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THE NEW AIRMINDED:

Civil aviation's post-pandemic transformation

Aviation's future and its impact on a changing global commons

by Paul Saffo

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Executive Summary

To no one's surprise, air travel is undergoing a stuttering rebound unfolding in concert with the COVID-19 pandemic's ebbs and flows. However, this rebound conceals deeper transformations poised to utterly change the air travel ecosystem at a scale at least comparable to the transformations that followed the introduction of jet travel in the 1950s. The pandemic has acted as a powerful forcing function, accelerating some trends, eliminating others, and above all creating openings for entirely new airborne innovations. And just as the advent of 1950s' jet travel influenced the shape of the late twentieth century global order, the coming transformation will have a profound effect on our notions of proximity and the shape of what constitutes our "global commons"—that ever complexifying shared social, political, and physical space in which we all live.

My shorthand for this transformation is "airminded," a term borrowed from the early twentieth century dawn of aviation that nicely captures both the technical reality of the coming aviation innovations, an underlying entrepreneurial optimism regarding future flight possibilities, and its impact on daily life and popular imagination in the decades to come.

Introduction

Aviation's Future: This Is Not Just a Recovery, It's a Transformation

Civil aviation: a gradual return to pre-pandemic levels, with a deeper transformation

As the world struggles to emerge from the depths of the COVID-19 pandemic wave, it is evident that air transport will experience a steady rebound as leisure travelers eagerly reschedule deferred family and tourist travel, while business travelers realize that not every deal can be closed via videoconferencing. The exact timing of the rebound will be gated primarily by the rate at which new COVID-19 variants and infection rates are brought under control. In the meantime, however, look for steady increases in both domestic travel and travel within regions where infection rates are brought under control and reciprocal arrangements are in place.[1]

As indicated in Figure 1, the International Air Transport Association (IATA) forecasts an overall return to historic trends by 2024, with international travel lagging slightly behind domestic travel. I am skeptical of the 2024 date but believe the shape of the trend line reflects the most likely scenario: domestic growth will lead international growth as Revenue Passenger Kilometers (RPKs) return to pre-pandemic levels followed by continued global aviation growth.

But this is more than a recovery: expect a profound transformation in the civil aviation ecosystem

This projected return to historic norms belies a range of profound changes with important geopolitical implications. More specifically, the effects of the pandemic have acted as a powerful forcing function, accelerating some trends already underway, extinguishing other trends, and above all, spurring both technological and commercial innovations all but certain to turn assumptions about the interaction between physical air travel and cyberspace on their head.

The combined cross-impact of these trends will result in a profoundly transformed air transportation environment. We will not just travel more, we will travel differently. And with this will come a profound change in our collective worldview that in turn will affect perceptions of geopolitics. Simply put, we are entering a new age of "airmindedness"—a realization that the world is at once smaller and larger than we assumed: smaller in distance, but larger in diversity and surprise than most have imagined.

1 "Control" does not mean that all incidences of infection are eliminated, but rather that infection rates are reduced to a low, and above all, predictable level.

"Airminded" was a phrase oft-heard in the early days of aviation a century ago.[2] At once both prophecy and reality, it neatly captured both the passion of early aviation innovators and the public's expectation of how air travel would transform the world. In this moment of ever-growing desire to travel and innovators creating everything from Jetson-like personal electric vertical takeoff and landing (eVTOL) aircraft to space flight tourism platforms, we have entered a new age of airmindedness in which both device and destination are capturing the public's imagination.

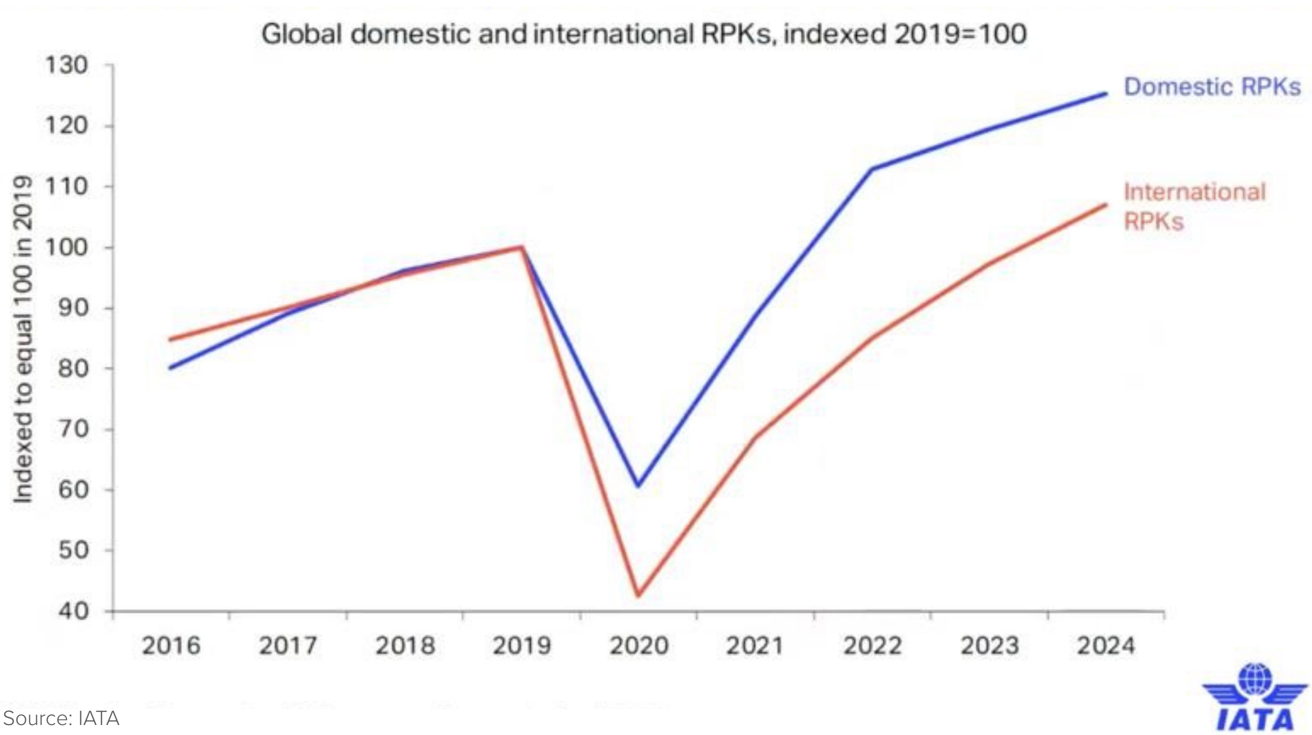
The immediate future resembles the dawn of 1950s' jet travel

In terms of overall scale, we are entering a period of transformation comparable to or greater than the transformations that ensued following the advent of jet travel with the DC-8 and Boeing 707 in the 1950s. Like then, we are witnessing a convergence of technical innovations, new business models, growing travel demand, and increased public fascination with the potential of new aviation platforms.

Historically, carriers tended to favor capacity over speed: carrying more passengers per flight translated into both economies of scale in the sky as well as efficient use of limited landing slots and gates at airports. The post-pandemic reality is shifting to a focus on speed, first in the form of shortening trip times with point-to-point routing and then followed by higher air speeds as a means to making more efficient use of landing slots with faster turnarounds.[3] This will be accompanied by an overall reduction in passenger capacity of individual aircraft, particularly as eVTOL "air mobility" offerings begin to arrive.

The most important factors and trends are outlined below.

International RPKs will lag domestic air travel markets



Source: IATA

2 For an overview of the history of airmindedness, see Joseph J. Corn, *The Winged Gospel: America's Romance with Aviation*, 1900-1950 (New York: Oxford University Press, 1983).

3 This debate was last joined in 2000, when Boeing bet on smaller aircraft and higher speeds in the form of its Sonic Cruiser, while Airbus bet on capacity in the form of its A380. Airbus won the bet: the Sonic Cruiser was cancelled in 2002, and the A380's first flight was in 2005, followed by commercial introduction by Singapore Airlines in 2007.

Global trends and implications for aviation's future

Farewell to the Jumbos (and Superjumbos)

One of the earliest impacts of the pandemic travel shutdown was the grounding of virtually all of the still-flying Airbus A380s and Boeing 747s (collectively, "jumbos") in favor of twin-engine wide bodies (e.g., the Airbus A350 and Boeing 767/777) and smaller narrow-body aircraft (e.g., the Airbus A320 and Boeing 737) pressed into service on routes previously served by the jumbos.[4] These smaller aircraft offered higher passenger load factors (PLFs), a measure crucial to airline profitability.

But PLFs are not the entire story. Carriers were already moving away from operating their jumbos before the pandemic, so this grounding merely accelerated the existing trend. It is thus unlikely that more than a few of either the A380s or 747s will return to the skies as travel volumes recover.[5]

The pandemic-related drop in passenger demand aside, the key factors driving this trend are cost and engine performance. The A380 and 747 are both quadjets, and four-engine aircraft are intrinsically more expensive to fly than twin-engine craft. Historically, quadjets were more reliable than twin-engine craft, leaving quads as the only options for long-haul overseas travel. However, advances in engine technology (discussed below) have removed the historic safety advantage of quadjet configurations, leaving secondary factors such as airport landing slot availability and passenger demand volume as the only rationale for operating the larger planes.

This shift has been especially stark for the A380: out of a total of 254 A380s built, only twenty-four remain operational, and the final A380 was assembled in 2020. Because the A380 is a relatively new aircraft (the first A380 flew in 2005), Airbus has not enjoyed the decades of sales required to recover its development costs, leaving the manufacturing line especially

Boeing 747s parked in an airplane graveyard in the Mojave Desert in California
Source: Sam Chui https://samchui.com

4 Technically speaking, "jumbo" refers to the Boeing 747 and certain large four-engine jets, including the Boeing 777 and Airbus A350. "Superjumbo" is reserved for the Airbus A380. For simplicity's sake, this paper uses "jumbo" to refer to all of the largest aircraft.

5 The exception to this may be the 747 in air cargo configurations. See the discussion of air cargo on pages 17 and 18.

vulnerable to a downturn.[6] Complicating matters further, the A380's unsuitability as a freight transporter closed the option of a secondary freighter income stream.[7]

On the carrier side, the pandemic sharpened the challenge of achieving high PLFs needed to profitably run large-capacity jumbos like the A380 and 747. Several carriers have permanently grounded their A380s, and others are likely to follow. In the long run, a diminishing number of A380s will be returned to service on high-demand routes, and others will likely be reserved for special mass travel events, such as carrying pilgrims to Mecca for the annual Hajj.[8] But the age of superjumbos like the A380 is gone for the foreseeable future.

Boeing's 747 has fared somewhat better. The 747's long operational history—its first revenue flight was in 1970—and a wide range of variants, including a successful freight configuration, mean that Boeing recovered its initial development costs long ago. Decreasing demand for the 747 a decade ago made it clear that the 747 was approaching its logical end of life. Boeing began cutting back 747 production in 2016 and again in 2020, and thus the 747 was well on its way to end-of-life status well before Boeing announced that the final 747 would be delivered in 2022.

The major carriers also began retiring their 747s in the years after 2015, so the pandemic-related collapse in air travel demand merely accelerated this already rapid decommissioning. Out of a total of one thousand five hundred built, less than thirty-five 747s remain in passenger service. It is possible that the last remaining 747s to be delivered will be the two 747-800s currently being configured as the new Air Force One.

Implications

The retirement of the 747 and A380 is both a contributing factor and a consequence of other factors transforming civil aviation discussed below. Specifically, engine reliability advances mean smaller twin-jet aircraft can be safely and profitably operated on long-haul routes once dominated by the jumbos, and a steady shift away from hub-and-spoke to point-to-point travel means there will be ever fewer routes where the high-passenger-capacity jumbos make economic sense.[9]

Videoconferencing Fuels Air Travel Demand—and Vice Versa

The pandemic-related stay-at-home orders caused an acceleration of videoconferencing adoption that is virtually unprecedented in the history of technology diffusion. Videoconferencing is now firmly embedded as a tool in both business and personal lives, and thus its use, and the use of collaborative software generally, will see steady growth even as the pandemic wanes. In addition, now that the videoconferencing market is firmly established, one can anticipate a steady stream of dramatic new collaborative platform innovations over the next several years, including the introduction of immersive videoconferencing with head-mounted virtual reality (VR) displays.

The dramatic spike in videoconferencing adoption has revived speculation that users will permanently trade airplane seats for screens and travel demand will thus decline. This notion of "travel substitution" has been a fixture on the telecommunications landscape for well over half a century, as each new communications platform was greeted with the expectation that it would free knowledge workers from the burden of business travel.[10]

History tells us otherwise. Long-distance telephony was a boon for the 1950s' jet age, email's commercial arrival in the 1980s boosted business air travel further, and air travel grew even more rapidly alongside the arrival of cyberspace, the World Wide Web, and the dot-com revolution.

6 In retrospect, the A380 is a brilliant plane that arrived over a decade too late. If it had launched in 1990, there would have been both the time and demand to allow for a full build-out of A380 variants and recovery of investment. Instead, the A380 began flying just as the superjumbo market was peaking and would-be carrier customers were getting cold feet.

7 The A380's design precluded the option of a lifting nose door, a feature designed into the 747 from the very start. This is a major reason for the 747's distinctive forward hump, which allowed the cockpit and attendant avionics and controls to be placed above the door hinge, greatly simplifying door design. The 747's nose door allows not only for more rapid loading and unloading compared to side-door operations, it also makes it possible to carry both wider and longer cargo loads.

8 In May 2021, Qantas announced its intention to bring a portion of its A380 fleet back into service as the pandemic wanes. Qantas is a good example of special circumstances, owing to its core long-haul routes.

9 The newest variants of the Airbus A350 and Boeing 777 twin-engine widebodies have passenger capacities comparable to the retiring jumbos, but at dramatically lower per seat operational cost. In the case of the new 777x variant, Boeing claims that it's per-seat cost will be 33% lower than that for a 747-400.

10 Paul Saffo, "The Future of Travel," *Fortune*, 128 (7) (Autumn 1993): 112–119.

The lesson is that electronic communication and travel are synergistic: the more individuals communicate with others remotely, the more likely they will travel to meet in person. And the more one travels to meet others in person, the more likely it is that the individuals will continue the conversation electronically between visits. Instead of travel substitution, we will enter a world of travel shifting in which travel becomes ever more convenient, and digital communications become ever more vivid and ubiquitous. And when convenience, ubiquity, and vividness combine, we will all inevitably travel more and communicate more.[11]

Implications

Videoconferencing, collaborative software, emergent immersive social environments, and the adoption of remote work practices will have a strong impact on both air travel demand as well as the nature of air travel offerings. It is already a key reason why business travel recovery is lagging tourist travel, as the once-reflexive assumption that critical business must be conducted in person is softened by the recent experience with videoconferencing and other digital tools.

Travel shifting will become an unremarkable norm as businesses discover that the ever-richer travel and telecommunication options can be recombined in ways that make businesses more effective while allowing greater work/life balance for former road warriors. It sounds counterintuitive, but in the long run, this richer set of options will inevitably lead to greater demand for both travel and remote communications.[12] This will also encourage the shift from hub-and-spoke to point-to-point routing, as electronically facilitated friendships blossom in regions beyond major commercial centers.

And, of course, there is one inevitable surprise: carriers are already reporting passenger requests for the ability to connect with Zoom conferencing while in flight, so say farewell to quiet naps on long trips. Let's hope we get VR headsets soon so we can shut out the noise while we are on an in-flight videoconference of our own.

Airline Networks: Hub-and-Spoke Yields to Direct Flights and "Skinny" Routes

Hub-and-spoke operations have been the dominant model for airline networks since the late 1970s. Hubbing's appeal to carriers lay in fostering higher PLFs and streamlined operations by virtue of having to maintain fewer routes compared to point-to-point direct flight networks. The hub-and-spoke model has also allowed airlines to more effectively protect themselves against competition by controlling resources at key hub airports such as gate availability and scarce landing slots. This translates into both higher PLFs and higher fares for carriers able to control key hubs.

Hubs thus are great for carriers but ask any traveler and they will tell you they would much prefer a nonstop flight to their destination, even if it means a longer flight leg on a smaller aircraft. The compromise offered by carriers was that even if a passenger had to change flights, at least they could complete their entire trip on one airline via flight legs that (hopefully) were sufficiently coordinated to avoid long waits at connecting airports.

Another factor favoring hub networks was technological: historically, engine performance limitations restricted extended overwater flight to larger aircraft with three or four engines. Only a hub network architecture could ensure the high PLFs required to make these overseas flights profitable. The situation began to change in the early 1990s when the Boeing 777 became the first twin-engine wide-body jet to receive ETOPS-180 certification, allowing the 777 to fly over water in the Pacific as well as the Atlantic airspace.[13] Twin-engine jets offer important fuel and other savings compared to their larger brethren, and their smaller capacity means they can achieve high PLFs with fewer passengers.

What followed was a gradual erosion of the strict hub-and-spoke model as more twin-engine jets received ETOPS ratings, allowing not only more efficient PLFs on mainline routes, but also making point-to-point service possible on "skinny" routes that would have been uneconomic for larger-capacity quadjets like the 747.[14]

11 On the horizon are new immersive social environments (what Facebook is billing as the "Metaverse"). We can count on the travel substitution believers to point to these platforms and claim "This time the technology really will eliminate the need for travel." Once again, they will be mistaken.

12 This travel-communications cocktail also inevitably includes high-speed rail networks. Business air travel in Europe has been in steady decline over the last two decades because of the availability of rail options, and we expect to see the same happen in China. Americans, eat your hearts out.

13 ETOPS is an acronym for Extended-range Twin-engine Operations Performance Standards. ETOPS-180 refers to the ability to safely fly over water for up to three hours from a destination or secondary airport.

14 A skinny route is one on which passenger demand is insufficient to profitably support jumbos but can be profitably operated with twin-engine wide-body or narrow-body aircraft.

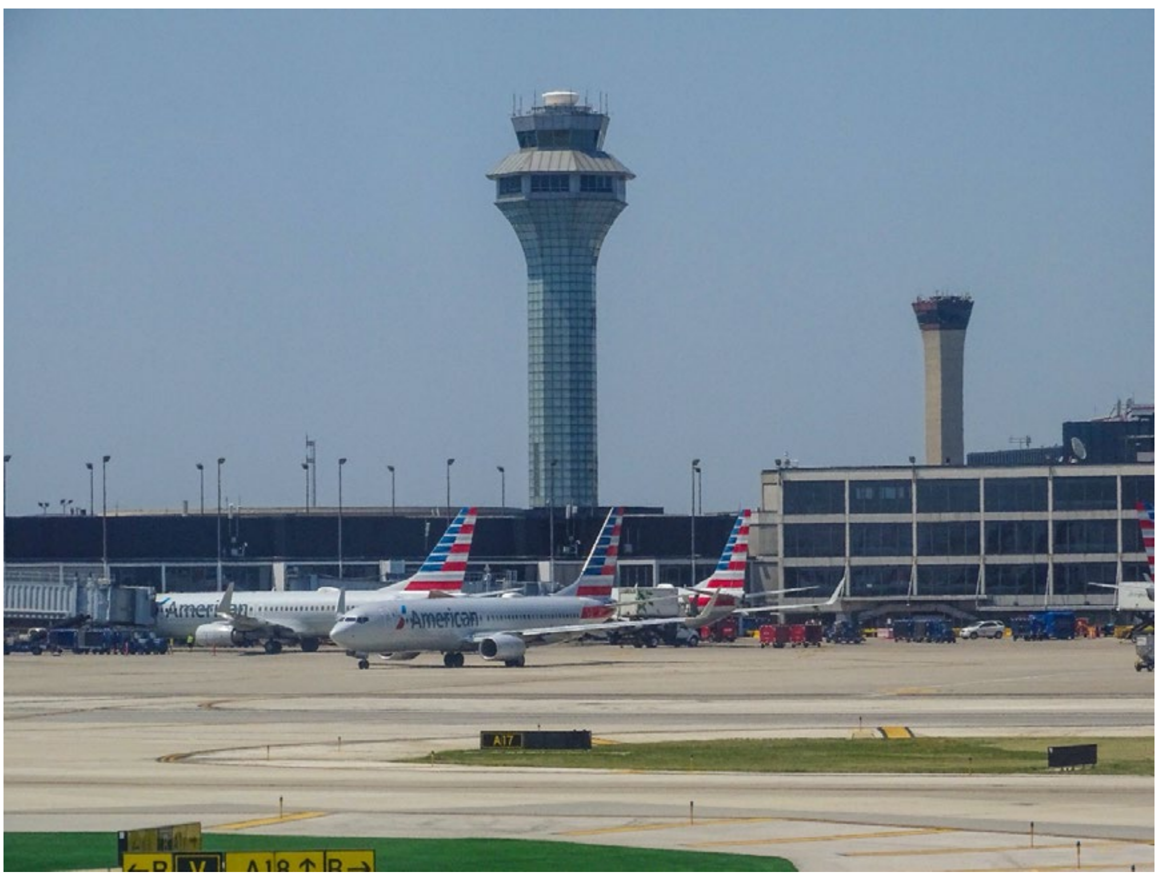
It is axiomatic that all aviation innovation follows power plant advances. The continued advance in jet engine efficiency, reliability, and emissions reductions since the early 1990s steadily eroded the operational necessity of long-haul hubbing built around four-engine passenger jets.[15] By 2010, it was clear that wide-body, and even narrow-body twin-engine jets (like the Boeing 737 and Airbus 330), would increasingly be capable of displacing quadjets on long-haul routes.

Jump ahead to 2019, and it seemed that the only thing holding the hub-and-spoke system together was habit and the market power of the larger carriers. Then the pandemic hit, triggering a drop in passenger demand and brutal cost-cutting measures as airlines struggled to survive. And as described above, this accelerated the commercial demise of both the Airbus A380 and Boeing 747 as there were simply too few passengers to profitably fill the planes.

Opinions are divided over what will happen as we emerge from the pandemic and passengers return to the skies. One school of thought argues that carriers will return to the hub-and-spoke model, but with ever more efficient twin-engine jets. I disagree. The most likely future is a hybrid network model in which high-demand long-haul routes will retain some hub-like characteristics, but hub-based connecting travel will decline as nonstop options served by twin-engine wide- and narrow-body aircraft increase.

Implications

A hybrid network favoring direct travel will result in greater volumes of passenger travel, and because it will weaken carrier monopoly control on critical hubs, may also lead to greater competition and thus lower traveler cost. As carriers learn to profitably operate on skinny routes, it is likely that air service will expand to previously unserved destinations. This shift will also have unintended consequences in the form of shifting traffic to currently underserved smaller airports, relieving landing slot pressures at major hub airports.



Chicago's O-Hare International Airport is emblematic of the historic buildup of massive airport hubs out of which specific airlines operate a majority of their flights.
Source: Miguel Ángel Sanz/ Unsplash

15 "Jet engine" remains in common use as a descriptive term even though technically speaking, modern jet aircraft are powered by turbofans and not jet engines.

Airport Surprises: Growth Away from Major Hubs—and an Airport Building Boom

The shift away from hubs to direct flight will have dramatic impacts on airports. Smaller airports will experience more direct flight traffic, particularly as narrow-body twin-engine aircraft are deployed on skinny long-haul routes. This will hold particular appeal for travelers who will be able to travel internationally from airports closer to work/home without the hassle of first traveling to a major international airport and enduring the attendant crowds and long walks to gates. The earliest expansion will be to underused airports on the fringes of major urban regions as well as more remote locations experiencing growth related to city dwellers moving to take advantage of remote work protocols and realize a better work/life balance.

This will reduce pressures on major hub airports to expand airport size, number of gates, and landing slots. In fact, it is possible that we will see some of the largest airports move to reduce their operational footprint, and perhaps even their size. An early candidate for this would be London's Heathrow Airport, which has long been bedeviled by growth restrictions, noise complaints, and weather headaches. I would not be surprised if Heathrow ceases to grow or perhaps is even downsized sometime in the next decade. The flip side of this shift will be revitalization and operational expansion of underserved regional airports. This will include terminal and runway expansion, and even the construction of entirely new airports.

Climate change presents a longer-term transformational imperative for existing airports stemming from increased storm intensity and longer-term sea level rise. Many of the world's busiest airports are located at or near sea level, and already experience storm-related flooding disruptions.[16] Recent research indicates that 269 airports globally are already at risk of coastal flooding, and even if the Paris climate agreement's targets are met and global mean temperature rise does not pass 2°C, the total of at-risk airports will rise to 364, with at least 100 airports becoming permanently below sea level.[17] If the Paris targets are not met and temperatures rise above 2°C, the number of at-risk airports will rise to nearly 600, forcing the move or outright abandonment of some of the largest airports on the planet.

Implications

Aviation innovations plus climate effects in the form of sea level rise translate into a major global infrastructure challenge. Smaller airports will have to be expanded as skinny route flights begin to serve them, and major airports located at sea level will have to rebuild infrastructure even as they risk losing traffic and revenue to smaller airports. Some airports will have to be moved and entirely new airports will have to be built.

The increase in the number of served destinations will present challenges for national border security. The age of checking travelers at geographic borders and a few "international" airports is quickly disappearing. Add in small business jets, particularly rental jets on top of skinny route arrivals, and protecting territorial integrity will become vastly more complicated.

Propulsion: From Molecules to Electrons—and Beyond!

We are in the early phase of a massive multi-decade shift in aviation propulsion, driven by two key factors: a decarbonization imperative forced on the industry by the climate crisis, and new opportunities created by rapid advances in technologies enabling a new era of electric flight. These factors have had the immediate effect of ending aviation's century-old propulsion monoculture built around engines powered by liquid fuels, setting the stage for deeper aviation disruptions.

Propulsion drives aviation innovation. This has been true since Kitty Hawk, where the Wright brothers' first flight was made possible by a novel gasoline piston engine designed and built by inventor and mechanic Charlie Taylor. More recently, the mid-twentieth century revolution in air passenger travel was the direct consequence of Frank Whittle's pioneering invention of the turbojet. Now the advent of high-performance electrics enabled the current drone revolution and is setting the stage for the arrival of small electric passenger craft in the near future.[18]

Behind these innovations lies an ironclad fact of aviation: It takes energy—lots of it—to keep a heavier-than-air craft

16 Images of the September 2018 closure of the Kansai International Airport in Japan after its runways all but disappeared under a typhoon-driven storm surge come to mind.

17 Aaron N. Yesudian and Richard J. Dawson, "Global analysis of sea level rise risk to airports," *Climate Risk Management* (2021) (31): 100266, https://doi.org/10.1016/j.crm.2020.100266.

18 An indicator company in this space is California-based Joby Aviation, which is building an integrated "all-electric air mobility" eVTOL offering likely to launch in the next two years. See www.jobyaviation.com.

Table 1: Comparative Energy Densities for Select Common Fuels and Storage Capacity of Lithium-Ion Batteries

FUEL	ENERGY DENSITY (MJ/Kg)
U-235 (in reactor plant)	3,900,000
Hydrogen	120
Gasoline	46
Jet A-1	43
Ethanol	27
Coal	24
Sugar	20
Wood	16
Lithium-ion battery	1

Notes: Values are approximate and do not reflect the full range within each category; MJ/Kg = megajoules/kilogram.

airborne. And all things being equal, the energy required increases disproportionately with the size of the craft. A child's glider can be successfully powered with a rubber band, but it takes a quarter million pounds of thrust to get a superjumbo airborne.

Aircraft design comes down to exploiting the highest energy density fuel available that can be efficiently converted to useful powered flight. The Wrights flew in 1903 because Taylor was able to power his engine with a newly developed fuel that was both energy dense and readily convertible—gasoline!

Taylor's choice was prescient because it turns out that hydrocarbons are aviation's Goldilocks fuel. They are energy-dense, readily ignitable, convenient to store, and, best of all, abundant. Little wonder then that the entire history of aviation innovations since 1903 has centered on optimizing liquid fossil-fuel propulsion. If Taylor were to tour a modern jet, he would instantly recognize the commonality of the major propulsion components with the original Wright Flyer.

But the propulsion landscape is about to change. After a century of failed attempts by other energy sources, electric power has become the first alternative to break the hydrocarbon propulsion monoculture. We are witnessing the beginnings of a massive propulsion shift from molecules to electrons. Fossil fuel-fueled propulsion is not going to disappear, but the fastest-growing segment of aviation will increasingly be electrically powered, and its growth will utterly transform how—and what—we fly in over the next several decades.

Electric propulsion as it exists today seems an improbable agent of disruption at first blush. As Table 1 indicates, even the very best batteries currently available have terrible

Airbus' E-Fan X aircraft is an example of the aerospace industry's efforts to harness electric propulsion as means of air travel
Source: Airbus

energy density compared to fossil fuels.[19] Today's lithium-ion batteries hold barely a fiftieth of the energy density of gasoline. Even sugar has a higher energy density than batteries, so why are we not fueling our drones with sugar cubes instead of battery electrons?

The reason is energetic convertibility. Sugar is energy dense, but unlike hydrocarbons that will burn (or explode) at the touch of a spark, sugar only releases its energy reluctantly. The conversion rate is perfect for refueling hungry teenagers, but too slow to power a plane. In contrast, energy release from a battery is even faster than exploding gasoline, and, moreover, can be delicately fine-tuned to everything from a slow trickle to light-speed release. This makes battery-delivered electrons perfect for flight power—and in many ways superior to hydrocarbon-based fuels—as long as the electron source (e.g., batteries or a generator) is not so heavy that the craft cannot get off the ground.

Electric power has another advantage. Modern jet propulsion represents the pinnacle of more than a century of design optimization. This means that engineers have already fully exploited the big, easy innovations. The improvements left to discover will be incremental at best and will only come at high R&D cost.

In contrast, electric systems have barely reached the point where piston engines were a decade after the Wrights first flew at Kitty Hawk. Electric flight's horizons are vast and open and the cost of discovery is low. In addition, Moore's Law is very much electric flight's friend as the exponential advances in the digital domain spill over into electric propulsion and digital electronic control. Simply put, a research dollar invested in electrics will yield orders of magnitude more benefit than the same dollar invested in conventional propulsion.

The other factor driving propulsion's transformation is the ever-growing pressure to decarbonize aviation emissions in response to the ever-growing climate challenge. As discussed later in this report, the industry is aggressively pursuing schemes to reduce the impact of current propulsion systems through ongoing engine efficiency gains, formulation of novel low-carbon impact sustainable aviation fuels (SAFs), and R&D around more exotic options such as hydrogen as a fuel stock. These efforts are vital to aviation's future, but the same decarbonization pressures are providing an even bigger boost to electric propulsion. Depending upon the source of the electrons, electric propulsion is intrinsically net-zero emissions, or even net-negative emissions.

Electric propulsion offers several other advantages compared to conventional combustion engines. Electric systems have the potential for dramatically lower cost of operation and maintenance owing to their lower parts count and simpler mechanical systems. Also, the nature of electric propulsion lends itself to far better interfacing with digital avionics as electric propulsion systems can be more finely controlled than is possible with fuel-based propulsion. This can lower the training level required of pilot operators and also greatly increase overall system safety.[20]

Electric propulsion's greatest immediate challenge remains one of battery performance and for that reason—as highlighted later in this paper—we will likely see electric propulsion first come to fruition in smaller manned and unmanned platforms. The good news is that multiple industries from consumer electronics to automotive, trucking, and power utilities are all pursuing the grail of high-performance storage as well. Electric aviation will get a boost from this cross-sector synergy.

Batteries are front and center when it comes to early electric flight, but there are also other ways to make electrons fly.[21] Hybrid electric/piston/turbojet propulsion is being explored; such systems still rely on fuel tanks rather than batteries, but are used to generate electricity to power the engines rather than propel the plane directly. Hydrogen also holds interesting long-term promise, both in the form of direct engine power and fuel cell electricity generation. All these options present daunting engineering challenges, but the fact they are under consideration is an indicator that the potential of electric flight is already having a broad transformational impact on aviation.

Implications

Changing propulsion inevitably leads to profound platform changes. The coming shift is not one of swapping electric propulsion for conventional power plants in existing aircraft platforms. Rather, this is about electric propulsion coevolving with airframe technology to create entirely new classes of platforms that open up entirely new air travel niches such as a novel "urban mobility" sector enabled by a new class of taxi-sized short-hop electric vertical takeoff and landing (eVTOL) aircraft, discussed later in this paper.

19 Noting that there are far more energy-dense options in Table 1, why are we not powering our airplanes with uranium? Well, the US Air Force tried. It even built several nuclear engine prototypes in the early 1950s, which worked fine—except for the radiation emissions in the exhaust and the possibility of radiation release in the event of an accident.

20 I am skeptical that AI and advanced avionics will lead to pilotless passenger craft within any reasonable time frame. Rather, these systems will serve as ever more powerful pilot assistants making flight safer and reducing the training levels required of pilots.

21 Elon Musk and others have ventured the opinion that electric flight beyond unmanned and specialty craft will require a battery density of at least 400 Wh/kg (current performance levels are less than half that). At current rates of innovation, we may see this higher density met or even exceeded within the next half decade.

Because electric flight is essentially a clean sheet technology building into the new aviation niche of eVTOL aircraft, it has the potential to reach operational reality faster than retrofit innovations to larger craft which must negotiate the operational subtleties of existing systems. It is quite possible that more passengers will be flying short distances in eVTOL "taxis" in the medium term than will be flying long distances in airliners fueled with zero-emission SAFs. The result will be the emergence of ever more diverse local and regional transportation ecosystems whose impacts will be felt as a transformative force on traditional high-capacity, long-distance air travel.

This paper is concerned primarily with passenger travel, but another impact of electrics is so great that it cannot be ignored. Electric propulsion's biggest short-term impact lies in the ongoing exponential growth of unmanned drones. We are racing headlong into an aviation future in which manned platforms will comprise only a small fraction of what is flying over our heads. Your Amazon packages are going to fly more frequently than you will!

This growth in unmanned platforms has obvious geopolitical implications. The first aerial bomb was dropped from a plane in 1911, the first civilian bomb casualties were reported in 1915, and the first combat strike by a drone occurred in 2001.[22] More recently, terrorists reportedly deployed a drone-mounted bomb against US military assets in Iraq and an autonomous AI-controlled drone reportedly attacked human targets in Libya without any operator intervention or control in 2020.[23]

Even as we wait for passenger electrics to become a commercial reality, unmanned drones are pursuing a cost/performance curve comparable to what Moore's Law anticipated for computers and communications. This will open vast opportunities for crime such as drug cartels moving product, and in the longer term, as platforms get larger (and in some instances, are piloted), moving humans across borders.[24]

On a brighter note, unmanned electric platforms will also perform happier tasks. One possibility is "Persistent High Altitude Solar Aircraft"—solar-powered electric drones operating at high altitude capable of serving as sensor or communications platforms. These will occupy a middle space between cell towers and low-level drones on one end and satellites at the other, flying high enough to stay above the weather, but low enough to take full advantage of proximity to the ground.

A Joby Aviation electric vertical take off and landing (eVTOL) personal aircraft is seen on a test flight
Source: Joby Aviation

22 An Italian pilot dropped the first "bomb" (several hand grenades) over Tripoli in November 1911, the first civilian casualty was an English child struck by a bomb dropped over London from a German Zeppelin in 1915, and the first successful "kill" by a Predator-launched Hellfire missile occurred in Afghanistan in October 2001.

23 A drone launched by an Iran-backed militia struck a CIA-operated hangar in Iraq in April 2021.

24 Drone advances will be closely followed by drone countermeasures (for example, use of microwave frequency directed beam weapons), but the steady advance of enabling technologies means this will be a never-ending race between challengers and defenders, with the defenders always being one step behind.

Global Aviation Personnel Shortage

The civil aviation industry is facing a growing shortage of workers across all categories from mechanics and technicians to cabin personnel and pilots. According to a Boeing study, the global commercial aviation industry will need more than 2 million new personnel between now and 2039.[25]

The Maintenance, Repair and Overhaul (MRO) sector is being particularly hard hit as boomer generation workers are retiring faster than next generation mechanics can be trained. This worker gap is made more acute by the fact that airlines are receiving ever more sophisticated new aircraft which require new skills, while MRO professionals must also still maintain decades-old systems. The pandemic-related downturn has further exacerbated the problem as laid-off workers take their skills to other industries, and would-be candidates opt not to enter the MRO field at all.

The situation is equally serious for pilots and cabin personnel. In the 1950s, an infant jet age got a huge boost from military pilots moving into airline jobs. With ever smaller military forces, this pilot pipeline has been reduced to a trickle. Airlines have been slow to create pilot academies and given the uncertainties of pay levels and job security in the airlines, potential candidates are unlikely to pay the tuition for flight school out of their own pocket.

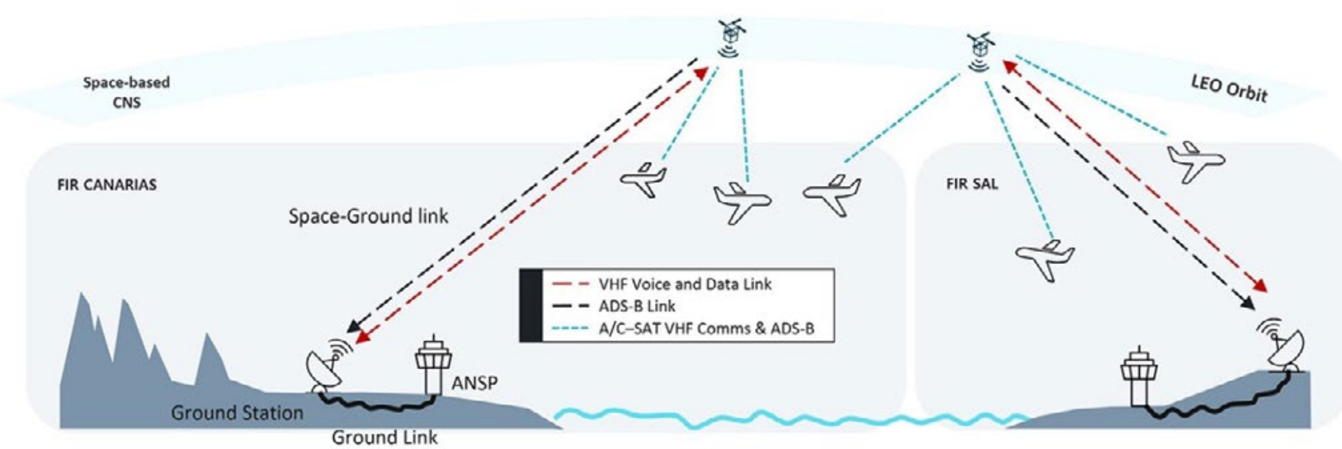
Implications

The implications of this growing personnel shortage have already shown up in flight delays and cancellations. Aircraft manufacturers recognize that future aircraft designs must include ease of maintenance and this issue may accelerate retirement of older airframes. On the pilot side, the advanced avionics made possible by electrically powered craft plus advanced air traffic control (ATC) systems may possibly reduce the shortage by lowering the requisite training for cabin personnel and eventually reducing the need for two pilots in larger aircraft.[26]

Air Taxis ("Urban Mobility Service"): A Big Step Toward a Multimodal Aviation Future

Electric propulsion has already created one industry—small, unmanned drones—and now it is poised to create a second: an "urban air mobility" (UAM) sector transporting human passengers. As noted earlier, airframes follow power plants, and electric power is finding its way into ever bigger airframes. An electric 737 or A320 remains science fiction, but electric craft the size of small private planes are flying

How spaced-based assets can support air traffic management



A graphic from the European Union's Single European Sky ATM Research Joint Undertaking (SESAR JU) shows how spaced-based assets can support air traffic management. Source: SESAR JU

25 "Pilot and Technician Outlook 2020-2040," Boeing, accessed July 2021, https://www.boeing.com/commercial/market/pilot-technician-outlook/.

26 Air mobility platforms will have only a single pilot from the start. Eliminating copilots on larger aircraft is likely not to happen anytime soon due to the industry's intrinsic conservatism and passenger perceptions. There is an old joke in the industry that eventually aircraft will be fully automated. There will be a single pilot up front—and a dog. The pilot's role is to intervene if something goes wrong. And the dog's job is to bite the pilot if they try to touch anything.

today. This, however, is not about swapping engines on small private planes. Rather, entirely new platforms are being built around electrics that in turn are being reconceptualized into new service models—urban mobility as a service. Joby Aviation is a leading example in a young sector already populated by at least half a dozen well-known start-ups and more than 100 companies trying to build out the space.[27] Large companies are also in the game: Airbus is reportedly working on a "CityAirbus" demonstrator, Uber briefly put a toe in the water with Elevate/UberAir, Daimler has invested in Volocopter, Boeing and Larry Page's Kitty Hawk have formed a joint venture named Wisk Aero, and Hyundai has invested more than $1 billion in a new UAM division.[28]

Electric propulsion is the critical enabler, making simpler, more reliable systems than is possible with conventional propulsion. This lowers build and maintenance costs, and critically, when combined with digital avionics greatly lowers the training/skills needed to pilot one of the craft by reducing the complex systems today's pilots have to constantly monitor, and by compressing other tasks into managed subroutines. These are not craft that dad will drive, but they also are nothing like the complexity of flying a helicopter. Fully autonomous aerial passenger transport is a long way off, but in the meantime, these new platforms will be flyable with training that is equal to or less than what private single-engine pilots receive.

The urban mobility space will follow a classic start-up trajectory serving up the usual share of start-up hype, spectacular commercial failures, and inevitably, a share of dramatic accidents.[29] Technical challenges are getting the most attention at the moment, but issues of noise and where landings are allowed are likely to come to the fore as these new platforms take to the sky. Neither can be definitively solved, but I believe both will be quickly managed to a point where they can be overcome: noise can be minimized by blade design, and landing areas will emerge from a balance of local concern and desires. The situation is not unlike concerns early in the last century when fears that automobiles would scare horses and pedestrians caused some to propose that all automobiles must be guided with someone walking in front of the vehicle holding a red flag to warn everyone. The flags never caught on, and everyone made accommodations for the automobiles.

Noise and landing spots aside, traffic control will be an especially knotty problem, as current ATC systems simply cannot handle the volume and complexity that will follow deployment of air mobility services and unmanned drones. This will likely accelerate the deployment of new advanced air traffic management systems.[30] But the appeal of flying taxis is so strong that even these problems are just speed bumps for a fast-growing young industry offering mobility as a service: commutes to work and between meetings, and critically, first-leg transport to airports. Just be sure to not talk about anything confidential on the flight, as the human pilot might be listening!

Implications

Airborne urban mobility will be affordable to the well-to-do and perhaps middle-class haves who will now be watched with resentment by the masses stuck in traffic looking up from below. And the demand for new "Vertiports" (landing points specifically for electric air mobility vehicles) will create further tension, particularly around issues of rotor noise (which can be minimized, but not eliminated). All in all, urban mobility will further underscore the economic stratification of societies, and that will create new social tensions.

Urban mobility platforms also offer unnerving implications for smuggling innovations. Unmanned drones are already figuring prominently in drug smuggling attempts, making the appeal of larger platforms obvious. The air mobility start-ups will, of course, build in layered protections to keep their craft from being abused, but that will not stop determined attempts by malign actors to break the features or even build their own craft.[31] Human trafficking or a spy/insurgent/terrorist air taxi service anyone?

27 These include Joby Aviation, ImagineAir, Propair, Skymax, and Volocopter.

28 Uber quickly entered and then departed the sector, offloading its air mobility unit in late 2020 to Joby Aviation along with a $75 million investment in Joby Aviation.

29 A key challenge of the space is that the failure mode of flying craft is intrinsically more hazardous than the failure mode of a highway-based vehicle: one rolls to a stop and the other falls from the sky. As has already been implemented in some small aircraft, built-in craft-sized parachutes may help. That said, the nature of UAM systems makes it likely that accident rates will decline significantly compared to conventional air travel.

30 The so-called NextGen ATC vision contemplates multiple technologies, including Automatic Dependent Surveillance-Broadcast (ADS-B) (GPS-based position information) and "UTC," short for unmanned air traffic control.

31 Geofencing aimed at blocking consumer drones from intrusion into National Parks and other sensitive areas is becoming ever more common as amateur drone operators have discovered to their dismay.

Air Traffic Control: Terrestrial Control is Replaced by a Space-Based Systems—and AI's?

Next to gate space, the single largest factor holding civil aviation growth are slots in the sky along air traffic routes. When one crosses an ocean, be it the Atlantic or Pacific, the sky only looks empty as there is a solid conga line of aircraft spaced 10 miles apart along the specified tracks. This system maximizes safety but greatly increases flight times compared to being able to fly a direct great circle route between airports. So-called direct flight would amplify the benefits of point-to-point flight trends, at once pleasing passengers as well as facilitating aircraft usage through faster turnarounds. And by eliminating the need to fly only within narrow designated air lanes, overall sky capacity would greatly increase.

The limiting factor is the centralized nature of the existing ATC system. The solution on the horizon is a combination of precision GPS location data with automated control for everything from collision avoidance to weather rerouting. This is beginning to take shape as "Unmanned Aircraft System Traffic Management" or UTM, an emerging framework for an overall air traffic management ecosystem. UTM is being vigorously pursued by both governmental agencies and aircraft manufacturers, but the myriad complexities from technology underpinnings to the dizzying number of stakeholders make any forecast of UTM's eventual arrival fraught with uncertainty.[32]

Implications

The eventual shift to UTM will have vast ripple effects everywhere from airport landing rates to the shape and function of cockpits—and who is sitting in them. And this, of course, will affect the shape and nature of the aircraft themselves. Historically, aircraft design has been gated by advances in propulsion systems. In the future, UTM and avionics systems may well displace propulsion as the key gating factor.

Aviation: It's Not Easy to Be Green

Defying gravity comes with a cost. In the case of commercial aviation, that cost includes a 2 percent contribution to global CO_2 emissions, and, overall, jet fuel consumption accounts for more than 5 percent of total global petroleum consumption. Both emissions and fuel consumption plummeted during the pandemic, but levels are quickly rebounding as restrictions ease and air travel resumes.[33]

A depiction of a Boom supersonic aircraft in flight. Source: Boom

32 The aviation industry is especially conservative when it comes to flight safety, a factor which will initially retard conversion to UTM, and then once critical mass is reached accelerate UTM deployment.

33 US jet fuel consumption in mid-2020 was at under 45 percent of daily fuel consumption a year earlier, according to the US Energy Information Administration.

Aircraft manufacturers continue to dramatically improve both emissions and fuel efficiency as a natural part of the innovation process, but the overall growth in air traffic means that this is a losing race on a merry-go-round for even as per passenger aircraft emissions drop, overall emissions will continue to increase.[34] This will be further exacerbated by anticipated growth in small business jets, and also by supersonic jets if/ when they arrive.

This emissions challenge is complicated by the fact that unlike other industries which are greater carbon contributors, aircraft loom large in our lives as modes of travel and planes flying overhead. The actual emissions are invisible but try telling someone that the contrails overhead are comprised mostly of harmless water vapor! Contrail fears and the nascent "flight shame" movement are a reminder that the aviation industry is under particular pressure to manage its carbon emissions.[35] This pressure will only increase as a steadily growing succession of climate-related disasters occur, further raising public angst and spurring governments to force further emissions reductions.

The aviation sector is responding to this environmental imperative with several broad initiatives, including:[36]

Sustainable aviation fuels (SAFs)

SAFs are clean substitutes for conventional jet fuel derived from non-fossil feedstock or zero-emission sources. The appeal of SAFs is that they can be used as "drop in" substitutes for conventional fuels, which means they could have an immediate reduction impact.[37] And being compatible with existing aircraft systems, SAFs can obviate the need for wholesale fleet replacements and the consequent capital expenditure.

The holy grail is a SAF created from electrolysis-generated hydrogen combined with CO_2 pulled from the atmosphere to yield a liquid drop-in fuel. The technology to realize this is not yet commercially practicable, so the next-best option is a SAF derived from plant-based waste (i.e., used cooking oil) and other plant sources.

The challenge is one of finding sufficient environmentally benign feedstock to make a dent in aviation fuel demand. Waste oil clearly qualifies, but the available volume falls far short of what is needed for more than a symbolic contribution. Agriculture-based options offer far greater volumes and a less complex logistics chain, but often come with hidden environmental costs. For example, palm oil is less than benign because of the destruction of natural forest required to plant palm plantations. And ethanol derived from corn and other food crops raises troubling ethical questions of taking food from the mouths of vulnerable populations in order to fly the well-off to business and vacation destinations.

Hydrogen fuel cells

Electricity-generating hydrogen fuel cells are an appealing alternative to batteries owing to hydrogen's greater energy density (see table on page 8). But unlike liquid jet fuel, hydrogen must be confined in a pressurized tank. This means that even though the fuel weight is less than batteries or traditional fuel, its relative volume is greater, and thus more space is required for fuel storage, reducing useful platform capacity.

Direct hydrogen combustion

Direct hydrogen combustion is simplicity itself—just replace existing jet fuel with hydrogen in the engine cycle. While not a pure drop-in option like SAFs as it still suffers from space issues, this approach theoretically would require less overall reengineering compared to designing a fuel cell-based electric aircraft. Hydrogen even offers several advantages compared to traditional fuel in the form of higher auto-ignition temperatures and a broader flammability range, resulting in lower operating temperatures and higher fuel economy.

All of these approaches offer real promise, but the devil is in the details, particularly when it comes to hydrogen sourcing. Until carbon-free (referred to by some as "green") hydrogen is available in volume from low-cost electrolysis powered by renewable zero-carbon energy, hydrogen must come from "brown" (coal and lignite) or "gray" (natural gas) sources. There is even a "turquoise" flavor of hydrogen derived from wood pyrolysis, but all of these different sources fall short of being truly green.

When hydrogen-powered flight arrives, it will likely also trigger radical changes in aircraft design. We take today's aircraft form factor—a long skinny tube with wings—for granted, but it was very much dictated by the convenience of carrying dense liquid fuel in unpressurized tanks. The logical airframe for hydrogen-fueled craft is a large blended-wing structure providing far larger interior spaces in which to carry ample compressed hydrogen along with plenty of space left over for

34 Global CO2 levels have reached a new record high (419 ppm) at the time of writing. There was no noticeable drop in CO2 levels during the pandemic despite the restrictions on travel and other sectors.

35 In particular, the "flygskam" ("flight shame") movement that began in Sweden in 2017 was popularized by environmental activist Greta Thunberg, and started mainstream across Europe in 2018.

36 I am grateful to Gregg Maryniak for helping me frame this discussion. Any errors are mine alone.

37 "Drop-in" is a slightly misleading term because the safety-oriented culture of civil aviation means that even comparatively simple innovations will take longer to be implemented than might seem reasonable to an outside observer.

passengers and freight. When hydrogen propulsion eventually arrives, it is likely to make today's aircraft look as quaint as the Wright Flyer seems to us.

Carbon offsets: None of the options discussed above—electric, SAFs, or hydrogen power—will come online quickly enough to have a significant short-term emissions impact for large passenger aircraft. This leaves the industry with only one short-term option: the pursuit of meaningful, measurable carbon offsets large enough to really change the aviation emissions equation.

Schemes like planting forests and buying carbon are the only immediate options but these steps are at best a stopgap; more feel-good marketing than actual impact. The industry needs a definitive ground-based scheme that captures and sequesters carbon in a precisely measurable manner. The good news is that nearly every other industry sector on the planet also is wishing for such a solution, and that being ground-based, there are numerous broad technical design paths to definitive carbon capture. The only challenge? Creating an economic regime where capture is economically feasible. Carbon tax anyone?

Implications

Aviation may contribute only a fraction of total carbon emissions, but it is a very visible contribution as the aircraft pass over our heads every day. The pressure on carriers and manufacturers alike to reduce emissions will be unrelenting. Constantly reminded by contrails overhead, the public will remain unsettled regarding aviation's impact on climate change.

This could affect business travel, as public opprobrium is likely to focus on the disproportionate impact of frequent business flyers—and the companies they work for. This could well affect traveling diplomats and politicians: traveling to Davos to hold conversations about saving the world could become very uncool. A key sector to watch is military transport, where the US Air Force has been testing SAFs and evaluating hydrogen options for more than a decade.

Supersonics Redux: Smaller, Quieter, and (Maybe) Practical

The possibility of supersonic passenger travel is quietly gaining more attention. I remain skeptical about the speed at which this sector might grow, but there is no shortage of activity. All of the major aircraft manufacturers are actively exploring supersonic options, spurred on in part by a cluster of start-ups hoping to launch supersonic passenger craft.[38] All of this is being enabled by new design, engine, and airframe technologies which combined promise to minimize the problems that plagued Concorde-era supersonics, such as extravagant fuel consumption, sonic booms, and landing/takeoff noise.

Sonic booms aside, the biggest change from the Concorde era is plane size and capacity. Supersonics are not unlike electric-powered craft: smaller is easier. Thus, the first of the new supersonics are likely to be the size of business jets and serve a similar function transporting VIPs and others who can afford the cost premium. In the longer term, look for larger multi-passenger supersonics capable of being integrated into commercial airline networks.[39]

Supersonics thus present a double transformation if they actually arrive as quickly as optimists claim. The first will be a new level of private business jet one-upmanship, comparable to the transformation that occurred with the arrival of the first business jets in the early 1960s. And the second will be the arrival of commercial aviation supersonics, which when it finally occurs, will have an effect comparable to the impact of the Douglas DC-8 and Boeing 707 in creating the consumer jet age.

However, this budding sector faces serious hurdles beyond technical feasibility. The new supersonics promise to be vastly more fuel-efficient than the Concorde, but they are still fuel guzzlers compared to conventional jets. And no matter how fuel-efficient supersonics become, they will still be pumping out exhaust at 60,000 feet in the high troposphere, the atmosphere's most sensitive greenhouse zone. This will unfold as other aviation sectors go increasingly green, making

38 These start-ups include Boom Technology, Aerion (which declared bankruptcy in May 2021), and Spike Aerospace.

39 For example, United Airlines announced in June 2021 that it had placed an order with start-up Boom for fifteen of their sixty-five-plus-passenger supersonic airliners. The financial details have not been disclosed, but I suspect that this is most likely more an investment/public relations play than an actual order.

the contrast ever more stark. All of the supersonic start-ups talk about reaching carbon neutral status with carbon offsets, but the distinction may be lost on policy makers and the public wondering whether these fast jets and their elite travelers should be up that high to begin with.

Implications

The prospect of private supersonic business travel followed by 737-sized commercial supersonics surfaces interesting issues of status and fragmentation. Once upon a time, everyone from tourists to movie stars all flew in the same plane. Then as the aviation sector grew, passengers still flew on the same plane, but in separate sections. Just over a decade ago the advent of business-only long-haul flights meant that different classes now flew on entirely different aircraft. With the advent of supersonic travel, status will equate with altitude as different classes of service will now be separated by elevation, with the well-heeled flying thousands of feet above other travelers bumping along atop thunderstorms at 30,000 feet.

Private business jet travel has also expanded thanks to fractional ownership and subscription-based services. The arrival of supersonic business jets will split up air travel even further. This trend raises the question of what exactly is seen as high status. Business jets are actually cramped compared to commercial first class and, of course, nothing like the private suites offered on the A380. Meals are also simply whatever can be pre-boarded, no chefs waiting to cook dinner. But what private jets deliver is time savings, avoidance of airport crowds, check-in hassles, and above all, privacy. This consideration alone will drive interest in supersonic small jet travel, and the large carriers will take notice, and find ways to play to this privacy-as-status on their larger craft.

But this raises a question: What are the consequences of this steady stratification? Airports are one of the few places today where rich and poor, executives and tourists, frequent fliers and occasional travelers all cross paths. What does it mean for a world in which everyone is increasingly traveling in their own defined bubbles?

And finally, a wild card. Will we see a supersonic Air Force One jet? One supersonic jet start-up, Exosonic, received a contract from the Air Force to explore design options.[40] The practicalities of mission function for presidential flights make actual deployment in any reasonable time frame unlikely, but the possibility is certain to capture the public's imagination.

How Soon Hypersonic?

Even as the new generation of supersonic start-ups try to get off the ground, another group of aerospace innovators have set their sights on building passenger hypersonic craft—planes theoretically capable of flying at speeds above Mach 5, or twice the officially acknowledged speed of the current record holder, the now-retired SR-71 Blackbird spy plane. That is approximately 4,000 mph, or fast enough to cross from New York to London in less time than a Lyft driver will get you from Manhattan to John F. Kennedy International Airport in rush hour.

The most visible player in the space is start-up Hermeus Corporation, which recently secured $60 million in funding from the Air Force to take its first prototype to initial flight testing.[41] Hermeus states that its core advantage is a proprietary engine technology and has optimistically posted an artist's rendering of a hypersonic Air Force One on its website.

While engines are crucial to making hypersonic flight possible, it is only one of a myriad of devilish problems to solve, from hypersonic flow skin heating to flight control under conditions of low air density and shock wave effects. Getting all these pieces to fly together as passenger craft at hypersonic speeds is a decade-scale problem at best.

The first hypersonics to arrive will be autonomous military systems. Being unmanned, they do not require complex and heavy life support systems and being weapons, they only have to fly reliably once. Passenger hypersonics must overcome all the problems facing military systems, plus other more practical wrinkles such as safety, reliability, and operational efficiency before hypersonic travel becomes a practical reality. I doubt that the first president to fly in a future hypersonic Air Force One has been born yet.

Implications

While we wait for hyper-speedy craft capable of delivering venture capitalists to their deals, or diplomats to trouble spots on an hour's notice, China, the United States, India, and Russia all have hypersonic weapons development programs underway. It is possible that such systems could be operationally deployed well before 2030. Such systems will greatly complicate the already fraught calculus of arms control.

40 Exosonic, "Exosonic Awarded Contract to Develop Low-Boom Supersonic Executive Transport Aircraft Concept for US," September 8, 2020, https://www.exosonic.com/post/exosonic-awarded-contract-to-develop-low-boom-supersonic-executive-transport-aircraft-concept-for-us.

41 "Building the World's Fastest Aircraft," Hermeus, accessed July 2021, https://www.hermeus.com.

Global Air Freight: Global Aviation's Hidden X Factor

The global air cargo system is a crucial—and largely invisible—part of commercial aviation. Even measuring it relative to passenger travel is tricky, but rough estimates based on fuel consumption suggest that air cargo accounts for approximately 25 percent of air travel.

A better measure of air cargo activity is cargo tonne-kilometers (CTKs), tracked by the IATA. In contrast to passenger travel which plummeted as much as 70 percent below pre-pandemic levels, air cargo demand dropped by far smaller margins. This drop was not the result of decreased demand, but rather the absence of cargo capacity in the form of now-grounded passenger aircraft—empty seats above full cargo holds. As passenger travel evaporated, some carriers continued operating passenger jets as de facto cargo flights. Recovery beginning in 2022 is likely to be swift: the latest IATA data indicate that global cargo volumes reached a historic high in the first quarter of 2021.[42]

Implications

Outside of companies devoted entirely to air cargo services, carriers have generally considered air cargo as an adjunct to passenger travel revenue. Noting how air cargo CTKs remained relatively steady during the pandemic, it is likely that carriers will rethink this assumption. The prospect of long-haul single-aisle jets on skinny routes and other factors suggest there is an opening for new cargo hauling innovations. The decline in the number of 747s will create new challenges for shipment of large-dimension cargos, and a fascinating wild card is the emergence of hybrid dirigible craft capable of heavy lift transport. In the meantime, logistics lessons during the pandemic add uncertainty to the details of air cargo operations, but it is hard to imagine air cargo CTKs not continuing to increase.

Unmanned Systems

This paper omits a detailed discussion of drones and other unmanned systems, a topic which could easily occupy a separate paper of the same length as the one you are reading. However, I note that many of the technical factors that are enabling civil aviation transformations are coming out of developments in unmanned systems and thus the ongoing intersection of the two areas is likely to generate more than its share of cross-impact surprises.

Near Space—and a Space Wild Card

The focus of this paper is on terrestrial aviation, but events afoot beyond the Kárman Line are certain to affect the order below.[43] As noted above, orbital space platforms are already beginning to play a central role in shifting air traffic routing away from the current structured track system toward a so-called free flight method that facilitates more efficient dynamic routing, particularly on overwater routes.

Near-Earth space is the newest and arguably the most valuable real estate on Earth. Companies like SpaceX are staking out their terrain in the form of Starlink and other satellite constellations. Billionaires are flying to suborbital space and selling tickets to early adopters. The mood feels not unlike the early barnstorming years of aviation a century ago, an indicator that this is an area likely to spin out more than its share of surprises.

Implications

Near-Earth orbital space is quickly becoming our planet's most valuable real estate. Ever more ATC systems will become space-based. And we will see entirely new applications, including orbital processing and data storage platforms. It is entirely possible that in two decades there will be more data processed and stored in orbital space than on the Earth's surface.

This has vast implications for notions of sovereignty and jurisdiction. As an example, consider the implications of orbital cryptocurrency platforms, enjoying the efficiencies of extra-atmospheric solar power and operating beyond the territorial reach of would-be regulators.

42 IATA (International Air Transport Association), "Air Cargo Market Analysis: Air cargo volumes reach an all-time high in March," March 2021, https://www.iata.org/en/iata-repository/publications/economic-reports/air-freight-monthly-analysis---march-2021/.

43 Named after the Hungarian-born US mathematician, aerospace engineer, and physicist Theodore von Kármán, the Karmán Line defines the boundary between the atmosphere and space for aviation purposes. Located at a somewhat arbitrary 100 km, the line represents the point beyond which aeronautic control surfaces no longer function, owing to the thinness of the atmosphere.

Conclusion: Geopolitical Implications of an Airminded Age of Aviation Transformation

The cross-impact of the foregoing factors raises a host of geopolitical implications. When "airminded" seeped into public consciousness after the flight of the Wright brothers, it triggered no end of utopian expectations that somehow the reality of flight would help usher in a new era of world peace. This expectation was quickly contradicted in the First World War, dispelled by Alexander P. de Seversky, and utterly atom-smashed in the Second World War.[44]

Sadder but wiser after a century of aerospace innovation, it is unlikely that anyone expects the coming aviation transformations to bring peace, but we are unquestionably entering a new airminded era in the sense of unfolding innovations and a consequent public fascination with the ensuing possibilities. Those transformations will most certainly generate no end of surprise beyond that already discussed. In closing, here is a sampling of possibilities offered to provoke further thought.

Post-pandemic tourism: new destinations—or back to the old dysfunction?

Immediately before the pandemic shutdown, tourist hot spots from Venice to the Taj Mahal were being overrun by hordes of plane-borne tourists. Spain's Santiago de Compostela pilgrimage route risked turning into a 500-kilometer queue as more than 300,000 hikers applied to travel in 2019, and Machu Picchu reportedly was seeing its slopes being eroded and destabilized by the sheer volume of visitors tromping around its ruins. Will post pandemic tourism disperse or return to its old crowded ways?

Accelerating the centrality of cities as geopolitical powers

This is unquestionably the century of the city. World population became majority urban sometime around 2007, and by 2050 it is estimated that two-thirds of the world population will live in cities. Will the projected advances in aviation and 3D urban mobility further concentrate the power of cities, eventually eclipsing national power?

Can international air transport regulations keep up?

IATA is the central governing body for global aviation. The pace of current trends from airport landing slot demand to electric power are challenging IATA's ability to keep up with events. Failure to do so could result in serious economic and travel disruptions.

Aviation innovation meets resource scarcity

Aviation's move to electric propulsion will depend heavily on the same scarce rare earths and other mineral resources already in demand for everything from smartphones to electric highway vehicles. Aviation's share of consumption might prove comparatively smaller than other sectors, but the high visibility of privileged travelers crossing the sky in rare earth-enabled electrics could prove a public perception nightmare.

Technology-enabled terrorist threats

The combination of electric propulsion and increasing automation has already delivered new risks in the form of inexpensive drones. Basic systems are already being used in smuggling operations and have clear potential as platforms for delivery of explosives to noxious aerosols. As platforms grow in capability, this problem will only become more acute.

Proliferating no-fly and no-go zones

The 2014 downing of MH17 was an ominous harbinger of future aviation conflict hazards. The arrival of free flight will exacerbate this risk, as the departure from defined airways will make it harder for observers on the ground to distinguish bystander, friend, and foe.

Flag protectionism?

As aviation becomes ever more central to economic and political power, there is the potential for the arbitrary blocking of foreign-flagged carriers as an incident to geopolitical competition. This was briefly the case in the late stages of the Brexit debacle, and thus there is precedent for others to contemplate interference with the free flow of air traffic as a geopolitical tool. Such flag-based interference is clearly irrational given the vulnerability from retaliatory action, but there is no shortage of instances where international players have chosen options that while irrational in the long term, satisfy narrow short-term goals.

Rise of the new global citizen (or is it the global nomad?)

From the moment our distant ancestors first learned to ride a horse or build a raft, the single greatest impact of transportation systems has been to unlock humans from the tyranny of place. The combination of the steady advance of cyberspace with the aviation innovations on the horizon will kick this unlocking into overdrive and in

44 Alexander P. de Seversky, *Victory Through Air Power* (1942).

the process create a new kind of global citizen. This will not be the global citizen envisioned by 1970s Earth Day activists or visionaries like Buckminster Fuller and Marshall McLuhan. The first wave of the new global citizens are the super-wealthy who, thanks to their wealth and convenient access to cyberspace and air transportation, can live and work from wherever they please.

Behind this first wave are the merely wealthy and the upper middle class. Just as the arrival of jet travel in the late 1950s created a new kind of global tourist, our new aviation systems will create a new global nomadic class. Almost-retirees will move from Los Angeles to run their online business from a Central American beach town, while others snap up real estate in depopulated Italian hill towns, creating new foreign enclaves in the Old World.

We can barely glimpse the implications of a world in which millions of wealthy nomads can move on a whim from destination to destination, never quite putting down roots, flying high in comfort over the hundreds of millions more who remain chained by economics and circumstance to a particular place. The obvious tip of the iceberg includes acceleration of the continuing demise of the nation-state as a meaningful political unit, new social frictions as the arrival of wealthy and footloose strangers disrupts local economies. And, of course, this new mobility will open vast new opportunities for tax evasion and trans-border crime. Watch this space for a deeper examination of this critical trend.

Accelerating the decline of the fading nation-state order?

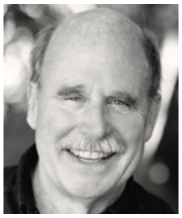
This aviation transformation creates as many challenges as opportunities for sovereign states—and in the case of fragile or failing states, the challenges seem to far outweigh the benefits. Specific issues include the inability to create and maintain formally designated landing sites attractive to commercial enterprises, coupled with the inability to control cross-border air traffic, thus complicating attempts to control borders and detect illicit activity. The result will be a perceived (and in many instances, actual) loss of territorial control that will force entities to ineffectually enforce their sovereignty, creating new uncertainties around air travel in specific regions.

The end of airspace as a global commons?

Airspace today is a de facto global commons supported by a host of international treaties underpinned by customary practice. The increase in both volume and variety of aviation platforms is certain to disrupt the existing order, triggering new uncertainties and a likely massive renegotiation of existing arrangements.

This happened with considerable success following the launch of Sputnik 1 in 1957. In contrast, the issue of renegotiating a commons arrived again in the form of the United Nations Convention on the Law of the Sea (UNCLOS) process beginning in the 1970s, and the result was at best a misfire. I hope for an optimistic result but fear the future will be more UNCLOS than Sputnik.

About the Author



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