SAF producers and others are essential to reach the air transport industry's net-zero 2050 goal. Across the industry, we must innovate separately and together to reach this essential milestone.

Supporting AAF in the value chain

- Since 2006, we have evaluated the compatibility of both blended and 100% SAF pathways through extensive testing of our commercial and military engines. We continue this effort in support of the aviation industry objective to identify multiple 100% SAFs that will minimize environmental impact, increase availability and reduce cost. We are currently partnering with ATR and Embraer on a 100% SAF flight demonstration program. We aim to enable release of industry specifications for 100% SAF that is safe and approved by regulators to operate on all current and legacy engines.
- We continue to support technical efforts to increase approval of multiple pathways for blended and 100% SAF as a founding member of the Commercial Aviation Alternative Fuels Initiative (CAAFI), an industry-government coalition charged with developing, approving and releasing specifications for SAFs that meet all regulatory safety requirements. The goal is to support the development of new pathways to scale up production capability and drive down cost.
- We support ATAG's efforts to collaborate with industry regulators, customers and partners to encourage global alignment for the development of a roadmap for sufficient global AAF production, including but not limited to SAF, to support 85% of aviation industry energy needs by 2050. And along the way, we aim to support the aviation industry to achieve 30% AAF (primarily SAF) availability relative to demand by 2035.

Partnering with government programs for a sustainable future

Around the world, government agencies are accelerating their efforts to achieve ambitious environmental and climate goals. As an enterprise with a global footprint, Raytheon Technologies is partnering with and participating in programs in both North America and Europe to develop a wide range of technologies, which include the following examples:

Canadian government and the government of Québec. As part of Canada's green recovery plan, the Canada Strategic Innovation Fund is backing the Collins and Pratt & Whitney hybrid-electric technology demonstrator. The government of Québec is supporting this project through Investissement Québec and the Ministère de l'Économie et de l'Innovation, as part of an initiative known as "Aéronef pour la mobilité numérique et verte de demain" (Green and Digital Aircraft of Tomorrow). (See "From gas to hybrid-electric: A demonstrator collaboration.")

U.S., FAA CLEEN III. Collins, Pratt & Whitney and RTRC have been selected by the FAA to develop technologies under the agency's Continuous Lower Energy, Emissions, and Noise III (CLEEN III) program. Under CLEEN III, Collins is leading the development of an exhaust noise attenuation technology reducing combustion noise, while Pratt & Whitney is leading the development of an advanced combustion system and a higher efficiency fan system, delivering noise, fuel burn and emissions reductions.

Europe, Clean Aviation and SESAR 3. Collins, through its Applied Research & Technology organization, has been accepted as a Founding Member in both Clean Aviation and Single European Sky air traffic management (ATM) R&D 3 (SESAR 3), which are funded from 2022 through 2030. This will enable us to contribute to new green technologies through our position on the governing boards of these programs, while shaping the direction of the R&D agenda.

U.S., MDA SBX. Raytheon Missiles and Defense and partners replaced the U.S. Missile Defense Agency (MDA) Sea-Based X-Band Radar (SBX)'s cooling system with a redesigned system that is more energy efficient and uses an environment-friendly refrigerant. The new design reduces the radar's annual power consumption by an estimated 4,346,000 kilowatt-hours, as well as its annual carbon dioxide equivalent emissions (CO_2e) by an estimated 17,786 tons. Further, the new design delivers better reliability, increasing redundancy by 150%. This project was recognized with the 2021 Secretary of Defense Environmental Award.

France, DGAC. Collins is investing $18 million to develop "smart" actuation components for both commercial airplanes and helicopters in our center of excellence for actuation systems in France. This program is supported through a four-year R&D program grant from the French civil aviation authority (DGAC).

U.S., DOE ARPA-E HySIITE. Pratt & Whitney has been selected by the U.S. Department of Energy's ARPA-E to develop the Hydrogen Steam Injected Intercooled Turbine Engine (HySIITE), which uses liquid hydrogen combustion and water vapor recovery to achieve zero in-flight CO_2 emissions, while reducing NOx emissions by up to 80% and reducing fuel consumption by up to 35%.

U.S., DOE ARPA-E REECH. Under the Range Extenders for Electric Aviation with Low Carbon and High Efficiency (REECH) program, RTRC is developing a compact propulsion engine optimized with waste heat recovery (CO-POWER) technology to achieve ultra-efficient and lightweight fuel to electricity power generation systems by using supercritical carbon dioxide (sCO_2) as a working fluid.

Our ESG journey

We are committed to transparency and regular reporting on our performance in helping people and the planet, as well as how we embody our principles. For more information on our ESG strategy and efforts to progress sustainable aviation, please visit **rtx.com/social-impact/our-esg-vision**.

Forward Looking Statements and Other Important Information

This report contains certain metrics and other information relating to Raytheon Technologies' ESG objectives, goals, plans, expectations, performance and data. The report describes topics which we consider to be the most salient to stakeholders when evaluating Raytheon Technologies' ESG-related information. However, the inclusion of information in this report is not an indication that such information is necessarily material as contemplated by the U.S. federal securities laws and the applicable regulations thereunder.

In addition, the metrics and other data information in this report are based on company data collection and are subject to uncertainties with respect to specificity of reporting, characterization, comparison and other process consistencies. In certain cases, this information is also based on our current best estimates and assumptions. We believe such information and metrics are reasonable and are generally consistent with current industry practices, legal and regulatory requirements, and other applicable frameworks, but they have not been audited or reviewed by a third party (other than audited financial data). Unless otherwise specified, metrics shared are for the calendar year January 1, 2021 – December 31, 2021.

Furthermore, this report contains statements which, to the extent they are not statements of historical or present fact, constitute "forward-looking statements" under the securities laws. Forward-looking statements can be identified by the use of words such as "believe," "expect," "plans," "will" and other words of similar meaning. Examples of forward-looking statements in this report include statements and assumptions relating to Raytheon Technologies' ESG-related goals, objectives, aspirations and commitments, planned efforts and activities, expectations on the results of such efforts and activities, and expectations on the performance of technology. These forward-looking statements are subject to risks and uncertainties that may result in Raytheon Technologies not achieving or changing, in whole or in part, goals, objectives, aspirations or commitments, or cause actual actions or results to differ greatly from those expressed or implied. These risks and uncertainties include, among others: (i) global macroeconomic, business, political and climate conditions; (ii) availability of funding; (iii) evolving legal and regulatory requirements; (iv) the success of our environmental, social and governance related initiatives; (v) the accuracy of our estimates and assumptions; (vi) the success of new technologies; (vii) the impact of acquisitions or divestitures or other changes in our employee or product and service base; (viii) the ability to attract and retain personnel and suppliers with technical and other skills; (ix) the willingness of suppliers to adopt and comply with our programs; and (x) the impact of business disruptions, including as a result of cyber or other security threats. Please consult our U.S. Securities and Exchange Commission (SEC) filings, including our Annual Report on Form 10-K and our Quarterly Reports on Form 10-Q, for further information regarding risks and uncertainties associated with our business. The forward-looking statements in this report speak only to the date of this report and Raytheon Technologies assumes no obligation to update or revise such statement, whether as a result of new information, future events or otherwise, except as required by applicable law.

Raytheon Technologies

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