GREEN IDEAS BORN TO FLY™:

HOW WEIGHT, DESIGN AND INTEGRATED SYSTEMS DRIVE SUSTAINABLE AVIATION AT UNITED TECHNOLOGIES

GREEN AVIATION STARTS HERE

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IN BRIEF

- While global aviation supports 3.4 percent of the world's economy, the industry's rapid growth over the next two decades requires an intensive focus on improved sustainability.
- Aerodynamics and jet engine efficiency are the most visible components of aircraft sustainability, but the weight, design, and performance found in dozens of integrated systems that operate an airplane also contribute in a critical way.
- Few companies understand this "systems perspective" as well as UTC Aerospace Systems, whose integrated, electric, and intelligent systems are deployed on 70,000 aircraft around the world.
- By investing aggressively in R&D, working with partners like NASA and the Federal Aviation Administration (FAA), and capitalizing on a unique systems perspective that reveals the integrated needs of an aircraft, UTC Aerospace Systems is making a powerful contribution to commercial aviation sustainability.

This is Paper 4 in a series of four.

Click to read Paper 1, "The Modern Silk Road: Aviation in the Age of Sustainable Urbanization,"

Paper 2, "The Future of Sustainable Aviation: Betting on Jet Propulsion & Lower Net Carbon Fuel,"

or Paper 3, "Greening Aviation from the Ground Up."

The Airborne Village

Imagine a village of 300 people.

"Now," says Bob Guirl, a strategy advisor for UTC Aerospace Systems, "lift that village 40,000 feet up and fly it across the Pacific Ocean. But make sure everyone has all the necessities and comforts they have on the ground," Guirl adds, "like air, food, water, electricity, lights, and of course, Internet service."[1]

This description of an "airborne village" captures the miracle of modern aviation, a global industry that safely[2] transported 3.5 billion people on 37.6 million flights in 2015.[3] In the United States alone, domestic and international airlines carried an all-time high of 895.5 million passengers,[4] the equivalent of nearly 3 million villages lifting off and setting down securely, connecting people around the world for business, family, and pleasure.

Consider all those people, all those systems enabling travel at 40,000 feet high at 600 miles per hour around the planet. And then consider, after millions of miles of travel, the "villagers'" single biggest complaint: *lost baggage.*[5]

But that's just a part of the miracle.

Global aviation supports 63 million jobs and $2.4 trillion in gross domestic product,[6] or 3.4 percent[7] of the world's economy. The industry plays a fundamental role in the creation of healthy urban environments, meeting the growing needs of a dynamic middle class that could double in number to 4.9 billion by 2030.[8] In a world where less than 20 percent of humankind has ever stepped foot on an airplane,[9] demand from these new travelers will require the world's commercial fleet to nearly double to 47,000 aircraft by 2030.[10]

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Given this growth, the airline industry is focused intensely on sustainability. Since the first jet aircraft flew, commercial air has lowered carbon dioxide (CO_2) emissions per seat kilometer by more than 80 percent, and perceived noise by more than 75 percent.[11] Between 2009 and 2014, average annual fuel efficiency improved by 2.4 percent annually.[12] And the future looks even brighter.

The United Nations' International Civil Aviation Organization (ICAO) has challenged the industry, which today produces about 2 percent of total human CO_2

emissions,[13] with an aspirational goal for 2050 of reducing net aviation emissions to half of their 2005 total.[14] In March 2017, ICAO formally adopted a new global standard for aircraft CO_2 emissions that could help save up to 650 million metric tons of CO_2 by 2040 while contributing to a greener aviation industry.[15]

Improved aviation sustainability depends heavily upon advanced gas turbines. Pratt & Whitney's (P&W) PurePower® Geared Turbofan™ (GTF) engine, for example, is transforming the single-aisle commercial aviation segment by reducing fuel burn by 16 percent and noise footprint by 75 percent overall, and it has a 50 percent margin below CAEP 6 nitrogen oxide (NOx) standards.[16] Sustainability is also dependent on continued industry investment and government support of lower net carbon fuels, and enhancements to air traffic control.[17] There are potential savings on the ground as well in the infrastructure that supports flight; a large airport consumes as much electricity and thermal energy annually as a city of 100,000 people.[18] Consequently, the industry's emphasis on greening airports can pay huge dividends in the coming decades.[19]

United Technologies, through its business units Pratt & Whitney and UTC Aerospace Systems (UTAS), is a leader in shaping aviation's sustainable future. Alongside Pratt & Whitney's groundbreaking GTF engine, and UTC Aerospace Systems' nacelle development work, the company is advancing a host of innovations designed to meet both the growth and sustainability needs of global aviation over the next generation.

Less is More: A Systems Perspective on Sustainability

A systems perspective on aviation sustainability bridges the dozens of technology platforms on modern aircraft. Bob Guirl recognizes this need for an integrated, comprehensive approach when he says, "Of course, you can't put a box around a village, bolt on wings, and fly it, because it would be immeasurably large."[20] And that's where the marvel of modern flight meets the elements of design, weight, power—and sustainability.

A commercial aircraft is a stunning work of human invention, but as one flies overhead, much of its technology is concealed from view. The Airbus 380, for example, which can transport a "village" of 850 people, requires 100,000 wires measuring 292 miles.[21] Sections of the A380's sophisticated landing gear, hidden away in the nose, wings, and body of the aircraft, stand 19 feet tall.[22] And the new Boeing 787 Dreamliner has about 2.3 million parts per plane.[23]

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Few companies understand the inner workings of an aircraft as well as UTC Aerospace Systems, which provides 26 different proprietary systems for the Boeing 787,[24] and more than 30 for the Airbus A380,[25] to name just a few. Formed in 2012, UTC Aerospace Systems combined two industry leaders, Hamilton Sundstrand and Goodrich Corporation, to create an organization that today has some 41,000 employees, including 8,000 engineers,[26] across more than 150 sites in 26 countries.[27] It is one of the world's largest suppliers of technologically advanced aerospace and defense products.[28] In all, the company sells 90 different product lines to 1,500 customers.[29] Components made by the company are at work on 70,000 aircraft around the world;[30] in fact, every second a plane takes off with its systems on board.[31]

Lufthansa Group's new A320neo upgraded single-aisle commercial airplane is a good illustration: UTC Aerospace Systems provides flight control actuation, cockpit controls, cabin pressure and control, electric systems, fire protection, emergency power, cockpit and exterior lighting, wheels and brakes, and air data sensors.[32]

This breadth of technology provides the company's engineers with a unique, holistic view into aircraft system design and its impact on sustainability. "A systems perspective lets us look across what, in aviation, have been historical boundaries," Guirl says, "or what would have been 'trades' in a village, like plumbers and electricians. That helps us to find integration opportunities which simplify a system, eliminate parts, reduce weight, improve efficiency, and increase reliability."[33]

John Sullivan, a Vice President of Engineering at UTC Aerospace Systems, explains how this view of sustainability extends beyond the aircraft. He asks, "How big a burden is making, fielding, and retiring a part or component to the world? Does it need a lot of maintenance? Does it contain, or require during fabrication, any materials which are caustic or dangerous to the environment? Does it add weight?" Sullivan adds, "Whatever we can do to help an aircraft burn less fuel makes it more sustainable. We reduce the overall burden as well by designing more compact, higher-performing systems. For example, the landing gear is one of the heaviest components of an airplane. When we reduce its weight, we improve the range of the airplane, but we also improve the overall value chain, starting at the point of origin of the raw material, all the way through to fabrication, logistics, delivery, and final assembly. It's a big ecosystem benefit beyond the airplane."

In other words, when UTC Aerospace Systems engineers design for sustainability, they factor in performance, cost, maintenance, and reliability. They make choices around materials, manufacturability, and supply chain. Informing these decisions are three underlying principles that drive systems sustainability: less weight, less drag, and less waste. When a system is lighter, more aerodynamic, and more streamlined, it becomes more sustainable. The company applies these powerful concepts across multiple systems in modern aircraft, resulting in elegant solutions whose total positive impact on sustainability vastly exceeds the sum of their parts.

Sullivan adds, "It's not one signature product that drives sustainability. It's all about the value of the system—actually, the system of systems—and the scientific approach to how we engineer their performance on the aircraft, pushing the envelope on innovation. It's the culmination of all of these things that ladder out to a bigger impact."

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Less is More: Weight and Sustainability

Less weight means less jet fuel burn, which of course means lower CO_2 emissions.

"Every time you think about an airplane design," Bob Guirl explains, "you think of weight. The first thing you think about is weight. The last problem you address is weight. Every model change factors in weight. How can we increase efficiency by reducing weight?"[34]

This emphasis, as Guirl notes, is pervasive throughout the industry. For example, there's an old story about the CEO of a major airline who called for the removal of a single olive from every first-class salad, hoping to save his company in reduced fuel costs.[35] Studies suggest that passengers' cellphones on a Southwest Airlines flight cost $1.2 million annually in weight-related fuel expenses.[36] Virgin Atlantic has calculated savings of 14,000 gallons of fuel annually by shaving a single pound off each plane in its fleet.[37] And, since fuel can represent 40 percent of an airline's operating costs—larger even than labor expenses[38]—every drop is precious.

The advantage of reduced weight has led in the last generation to a steep rise in the use of composite materials, which are stronger, lighter, and more resistant to corrosion than the metal they replace. The Boeing 777, now more than 20 years old, is comprised of 12 percent composite material, while the latest Boeing 787 Dreamliner[39] and the Airbus A350[40] are 50 percent composite.

As a company responsible for millions of parts on thousands of airplanes all over the world, UTC Aerospace Systems applies a combination of advanced composites, additive manufacturing techniques (like 3-D printing), and its unique systems perspective to reduce weight throughout an aircraft. This combination of forward-thinking design and science-based materials selection results in fewer components and reduced weight.

One good example is aircraft brakes, essential to bringing an 850,000-pound aircraft[41] to a safe and comfortable stop under any and all conditions. UTC Aerospace Systems has developed an advanced manufacturing process involving chemical vapor infiltration of a network of very thin carbon fibers woven into a mat "like a steel wool pad," says Richard Jones, General Manager of Boeing Programs Landing Systems at the company.[42] The result of this process is carbon-carbon (or C/C, meaning "carbon fiber-reinforced carbon") brakes that save hundreds of pounds in comparison with brakes of traditional metal construction.[43]

On a Boeing 737 with four brakes, C/C brakes save about 700 pounds from the traditional steel brake

"And just to give you a sense of how significant the weight savings are," Jones says, "on a Boeing 737 with four brakes, C/C brakes save about 700 pounds from the traditional steel brake. Seven hundred pounds amounts to, potentially, a few more passengers and their luggage, or the equivalent reduced fuel burn. "We've roughed out estimates of savings," Jones explains, "and it's on the order of a couple of hundred metric tons a year (per plane) of CO_2 reductions by moving to a C/C brake. Nitrogen oxide emissions are reduced as well. And the operators gain the financial benefit of burning less fuel."[44]

The sustainability benefits of the C/C brakes manufactured by UTC Aerospace Systems extend well beyond the runway. "There are also a lot of efficiencies to be gained through design," Jones says. "Our carbon material has about a 35 percent advantage in brake life over competing manufacturers' material. That means we produce dramatically less carbon and use fewer resources to manufacture the brakes in the first place."[45] That's an important, sometimes hidden contribution to system sustainability.

And there's more. "The 35 percent wear-rate advantage roughly equates to 35 percent longer time on an aircraft which, depending on the aircraft and operator, might be one to three years. So," Jones continues, "this wear-rate advantage has a very positive impact in reduced overhaul cycles. And the overhaul process entails a lot of maintenance processes, such as paint stripping and repainting—so there's significant environmental impact avoidance by reducing the number of shop visits. And there are also consumable components that get changed out on overhaul," Jones concludes, "so, we decrease our footprint again by virtue of making the brakes last longer."[46]

The manufacture of brakes also consumes significant amounts of energy, which company engineers are working to reduce by eliminating waste. For example, a traditional manufacturing process might result in a final "buy-to-fly" ratio as high as 10—a 10-pound block yielding a 1-pound part, a waste of 90 percent. With additive manufacturing, UTC Aerospace Systems can achieve buy-to-fly ratios closer to 1, meaning no material is wasted in the manufacturing process.[47]

Additive manufacturing can also benefit aircraft repair. Having additive-repair machines at maintenance, repair, and operations (MRO) sites around the world will one day allow for the manufacture of new parts and tools on-site, eliminating inventory, aircraft downtime, global shipping time, and cost.

Brakes are part of the larger landing system, an area that has also steadily shed weight over the years. On a large commercial airplane, a set of landing gear can weigh between 10,000 and 20,000 pounds. A decade from now, it is anticipated that the shift to composites in landing gear will result in an additional 15-25 percent weight reduction, saving 2,000-3,000 pounds per ship set. The supporting aircraft structures would see additional weight savings due to carrying lighter landing gear.

Composites and additive manufacturing are forecast to have a dramatic impact throughout the entire aircraft, eventually reducing overall weight by as much as 7 percent while reducing fuel consumption by 6.4 percent.[48] A second model estimates that additive manufacturing of aircraft parts, fleet-wide through 2050, could result in the cumulative emission reduction of up to 217 million tons of CO_2 equivalent.[49]

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Another area where UTC Aerospace Systems has a unique perspective to reduce weight and improve performance is actuation. "There are actuators all over an airplane," says John Sullivan. "Actuators are the things that make other things move on an airplane, and we make thousands of them. You will find them on primary flight controls, secondary flight controls, the rudder, the aileron, the thrust reverser, and the elevators." Many today are mechanical by design; Sullivan says, "There is a benefit to the airplane to remove traditional hydraulic and pneumatic actuation systems and put in electrical systems."[50]

The less weight in the airplane, the less structure that's required to support that weight

For example, nearly every system on a Boeing 787 is electric, relying on motor controllers instead of hydraulic valves. "In many cases, the airplane is no longer carrying hundreds of pounds of hydraulic fluid and hydraulic pumps," Sullivan continues. "So there's a significant benefit in cost and fuel burn savings, largely from a reduction in weight and parts count. We eliminate miles of hydraulic tubes designed to carry fluid at a thousand pounds per square inch of pressure." Sullivan adds, "With electric actuation you can eliminate both the hydraulic fluid and pumps, along with the associated tubes, O-rings, seals, inspections, and potential hazardous leakage. The electric wiring can last 20 years or more, with inspections at the systems level, rather than detailed visuals. So, the aircraft immediately gets lighter, more reliable, and easier to maintain."[51]

A similar story is being written at UTC Aerospace Systems around oxygen generators, which traditionally have been encapsulated because they can reach temperatures of 900 degrees Fahrenheit when they generate oxygen that allows passengers to breathe when the masks deploy. Sullivan says, "These systems are very expensive to install and expensive to replace. We're now looking at new systems that operate differently, and are scalable. These systems are likely to last the life of the airplane, unlike current versions that need to be replaced every 10 years, or after they deploy."[52]

Reducing weight in a plane, whether from landing gear, brakes, or actuators, is a virtuous cycle. "The less weight in the airplane, the less structure that's required to support that weight," Sullivan concludes. "As the structure gets thinner, it requires less fuel, and the airplane gets lighter and more efficient. At UTC Aerospace Systems, we're energized to do this—to remove weight and improve efficiency and sustainability. We're actively implementing these new technologies today."[53]

Sustainability in aerospace is not an afterthought—it's designed from the beginning.

Take, for example, UTC Aerospace Systems' engineering expertise in producing the nacelle system—the sophisticated aerodynamic structure that surrounds a jet engine[54]—for Pratt & Whitney's groundbreaking PurePower® Geared Turbofan™ (GTF) engine. By combining new designs with the latest in composite technology, the team at UTC Aerospace Systems created a 360-degree acoustically smooth inlet that helped to reduce fuel burn and engine noise, enabling a fully integrated propulsion package that optimized performance and sustainability.[55] The ability to reduce drag even as the fan grew in size resulted in a system now in production for more than 80 customers in more than 30 countries.

UTC Aerospace Systems is currently developing technologies for the next generation nacelle, known as the ecoIPS™ (Ecological Integrated Propulsion System), alongside two partners in a program that demonstrates the power of a broad, systems perspective in enhancing aviation performance and sustainability.

UTC Aerospace Systems is currently developing technologies for the next generation nacelle, known as the ecoIPS™

In 2015, the FAA announced that UTC Aerospace Systems had been selected to participate in the FAA's Continuous Lower Energy, Emissions, and Noise (CLEEN) II initiative.[56] Under the agreement, the company is designing and producing next-generation nacelle technologies for an advanced thrust reverser with lower drag, and improved acoustic treatment for noise reduction. The ecoIPS™ will be tested on a Pratt & Whitney GTF engine.

"This is an important, exciting step-change in our reverser technology,"[57] says Teresa Kruckenberg, a Director of R&D for the company's Aerostructures business. "There is strong alignment between where we need to be in the future and what the FAA is promoting. With the ultra-high bypass engine in the nacelle, we were attacking the fuel burn—around a 1 percent savings from the reverser—as well as noise."[58]

"The work we're doing has nothing to do with getting better reverse thrust efficiency, though," adds Stephane Dion, Vice President, Engineering, Aerostructures. "What we're really trying to do is get better performance in flight—to have the lowest drag reverser in flight. That means making it slimmer and shorter;

we're looking at opportunities that give us 30 percent reduction in length. What usually drives the design is acoustic treatment areas," Dion says. "As you make the nacelle shorter, you have to have novel solutions to be able to absorb the same amount of engine noise."[59]

The thrust reverser is a component with some 1,500 parts. "But the novelty is not in changes to all these bits and pieces," Dion adds. "It's really the system architecture that we're focused on. It's the mechanism that drives the blocker doors that reverse the flow, the way the actuators are designed, the kinematics of the doors—the system architecture."[60]

NASA is another important partner to UTC Aerospace Systems on the ecoIPS™ project. "NASA has very specific strategic thrusts, and one of them is for ultra-efficient commercial vehicles to develop technologies which provide high levels of aerodynamic performance. Advanced laminar flow is one of these technologies, especially for high bypass ratio engines," says Kruckenberg."[61] "Laminar flow overwhelms everything else in a way," Dion adds. "It is so important from a fuel burn standpoint, that achieving laminar flow lines, and keeping the flow attached, is nearly double everything else we could do on an inlet, or the nacelle."[62]

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The ecoIPS™ project further demonstrates the broad, systems approach that UTC Aerospace Systems engineers bring to aircraft sustainability. Being considered, for example, is electric ice protection, a design that would place heating elements in the nacelle inlet instead of pneumatic ice protection. Electric ice protection could potentially leverage power sharing within an all-electric aircraft systems architecture. "As part of these various projects," Kruckenberg says, "we're also going to demonstrate a number of our conversion coatings and primers that are chromate-free. Our goal," she adds, "is to have fewer hazardous materials in our product, which gives us a better end-of-life recycling capability as well. Those are key contributors to sustainability."[63]

When simplicity can remove obstacles, often sustainability wins.

As actuators and other systems on modern aircraft become electric, issues of system architecture and power density arise. UTC Aerospace Systems employs a combination of technology and forward design to simplify individual aircraft systems, resulting in fewer raw materials, lower maintenance, and reduced weight.

In all, UTC Aerospace Systems has invested $3 billion over the last decade to develop more-electric aircraft systems, including the creation of 15 research labs and the generation of more than 1,000 patents

For example, the company develops systems that generate and control the flow of power throughout an aircraft, from critical functions like navigation to in-flight entertainment and seating lights. “We work closely with the airframer,” John Sullivan says, “to design the electrical system architecture on an airplane. We make decisions together: What is the optimum architecture when considering where the power is generated, how should it be distributed, and where is it consumed? How do we minimize the amount of transmission wires we need in terms of weight?”[64] The stakes in this are surprisingly high; the 292 miles of wiring on an Airbus 380, for example, weigh nearly 6 tons.[65]

One goal of improved electrical system architecture is enhanced power density. “The Boeing 787 is a 1.5 megawatt airplane,” Sullivan says, “enough to power a small neighborhood. UTC Aerospace Systems makes the power generators for that airplane: two on each main engine, and two on the Auxiliary Power Unit (APU). The power density of that system has improved by double-digit percentages in the last 20 years, meaning more power is distributed by the same generation footprint,” he says. “As we look at alternate materials and improved methods for power generation, we see further improvement.”[66]

“Similarly,” Sullivan adds, “our electric systems experts looked at power distribution, which has always included electro-mechanical switches, like the circuit breakers in your home. We are developing digital technologies that employ solid-state switches and microprocessor controls, providing reduced weight and higher reliability.”[67] In all, UTC Aerospace Systems has invested $3 billion over the last decade to develop more-electric aircraft systems, including the creation of 15 research labs and the generation of more than 1,000 patents.[68] The company’s goal is to reduce the weight of the components and system packaging required per kilowatt of power converted.[69]

In addition, the company's multiplexed common motor starter controller (CMSC) can be used to power different components on an aircraft at different times, allowing for the complete elimination of extra controllers. On some platforms that equates to a reduction of five motor controllers at 500 pounds combined.

Less is More: What's Next?

An estimated 2,000 to 3,000 pounds less for composite landing gear. One thousand pounds less of wire. Five hundred pounds less for motor controllers.

Pretty soon, as they say, it's real weight. Add to that an emphasis on aerodynamic design, a systems perspective that promotes simplicity, and the company's commitment to lower fuel burn and improved sustainability, and commercial aviation can achieve its long-term goals.

While UTC Aerospace Systems has important partnerships with NASA and the FAA, and works closely with other UTC business units like Pratt & Whitney, its future success will evolve from its close relationships with other original equipment manufacturers (OEMs) and aircraft companies. "We engage with an OEM very early on," Richard Jones explains. "The OEM will have lots of conceptual trade studies around what their customers want in terms of market space. What sort of payload and passengers? How far does it need to fly? What does the airplane need to look like to fill the airports as they are, and the passenger flying patterns as they're projected to be over the coming decades?"

Jones continues, "As the OEMs are doing that they'll reach out to us, and we'll engage with information around how we would scope, for example, the size of a brake to support a given amount of energy. That's a physics question. And then we get into the system level of an airplane: How long are my axles? How large a diameter are my wheels? So, we engage in those trade-off studies with the OEMs. At some point the OEM will give us a maximum weight for our product, though it really behooves UTC Aerospace Systems to design the lightest product that we can but still have the reliability that the operators expect. It comes down to a classic design problem," Jones says, helping to explain the kind of systems thinking that distinguishes UTC Aerospace Systems. "We have to meet performance specs while managing the costs and benefits associated with reliability with weight."[70] And in the case of systems like brakes, that thinking extends from material selection to the company's green supply chain.

"The major engineering thrusts for the next five years are advanced manufacturing and advanced materials, and solutions that are more electric, more connected, and more intelligent," John Sullivan explains. "We can bring this to the market. And thanks to our broad capabilities and offerings, we can see things that others might not see."[71]

One example is UTC Aerospace Systems' SmartProbe® Air Data System, a high-performance air data solution in service on 15 programs today, with nine more in development. The system integrates sensing probes, pressure sensors and powerful air data computer processing to provide all critical air data parameters, including pitot and static pressure, air temperature, air speed, altitude, angle of attack, and angle of sideslip. This is where intelligence meets sustainability through design, weight, and simplicity: The SmartProbe® Air Data System eliminates the need for individual sensors, associated wiring, and pneumatic pressure lines of traditional systems, offering a 50 percent weight savings when compared with a traditional air data system.[72]

UTC Aerospace Systems' broad perspective and commitment to less weight, less drag, and less complexity is a story of continually improving sustainability and moving the entire aerospace industry forward.

At the parent company level, United Technologies is uniquely positioned to meet the challenge of efficient aviation head-on through existing technology, processes, and innovation. The company has tripled its revenues since 1997 while reducing water consumption by 60 percent and greenhouse gas emissions by 34 percent. The company is on track to reduce greenhouse gas emissions 80 percent by 2050 in support of the United Nations climate goals.

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Sustainability is core to UTC's business growth. For almost 30 years the company has made significant progress and is committed to doing more. When it comes to sustainability, it's not an option—it's an imperative.

[1] Telephone interview, Bob Guirl, February 14, 2017.

[2] "American commercial aviation is, by huge margins in terms of fatality rates per billion passenger miles traveled, the safest way to travel. . .[and] with only a few exceptions in very troubled nations, commercial aviation around the world remains extraordinarily safe, statistically speaking. And even in those countries and/or aboard airlines about which the FAA occasionally issues traveler-beware warnings, flying is safer than driving, taking a bus or a train, riding a bike or a motorcycle, or even walking. . . ." See Dan Reed, "In A Dangerous World, U.S. Commercial Aviation Is On A Remarkable Safety Streak," Forbes.com, December 28, 2016, Web February 23, 2017, http://www.forbes.com/sites/danielreed/2016/12/28/in-the-last-7-years-you-were-more-likely-to-be-run-over-by-a-car-than-to-die-in-an-airline-crash/print/.

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[6] "Environmental Policy," International Air Transport Association, 2017, Web February 25, 2017, http://www.iata.org/policy/environment/Pages/default.aspx.

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[8] Mario Pezzini, "An Emerging Middle Class," OECD Observer, 2017, Web February 26, 2017, http://oecdobserver.org/news/fullstory.php/aid/3681/An_emerging_middle_class.html.

[9] In 2004, only 5 percent of the world's population had ever flown. See "VITAL FACTS: Selected Facts and Story Ideas from Vital Signs 2006-2007," Worldwatch Institute, 2013, Web October 13, 2016, http://www.worldwatch.org/node/4346. No worldwide database keeps track of this statistic, however, 5 percent of the world's population in 2004 represented 321.7 million discrete global flyers. The global middle class grew 7 percent annually between 2001 and 2011. If we apply this growth rate to discrete travelers through 2015, we estimate 677.3 million, or about 9 percent of the global population, which may have been accelerated by the rise of low-fare airlines. That suggests something greater than 9 percent of humankind has flown as of 2017, but probably well under 20 percent. See also Christine Negroni, "How Much of the World's Population Has Flown in an Airplane?", *Air & Space Magazine*, January 6, 2016, Web October 13, 2016, http://www.airspacemag.com/daily-planet/how-much-worlds-population-has-flown-airplane-180957719/?no-ist, "A Global Middle Class Is More Promise than Reality-From 2001 to 2011, Nearly 700 Million Step Out of Poverty, but Most Only Barely," Pew Research Center, July 8, 2015, Web October 13, 2016, http://www.pewglobal.org/files/2015/07/Global-Middle-Class-Report_FINAL_7-8-15.pdf, 13. "Aviation: Come Fly with Me," *Time*, Friday, June 25, 1965, Web October 13, 2016, http://content.time.com/time/magazine/article/0,9171,833812,00.html.

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[12] Aviation Benefits Beyond Borders, Air Transport Action Group, July 2016, Web February 26, 2017, http://aviationbenefits.org/media/149668/abbb2016_full_a4_web.pdf, 8.

[13] Aviation Benefits Beyond Borders, Air Transport Action Group, July 2016, Web February 26, 2017, http://aviationbenefits.org/media/149668/abbb2016_full_a4_web.pdf, 7.

[14] "Aviation Benefits Beyond Borders," Air Transport Action Group, July 2016, Web February 26, 2017, http://aviationbenefits.org/media/149668/abbb2016_full_a4_web.pdf, 29.

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[19] See the United Technologies white paper, "Greening Aviation From the Ground Up" at http://naturalleader.com/wp-content/uploads/2016/12/UTC-8176-GreenAviationWhitePaperRv.pdf.

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