WHITE PAPER

MAKING MORE POSSIBLE

MORE INTELLIGENT

MORE CONNECTED

MORE ELECTRIC

Collins Aerospace

AEROSPACE REDEFINED

THERE'S MORE THAN ONE WAY TO REDEFINE AEROSPACE

At Collins Aerospace, we're dedicated to tackling the toughest challenges facing our industry – all to make the skies and spaces we touch smarter, safer and more amazing than ever.

Among these challenges:

- How to best use technology and autonomous solutions to enhance safety – in the defense and commercial arenas – while improving collaboration and optimizing workloads?
- How to take advantage of the data being generated across the aviation ecosphere to unlock new insights that deliver efficiencies for operators and more seamless and rewarding travel experiences for passengers?
- How can we drive breakthroughs in electric technology to reduce aviation's carbon footprint, noise pollution and operating and maintenance costs?

The short answer to all of these challenges? "**More**." More intelligent solutions for the modern battlespace, in the form of advanced secure communications; assured position, navigation and timing, and enhanced intelligence capabilities. A more connected commercial aviation ecosystem that links key partners and touchpoints with powerful data for unprecedented insights. And more electric innovations that will significantly increase power system density, laying the groundwork to fly a hybrid-electric regional passenger aircraft by 2020.

At Collins Aerospace, we are redefining aerospace by shaping a future that is more intelligent, more connected and more electric than ever … and we can't wait to show you **more.**

MORE INTELLIGENT SYSTEMS

Collins Aerospace is driving breakthroughs in intelligent systems design and automation. Our expertise in intelligent technologies – from advanced secure communications to assured navigation and timing, and flight management systems to sensor, navigation and communications solutions – provide users with more powerful situational awareness, increased collaboration and ultimately, success in the battlespace and in commercial flight. And through our advanced flight control, data link and guidance technologies, we're enhancing the integration and safety of manned and unmanned flight. **It's about keeping those who benefit from our technologies safer, more secure and more informed by taking a more intelligent approach to redefining aerospace.**

A more intelligent battlespace

From the tactical edge and into space, Collins Aerospace enables our customers to expand their reach with proven, full-spectrum capabilities. Warfighters gain secure, up-to-the-minute tactical and near real-time situational information – a force multiplier that empowers them to make better, faster decisions and take action, when it matters most.

Our solutions empower the intelligent battlespace of today and tomorrow:

- Next-generation software-defined radios ensure secure connectivity between airborne, ground and sea-based elements
- Advanced sensors work in concert with data links and communication devices to rapidly distribute information throughout the battlespace
- Navigation capabilities ensure the critical location accuracy of the information, and – when paired with our anti-jam technologies and assured position, navigation and timing (PNT) capabilities – ensure soldiers stay connected and maintain their information advantage, even in the most degraded battlespaces

Whether in the air, on the ground or at sea, we keep defense forces decisively aware and navigating confidently with innovative, intelligent technologies to exploit every advantage within the battlespace.

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For example, consider the intelligence delivered through these solutions:

TRUNET™ NETWORKED COMMUNICATIONS SOLUTION

Our TruNet™ networked communications solution enables defense forces to stay connected across the entire battlespace. TruNet is the most advanced, integrated software-defined communications solution available, and gives ground, airborne and mobile forces the power to share critical data, image, voice and video securely and in real time. Our multi-hop technology enables users to communicate beyond line of sight, and our low-latency speeds – even in a multi-hop topology – ensure forces receive mission-critical information sooner.

MS-110 MULTISPECTRAL RECONNAISSANCE SYSTEM

In the fog of war, actionable intelligence on enemy movements and force strength can be the difference that delivers battlefield success. Mount our long-range, stand-off MS-110 multispectral reconnaissance system to fast jets or Unmanned Aerial Vehicles (UAVs) like the Reaper to get high-resolution day and night

imagery, from overhead and at long ranges – a slant range of 80-plus nautical miles. Multispectral imaging enables operators to detect a new range of threat and call out decoys, camouflage and obscurants even at long distances.

Enhancing situational awareness in commercial aviation

We're also bringing more intelligent systems to the commercial aviation sector, delivering solutions that reduce pilot workload, enhance situational awareness and assist with smarter, timelier decision-making.

Our Enhanced Flight Vision System on dual head-up displays is available on the Boeing 787, 777X and 737 MAX

For example, consider the value these solutions deliver:

ENHANCED FLIGHT VISION SYSTEM (EFVS)

Poor visibility due to fog or precipitation is the cause of many frustrating and costly airline delays. But Collins' EFVS gives pilots unparalleled situational awareness, even in poor conditions. When combined with our advanced EVS-3600 multispectral sensor, EFVS blends multiple infrared and visible light cameras on dual head-up displays, enabling pilots to better detect the runway in poor weather and continue to operate the aircraft in adverse conditions. Recently released regulations will enable airlines to leverage the EFVS to perform operations in lower visibility conditions than previously possible, reducing costly delays for airlines and improving on-time performance for passengers.

AVOIDANCE RE-ROUTER (ARR)

Today, pilots have to request – or be directed by air traffic control – to go around a thunderstorm in the aircrafts' path, and other aircraft in the area are daisy-chained to follow the new route. To compensate for weather changes, these routes often add significant time to the flight plan. Now, we're evolving our ARR – which projects weather over time and recommends a flight path to avoid potentially hazardous weather – from a ground-based tool to a flight deck solution. It will leverage data such as prevailing winds from a variety of connected sources to account for the *future* movement of hazardous weather, suggesting a new route that pilots can choose to avoid adverse weather while still reducing flight plan deviations, saving time and fuel, and enabling passengers to make their connections.

Autonomous advances

With our autopilot and flight control systems, and our sensors, navigation, communication and laser systems, we're developing technologies that enhance the integration and safety of manned and unmanned flight. These secure, reliable solutions reduce workload and enable smarter decision-making today, while enabling autonomous applications for the future airspace.

For example:

THE NEXT-GENERATION VEHICLE MANAGEMENT COMPUTER (VMC)

Aircraft are getting more autonomous – in fact, 90 percent of an average commercial flight today is flown by autopilot. And the

aviation industry wants to expand its ability to fly 24/7, while maintaining safety for operators and passengers. To enable these capabilities, we are developing a next-generation VMC that will enable fly-by-wire technology and more autonomous flight for new and retrofit applications. With triple multi-core processors providing 20 times the processing power of our existing flight control computers, the VMC can assume multiple-mission roles across a wide range of commercial and military, manned and unmanned, and fixed- and rotary-wing applications, providing redundancy, reducing pilot workload and offering a safer environment for crews in degraded visual conditions.

With 20 times the processing power, our VMC can provide redundancy, reduce pilot workload and offer a safer environment for crews in degraded visual conditions.

POWERFUL FLIGHT MANAGEMENT AND FLIGHT-CRITICAL CONNECTIVITY FOR UAS OPERATIONS

As aviation authorities work to complete the regulations to enable the full integration of Unmanned Aircraft Systems (UAS) into the civil airspace, Collins Aerospace is prepared to meet the new safety standards. Our UAS-certified Flight Management System (FMS) automates a wide variety of in-flight tasks to maintain precise navigation along a flight plan. With our FMS, operators in ground control stations can pilot a UAS using standard navigation routes, waypoints and more. And our reliable, safe and secure Command Non-Payload Communications (CNPC) data links provide a high-integrity pathway for the critical command and control signals that are crucial for operating in civil airspace. CNPC is an important part of the NASA Systems Integration and Operationalization research program that tests civil airspace access standards.

INTEGRATING UAS INTO THE AIRSPACE

Ensuring command-and-control capabilities for individual UAS is critical. But so is the ability to manage the bigger picture of the mixed airspace. Today we're working with NASA and other entities to use our web-based WebUAS℠ flight data display to successfully manage multiple UAS in the air and redirect aircraft set on conflicting flight paths as needed. Designed to support small UAS operations as well as more complex large UAS operations in civil airspace, this secure, flexible and scalable system is already in use by railways for remote monitoring of tracks and the North Dakota-based UAS Traffic Management (UTM) Pilot Program.

MORE CONNECTED SYSTEMS

An all-too-typical scenario:

It's a late-day flight from New York City to Denver – the last flight of the evening. The northeast corridor is experiencing departure delays due to traffic congestion. Denver is expecting snow.

Thirty minutes late, the flight finally takes off, leaving Manhattan behind. The pilot comes on the intercom. "Hi, folks. Sorry about the delay getting you off the ground tonight. But good news! I've gotten permission from operations to fly at a faster speed, and I can recover most, if not all of the time for an on-time arrival."

Passengers settle back into their seats, relatively confident that all is going to be resolved. Until the plane lands.

It turns out Denver's snow was worse than expected, resulting in departure delays.

As the flight taxis to the terminal, it becomes clear there's no gate for the plane, and it will take half an hour until one will be open.

In this scenario, passengers have gone from unhappy to happy to happy and back to unhappy. And the airline burned a host of fuel.

All for no gain.

Every day, the commercial aviation ecosystem safely transports millions of passengers to thousands of destinations around the globe, making it among the most complex operations in the world.

But as practiced as that operation is, it's also full of inefficiencies, small and large, like the example above. Information can be incomplete or maddeningly delayed. Different players within the ecosystem – from pilots to air traffic controllers to airline back offices to fueling and catering crews – often operate in silos within a very small island of influence, with goals (e.g., turnaround times or reduced costs) that can conflict with others' and the larger, shared goal of moving those millions of passengers as efficiently and effectively as possible. While there have been advances in optimizing the operational or experiential benefits in each player's limited span of control, those have all too often been incremental changes to primarily manual processes.

> With air travel expected to grow over the next 20 years, existing infrastructures and processes are destined to strain or break completely without significant change.

Yet, with demand for air travel expected to grow robustly over the next 20 years, existing infrastructures and processes are destined to strain further or break completely without significant change.

A tale of touchpoints

Today, almost every step in the commercial air travel process generates information. Around the globe, from the moment passengers make a reservation in their departure city, to the moment they catch a cab at the airport in their arrival city, they interact with a wide variety of systems. For instance:

- **Days before, or on their way to the airport,** travelers make airline reservations, confirm boarding passes, request seats and reserve special meals
- **At the airport,** they check in, check large baggage, pass through security, and sometimes dine and shop before going through the boarding process
- **On the aircraft,** connectivity enables work and play for passengers, while flight crews file flight plan updates, process credit card transactions and more, and smart products and systems collect health information and other crucial data
- **Behind the scenes,** a host of activities keeps airlines on schedule and aloft: scheduling, operating and maintaining the fleet; checking fuel supplies; planning crew training; and solving maintenance issues with each aircraft

Each of these interactions, each of these touchpoints, generates data – from a biometric face scan to a fleet's worth of fuel efficiency data on a particular aircraft platform. Sometimes it's immediately used, sometimes it's almost immediately thrown away, and sometimes it's stored *somewhere* – but for undetermined or unclear purposes.

The one thing the data is likely not? It's likely not connected – to other sources of data, to people or companies who can use the data like OEMs and airlines, and to others who can effectively analyze the data, so our industry can work together to ensure travelers reach their destination safely, comfortably and on time.

That's where Collins Aerospace comes in.

A rich history of connections

The history of Collins is, in large part, a history of connections. Collins' equipment connected Admiral Byrd from the South Pole and Neil Armstrong's first steps on the moon to Earth. Our ARINC global network rose from the early days of airlines needing to connect within a fleet and between each other. Today, that trusted, high-integrity, secure network delivers more than 60 million messages a day.

We are also investing in the next generation of system that creates that data in the first place. Kiosk-based and cloud-based passenger processing solutions. Self-baggage drops and management. Single-token biometric systems. Airport operations databases and management software. A variety of connectivity solutions – from traditional VHF to broadband solutions – that link passengers and flight crews alike to the ground. And information-enabled products like advanced avionics, power, mechanical and environmental systems – as well as powerful airborne information systems and airborne networks – that generate data, collect it and transmit it efficiently and securely to destinations near and far.

In fact, Collins is among the only companies in our industry able to provide end-to-end enablement – creating systems that generate data; enabling access to that data and data from other systems on the aircraft through on-aircraft network solutions; and through our air-to-ground and ground-to-ground networks, delivering that data to participants across the aviation ecosystem.

Linking data sets across different operations can forge new connections and understandings between now-siloed systems and organizations, offering new opportunities for collaboration, better decision-making and shared growth.

Digital transformation

What does our broad footprint and deep expertise bring to our customers and the industry? The distinctive pedigree to lead the digital transformation of one of the most complex ecosystems in the world.

Built on our global network and growing information enablement and aviation products, Collins Aerospace is uniquely positioned to link key touchpoints and partners across the commercial aviation ecosystem – from passengers, airlines and airports to aircraft manufacturers, system suppliers and service providers.

Through these connections, partners from across the industry – airlines, airframe manufacturers, and system suppliers and software developers – will all be empowered to solve the many and complex challenges of commercial aviation like never before. New insights can deliver improved efficiencies for operators and more seamless and rewarding travel experiences

for passengers. Linking data sets across different operations can forge new connections and understandings between now-siloed systems and organizations, offering new opportunities for collaboration, better decision-making and shared growth.

Returning to the example that opened this piece, the delayed flight from Manhattan to Denver: In a connected ecosphere, information about developing weather, traffic patterns, gate availability and more could have been shared with the airline, air traffic controllers, Denver airport operators and more – long before it became a problem – to enhance the precision and ultimate success and passenger experience for that single flight and thousands of others, every day.

What will it take?

We are committed to playing a leadership role in this transformation, but it's a path we can't embark upon alone. Collectively, we will need to embrace a new model of relationships among the industry's many and varied players, defined by:

- Embracing advances in digital technology that open the door to a new age of aviation innovation, in which entire processes will be reimagined and re-engineered to deliver never-before-possible performance improvements

Collectively, we will need to embrace a new model of relationships among the industry's many and varied players.

- Ecosystem-wide innovation driven by enhanced digital connectivity, continuous data collection and intelligent systems
- A recognition that no single OEM, airline, supplier or service provider can do this on its own. Instead, many entities will need to engage collaboratively to design and implement new digitally based solutions that will reshape the aviation industry as a whole

There is a broad expertise in our industry, ranging from the OEMs that design and produce aircraft to small software vendors around the world with the analytical know-how to help discover new operational insights. All these entities and their digital innovations will power the future of aviation. Together, we can engage and empower our industry to solve some of the toughest challenges confronting aviation today.

Our ARINC SelfDrop™ self-service bag drop solution streamlines passenger flow

MORE ELECTRIC SYSTEMS

Moving billions of people around the world every year calls for billions of gallons of fuel (17.3 billion gallons in 2017 alone). In fact, the International Air Transport Association (IATA) projects this year's global airline industry fuel bill to be $206 billion, accounting for a full 25 percent of operating costs. **It's estimated that the aviation industry contributes 2-3 percent of the world's human-generated carbon dioxide emissions and 12 percent of CO_2 emissions from all transportation sources.** And aircraft noise is a growing issue with communities around the world.

At Collins, we view these cost and environmental impact challenges as critical to both our industry and our world, and we're putting our 70+ years of expertise and power management and electrical architecture to work to tackle it.

Through significant investments and dedication, we're on a transformational path to significantly increase power system density and – together with United Technologies – fly a hybrid-electric regional passenger aircraft by 2022.

An electric pedigree

At Collins Aerospace, we've been working to harness the power of power for generations, and today we are the leading provider of electric power systems in the aviation industry. We provide the world's largest flying micro grid: the 1.5 megawatt Boeing 787 power management and distribution system. We also supply key systems for the F-35, the most technologically advanced fighter in the world and the most electric plane flying. This work has enabled Collins to develop electric systems knowledge and experience unmatched in the industry.

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In the past decade, we've invested $3 billion to advance more electric architecture, and we'll invest more than $150 million additional in the next few years. These investments have enabled us to improve the power density of key parts of electric systems, and we have ongoing research to support more electric architecture in both next-generation single-aisle commercial air transport aircraft and 6th-generation fighters.

In short, we're powering the promise of more electric flight.

Powering through power challenges

A fully electric, transcontinental aircraft would quickly address the fuel, carbon and noise issues outlined previously – but unfortunately, at this time it's untenable.

It comes down to the challenge of energy density and power density. The task ahead of us is evident when you consider that jet fuel has 50 times the energy density of today's batteries, and a typical jet engine has three times the power density of today's electric engines.

In practical terms, this means that a sophisticated battery that could power a commercial air transport aircraft would be so heavy that the aircraft would be unfeasible – aerodynamically, operationally and economically. Even at a smaller scale – for instance, a smaller, regional electric aircraft – battery weight is more achievable physically, but the lower power density means the plane would have a range so limited it would essentially render it economically unsustainable.

Our 1.5 megawatt power management and distribution system on the Boeing 787 is the world's largest flying micro grid

Project 804 will re-engineer a Bombardier Dash 8 Series Q100 into a hybrid-electric aircraft

But it's not just about generating more power, it's also about being able to control, protect and manage the power and thermal environment. Significant amounts of electrical power at altitude is not an easy thing to manage, and real expertise is needed.

Highly efficient power distribution and conversion is required to maximize the use of available power and minimize the thermal management system. High voltage systems will be required to help achieve this for commercial aircraft. However, isolating very high voltage at altitude is challenging. Additional spacing and insulation systems are required, and that impacts weight. Also the safe use and management of electricity on an aircraft – the system design – is critically important and another crucial challenge.

While an all-electric transcontinental aircraft will need orders of magnitude improvement in energy and power density (along with heightened power management solutions), we see another option to deliver electric propulsion in a technologically feasible way: hybrid-electric propulsion.

The promise of hybrid-electric power

By combining the power of traditional engines with energy-saving and environmentally friendlier electric technologies, we believe we can achieve an optimum balance in a relatively quick time frame.

> We believe that a hybrid-electric passenger aircraft with a range of 500 miles and capable of carrying 50 passengers will be certified within the next 10 years.

It would begin small, of course. To power a regional, hybrid-electric aircraft with usable range and fewer than 50 passengers, the energy and power density of current batteries will need to double. That's challenging but doable. In fact, we believe there is a path to achieve this in the next few years, and that a hybrid-electric passenger aircraft with a range of 500 miles and capable of carrying 50 passengers will be certified within the next 10 years.

Thinking bigger, to make a single-aisle, 100-seat hybrid-electric aircraft viable will require densities to double yet again. This capability is at least an additional 10 years beyond the regional case, and would mark a 4x density improvement over 15 years.

Proving power through Project 804

In March, Collins Aerospace, alongside United Technologies Advanced Projects and Pratt & Whitney, announced Project 804 – a hybrid-electric X-plane based on a Bombardier Dash 8 Series Q100 aircraft. Working together, we will re-engineer one side of the aircraft with a 2 megawatt-class propulsion system combining an engine (sized for cruise power) and a similarly

sized, 1 megawatt motor, motor controller and battery system to provide supplemental power during takeoff.

This system is expected to yield an average fuel savings of 30 percent, effectively making regional flights as practical as a Greyhound bus trip. We project a mission range of approximately 600 nautical miles – and a first flight in less than three years from now.

To support this endeavor, we recently unveiled our plans for The Grid: a 25,000-square-foot, high-power, high-voltage electric systems lab in Rockford, Illinois. The lab will serve as the development center of the 1 megawatt motor for Project 804 – the aerospace industry's most power-dense and efficient to date. In fact, The Grid will be one of a select few facilities in the world with the capability to test complete electric propulsion systems of this capacity. We will also continue to leverage the lab to create advanced electric systems for the next generation of more electric fixed-wing and rotary aircraft, including commercial, military, business, UAV and urban air mobility platforms.

United Technologies studies indicate that hybrid-electric propulsion will reduce carbon dioxide emissions by more than 20 percent and improve fuel consumption up to 40 percent.

Planning for a more electric world

As we look at the route ahead, there are clearly challenges in moving our industry toward a more electric world. But Collins Aerospace is prepared to embrace them, and the combination of skills and experience we bring to the challenge – our expertise in electric systems, environmental systems and engine systems – is unmatched.

And, most important, the results of this investment for OEMs, airlines, passengers and the global environment will be transformative. In fact, in addition to significant reductions in airline operating and maintenance costs, United Technologies studies indicate that hybrid-electric propulsion will:

- Improve fuel consumption up to 40 percent
- Reduce carbon dioxide emissions by more than 20 percent

This investment in next-generation electric and hybrid-electric systems for use on current and emerging commercial and military platforms is not just the right call. It's a critical first step in sustainably growing the industry – from the company that's dedicated to redefining it.

Earlier this year we announced our $50 million advanced electric power systems lab, "The Grid"

TOGETHER, WE'LL ACHIEVE EVEN MORE

We live in an exciting moment in history, where a spirit of "**more**" – in intelligent and autonomous systems, new realms of digital connectivity and collaboration, and breakthrough advances in electric power – has the potential to resolve some of our industry's toughest challenges.

But this innovation isn't ours alone. At Collins Aerospace, we believe in the powers of intelligence and partnership to guide our customers and our industry into the future. So "**more**" also means **more** opportunities for collaboration – to work side by side with our customers, suppliers and others who embrace bold, compelling innovations, paving paths together that lead to limitless possibilities.

At Collins Aerospace, we are redefining aerospace by shaping a future that is more intelligent, more connected and more electric than ever ... and we can't wait to show you – and work together to achieve – **more**.

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