Regional Air Mobility

Leveraging Our National Investments to Energize the American Travel Experience

April 2021

RAM will increase the safety, accessibility, and affordability of regional travel while building on the extensive and underutilized federal, state, and local investment in our nation's local airports.

Executive Summary

America is home to over 5,000 airports available for public use, yet only 30 of these airports serve over 70% of all travelers.[01] Despite this vast network of airports, the majority are underutilized due to air transportation services that have trended towards consolidation by putting more people into fewer, larger aircraft on well-traveled routes. Also, these bigger jet-propelled aircraft can only take off from and land on longer airstrips.

Regional Air Mobility (RAM) will fundamentally change how we travel by bringing the convenience, speed, and safety of air travel to all Americans, regardless of their proximity to a travel hub or urban center. We advocate RAM technology investment as complementary to and an accelerator for Advanced Air Mobility (AAM) and other initiatives that aspire to transform the airspace. Through targeted advanced technology investments, such as aircraft automation, enhanced operational models, more efficient aircraft and propulsion systems, and expanded airport renewable energy generation, many of which are already underway, RAM will increase the safety, accessibility, and affordability of regional travel while building on the extensive and underutilized federal, state, and local investment in our nation's local airports.

Who Should Read This Report

Investors: RAM is a measured investment. Early returns are feasible from a variety of independent technologies and services that will amplify each other as RAM grows. Importantly, success is not contingent on all technologies fully maturing before meaningful revenue is realized.

Community Leaders: That airport in your jurisdiction can bring sizable economic development, employment opportunities, and a better quality of life to your community.

Policymakers: Public investment in RAM can catalyze regional and national goals for renewable energy, sustainability, and economic growth.

Industry: RAM has the potential to develop into a large market that should warrant dedicated exploration alongside other related applications such as Unmanned Aircraft Systems (UAS) and Urban Air Mobility (UAM).

Public: Just because we are used to limited options for mid-distance travel, and just because we are accustomed to car culture, does not mean that ground travel is the best choice for every trip. Compared to road trips, RAM offers a more advantageous and enjoyable way to travel.

01 National Plan of Integrated Aiport Systems, 2021-2025, Federal Aviation Administration, p. 2, 4

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Voices From the Near Future: RAM will Transform Travel

Ever since I went back to work after our youngest son was born, it seems like we just can't find a moment to relax. My mom suggested a weekend getaway, and I really wanted to spend some time by the water. But the traffic is so bad – we spend hours frustrated and tired and have to turn around and do the drive again the next day. It's just not worth it. I work just outside the Bakersfield airport solar farm, and I saw a bunch of quiet planes. My colleague told me cheap flights are available to lots of places now, and after a quick search, I saw there's an airport on Catalina Island! My husband and I took a flight the next weekend, and I swear it was like being in our own private limo in the sky. We felt spoiled! It was so relaxing to take a little time for ourselves. On our way back, we split a flight with a nice family, and it made us start to think about when we could do this with the kids. I see Fullerton and Carlsbad have airports, so maybe we'll go to the theme parks when they're a little older. It's a whole new way to travel – we're hooked!

My family has lived in southwest Texas for generations. It's a great place to be, but it sure is remote. You wouldn't think so if you go to the airport! I've worked there for two decades, and we've recently had to double our staff just to handle the workload. We get these new planes bringing people in and out all day. The same planes, but without people – not even pilots! – bring cargo at night – and they're super quiet! It was weird at first unloading cargo from a plane with no pilot. I never really thought about how much more passenger traffic and especially air cargo we get now, but I guess it's way cheaper with these new planes. It makes a big difference. We just got a shipment of flu vaccines in from Austin last week, and my wife tells me they're going to get this whole area vaccinated with a few more shipments. It'll be nice to get ahead of flu season this year. It makes me proud to be a part of keeping my community safe.

I knew when I came to America that it would be hard being so far from my parents. It was a dream to run my own farm, but we're so far out that it's a struggle to get all the way to Chicago to catch a flight. When we found out my dad was about to go in for an unexpected surgery, it seemed that there was no way I could see him in time. I don't love to fly, but my wife arranged a trip that started from a nearby airport I didn't even know existed, and she scheduled it to get me to Chicago in perfect time to walk onto the next flight to Mexico City. I was scared at first to be in such a small plane, but it was smoother and quieter than I ever expected. I don't know who felt better when we first saw each other – me or my dad! On my flight back home, I landed in Chicago and the small aircraft was already waiting to take me back home! I'm actually looking forward to flying again!

Our latest project has me traveling to Connecticut for periodic and sometimes last-minute quality assurance inspections. I used to dread these trips when it took three working days for what is usually a 4-hour inspection – it didn't matter if I drove, took the train, or an airplane. Now, I go to the airport in Newport News in the morning and jump on one of the northbound airplanes, normally getting dropped off in Groton after only one or two stops in between. I usually finish up in time to fly back in the evening to get home in a single day. I love getting a couple of days back on these trips, and it's good for the company, too – they don't have to pay to put me up in a hotel for those extra nights or for all that wasted driving time.

Air transportation in the USA:

5,050 under-utilized, public-use airports in the U. S. [04]

16 minutes from your closest airport [02]

1.6% of all trips between 50 and 500 miles are taken by air [03]

$3.2B in annual grant funding to local airports [05]

0.6% of U.S. airports currently support 70% of domestic air travel [06]

Introduction

You may live in an urban metroplex or a rural expanse, enjoy snow-capped mountain peaks or poppy-filled desert valleys, root for the Red Sox or the Yankees, and drink soda or pop. But, one thing that is true for most Americans is that they live within 16 minutes of an airport.[02] This fact is thanks to an extraordinary air transportation infrastructure in the United States that has received strong national investment for decades.

If an affordable, efficient, robust, and environmentally friendly aircraft network were implemented across these thousands of airports, more people would be able to choose convenient air travel over cars for mid-distance trips around 50-500 miles. RAM's vision is to make these local airports the community hubs they were always meant to be, and innovative aircraft, operational models, and infrastructure are the keys to making that happen.

The result of the air travel statistics shown above is that the average American has limited travel options. Unless a person's desired origin and destination are near major air transportation hubs, they will have to travel great distances to reach an airport with reasonably priced commercial service. They will wait in long lines, fly non-direct routes, and endure a lengthy ground transportation journey from the airport to reach their ultimate destination.

When it comes to distances of a few hundred miles, also known as mid-distance travel, it's no wonder 73% of Americans prefer road trips over flying despite the added time and unforeseen issues that road work and accidents may cause while driving.[07] These obstacles are still better than commercial air travel's inevitable delays, security woes, cramped seats, and a myriad of other frustrations that we have all experienced.

The most common mode for regional travel – taking to the highway – costs billions in upkeep. The National Transportation Research Board recently recommended that

02 Advanced Air Mobility Markets: Where is the Opportunity? McKinsey & Company, January 14, 2021

03 Long-Distance Travel, Bureau of Transportation Staistics

04 Number of U.S. Airports, Bureau of Transportation Statistics

05 U.S. Department of Transportation Announces $76 Million in Airport Improvement Grants

06 National Plan of Integrated Aiport Systems, 2021-2025, Federal Aviation Administration, p. 4

07 Do Americans prefer planes, trains or automobiles?, Tyler Schmall, SWNS

the combined state and federal spending to maintain our Interstates be raised from $20-$25 billion to $40-$70 billion annually.[08] These investments are necessary to maintain the ground infrastructure already in place – billions more are needed to further improve access and throughput.

All of this is to say that if you're driving, you're not alone. But, that doesn't mean more driving is the best solution to how we can optimize our mid-distance travel experience in the future. In the following pages, our vision for enhanced RAM addresses the regional travel problems we face with practical, affordable, and effective solutions that define a new era of transportation.

Vision of Regional Air Mobility (RAM)

RAM focuses on building upon existing airport infrastructure to transport people and goods using innovative aircraft that offer a huge improvement in efficiency, affordability, and community-friendly integration over existing regional transportation options. These aircraft, that typically carry less than 20 passengers or an equivalent weight in cargo, are flexible in terms of where they can take off and land, even using existing runways and infrastructure to maximize compatibility with today's airports. In short, RAM provides air accessibility that is dependable, efficient, and affordable.

RAM presents an exciting, convenient, and affordable way to see more, do more, and dedicate less time in transit to do so. Unlike car travel, RAM does not rely on a path-based road system where only two or three routes are desirable. It uses a node-based system where aircraft are free to travel "as the crow flies" from one airport to the next – gridlock, road construction, and accidents no longer slow you down. Importantly, RAM uses the thousands of existing and mostly under-used airports across the United States.

Regional Air Mobility provides a cost-effective solution to connect communities that have been underserved by current aviation norms while also providing needed relief to capacity-constrained aviation hubs. As this new generation of aircraft is developed, communities will welcome the benefits of utilizing their local airport infrastructure to provide a conduit for new opportunities in their region.

It may all sound like a fictional episode of The Jetsons, but these technologies will be commonplace in our near future.

One of the most powerful aspects of the vision is that multiple technologies do not need to mature simultaneously in order for RAM to advance. When innovations are contingent on too many pieces working together, the probability of successful implementation diminishes. Instead, RAM's scale will simply multiply as each technology and capability is introduced. And, crucially, each new component moves the needle by itself without relying on the simultaneous coupling to other new technologies.

New capabilities associated with RAM can be placed into three main categories:

- Community-compatible aircraft
- Autonomous capabilities for operational enhancements
- Seamless ecosystem

While the complete RAM vision is realized at full scale in a future where all three work in concert, each point in isolation would meaningfully transform the industry.

Community-Compatible Aircraft

"Community-compatible aircraft" can be defined two ways. First, they are able to operate physically close to communities. This is due to characteristics like their low emissions, low noise, and steep climb/descent profiles reducing nuisance factors. Their ability to operate from short runways that can be located closer to the populations they serve is also a factor. Second, community compatibility provides overall value such that the communities served, despite some drawbacks, on average they reap a net benefit. This benefit comes mostly from increased access to air mobility for individuals and communities, so it is essential to keep operations safe and costs affordable whenever possible.

When community-compatible aircraft are available, the frequency and density of flights can grow at existing airports where, currently, runway quantity, runway length, and noise restrictions are actively limiting operations with more traditional aircraft. Most importantly, the two sides of community-compatible aircraft – the low nuisance factor and the community access – work together to assuage any social and political opposition to the growth of air mobility. Along with the two main tenets of community-compatible aircraft, there is also an opportunity to energize the local community through renewable energy.

Energy Options

One of the challenges associated with travel is the monetary and environmental costs of burning fossil fuels. Aviation is responsible for a small but growing portion of global carbon emissions, and current aviation architectures are almost exclusively powered by oil-based energy sources. This has already led to movements to curb travel by air, so any vision that looks to expand air travel will be met by increased environmental scrutiny.[09] Critical RAM technologies, particularly the use of electrified aircraft propulsion, can reduce the environmental impact associated with air travel. These innovations may include fully electric motors or those that use hybrid architectures or alternative fuels.

08 Renewing the National Commitment to the Interstate Highway System, Transportation Research Board

09 Flight-Shaming Is Now A Thing – Will It Keep You From Traveling? Forbes, July 2, 2019

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Bringing a large consumer of electrical energy to the airport helps improve the return on investment for airport renewable energy solar projects. Regional airports typically sit on hundreds of acres of public-use land, which is well-suited for renewable sources such as solar power generation. Whether this energy is used to charge the batteries of electric RAM aircraft, ground transportation, or sequester carbon as part of a fuel offset, RAM operations are well-positioned to catalyze the transformation of local airports into renewable energy hubs and well-distributed networks of self-sufficient grids.

Autonomous Capabilities for Operational Enhancements

Advancements in autonomous (pilotless) capabilities will enable new or lower-cost operations for RAM services. Even if an autonomous capability only moves the professional pilot from the aircraft to the ground, it still addresses three major factors inhibiting growth.

1. A service network with both aircraft and pilots incurs major costs and overhead due to rebalancing (e.g., transporting pilots to their home airport even if the flight isn't full, referred to as "dead legs"). Unlike pilots, aircraft don't mind sitting idle (e.g., to accommodate asymmetric demand cycles) and don't necesarily need to have a "home" that they need to return to at the end of the day.
2. Trends in commercial pilot shortages will only get worse with growth in RAM operations.
3. Since RAM aircraft carry fewer passengers than large transports, the relative per-passenger costs of a pilot, including occupying space that could be used for revenue, can be sizable. Remote and/or autonomous operations can reduce these costs and increase route flexibility. Even if autonomous or semi-autonomous operations are initially only allowed for cargo or repositioning flights, they will still contribute to lowering overall costs. This will also reduce the need for onboard pilots to just a portion of operations.

Even if decoupled from other RAM enablers like new technologies, a seamless ecosystem, and advancements in electric propulsion, obtaining a pilot license still poses a difficult, time-consuming and expensive barrier that could slow down RAM's impact and growth. That's why creating small aircraft that can operate independently, or autonomously, from an onboard crew removes a significant obstacle to accessing personal, on-demand aviation as it exists today. If a paying customer can occupy what was once the pilot's seat, potential revenue can also be found there. As trust in autonomous operation grows, future passenger-carrying operations will benefit from reduced operating costs and increases in revenue.

Seamless Ecosystem

RAM can access thousands of existing airports available today. Better yet, travelers will not be required to put as much time into planning and preparation as they have grown accustomed to with the typical commercial airline experience. The user experience for scheduled RAM flights will feel smooth, uniform, and seamless from one airport to the next. On-demand flying should be as simple to access as a car-share style experience that feels as quick and convenient as having your own car (minus the headache of actually owning and maintaining that vehicle).

Most importantly, no matter what business model is used (scheduled, charter, or other on-demand operations), users should not need prior knowledge or experience to successfully use the RAM system. This includes everything from the journey to the airfield, security screening (when necessary), baggage handling, boarding, inflight experience, egress, and transfer to the next transportation mode. Most aircraft that fit into the RAM vision are not required to have a flight attendant so travelers must be able to navigate the entire process easily, safely, and on their own. Here, the practices used by some recent on-demand charter operators and emerging Urban Air Mobility (UAM) operations, discussed later on in this paper, may be leveraged to ensure that the passenger experience is seamless, pleasant, and safe.

Most RAM operations can be integrated into existing airport infrastructure so that no additional services or facilities will be needed. Alternatively, additional benefits come about when airports add services or modify their operations, such as participating in a common fleet management, inspection and maintenance systems, adding additional electric infrastructure, facilitating connections to ground transportation (especially at rural or unattended airports), or participating in small-scale parcel sorting to harmoniously blend cargo and passenger operations.

Ensuring smooth transitions between all user touch points is one of the most critical aspects of RAM in order to reconcile our very decentralized and heterogeneous modern-day airport system. Fortunately, creating more uniformity is also the aspect that requires the least amount of investment in new technologies and should motivate stakeholders to fully participate in large-scale RAM operations.

The Future is Now

The concepts presented in this paper are new to most people, and questions regarding RAM are normal and expected. While we may not be able to address every potential item, we will address concerns related to passengers, communities, infrastructure, and public policy through discussion of the following key aspects of RAM:

1. Market Landscape
2. Your Travel Experience
3. Electrifying RAM
4. Autonomous Systems
5. Infrastructure Landscape
6. Parallel Trends

With an informed understanding of the entire environment, you will be empowered to ask more questions and decide for yourself if RAM is a critical part of the future American transportation portfolio.

RAM presents an exciting, convenient, and affordable way to see more and do more and to dedicate less time in transit to do so.

RAM will operate aircraft so quiet and unobtrusive, and provide services so accessible and useful, that stakeholders will want RAM flights in their communities.

Market Landscape

The Airline Deregulation Act of 1978 removed price and route restrictions previously imposed on U.S. air carriers by the federal government. This allowed domestic air carriers to compete for routes, enabling a vastly different network of origin/destination pairs to emerge. High-demand routes were served by numerous airlines, reducing ticket prices for these travelers. However, lower-demand routes, which could be served by smaller aircraft with lower revenue potential and margins, started to get squeezed out. As such, Congress established the Essential Air Service (EAS) program to maintain some level of scheduled air service for small communities that were served prior to deregulation.

The EAS program primarily provides subsidies to air carriers to maintain air services to local communities for what would otherwise be unprofitable routes. When it was first created in 1978, it was expected to "sunset" in 10 years; however, funding for the program has been appropriated every year since its inception. In 2020, approximately 170 communities participated in the EAS, including 60 in Alaska alone, at a cost of $312 million.[10] The future of EAS is uncertain, as it is a frequent target of critics seeking to reduce government expenditures. However, support of its continued existence well past its original sunset date hints at the challenging economics associated with these routes in a purely competitive market landscape.

In the 1990s, the commercial aviation market saw a large growth in routes, fueled in part by market conditions and the introduction of new regional jets in the 50-passenger class of service. The new aircraft gained broader acceptance by the traveling public, and airlines were able to keep these regional jet operations cost-competitive with existing turboprop aircraft flying these routes. The result was an increase in short-haul traffic, serving more of the traveling public with additional origin and destination pairs. This bounty diminished during the 2000s, when a confluence of conditions led to airlines reducing or eliminating regional jet services. A recent NASA report studied this market extensively, including a look at the technology and market factors that could help restore this service. This study included sensitivity analysis of market conditions with respect to cost reductions. The study considered aircraft with seat capacities from 20 to 80 seats and concluded that a hypothetical 40% reduction in operating cost compared to today's regional aircraft would push the market to a huge expansion in small regional flights serving far more airports.[11]

From 2015-2016, NASA and the FAA hosted several events open to the public to establish a roadmap for development of enhanced aerial on-demand mobility (ODM).[12] These workshops gathered together aviation producers, commercial operators, researchers, standards organizations, regulators, and users to understand the barriers to ODM and a path to mitigate these barriers. While the ODM workshops have been cited by other mobility efforts, such as those in the UAM realm, one presentation from the 2016 gathering of a commuter airline operator highlighted that, of the routes served by their service, almost all of the routes below 100 miles were able to be sustained without EAS subsidies using their current aircraft. If this were true for all commuter airlines and EAS routes, a savings upward of $312M to taxpayers annually could be realized.[13] They also outlined requirements for a modern commuter aircraft. Aircraft conforming to these requirements were investigated in a 2016 NASA-sponsored study, including the introduction of new propulsion technologies and novel aero-propulsive integration.[14] In this study, the authors estimated a total cost reduction of approximately 25% from a baseline modern aircraft was possible with electric propulsion technology (with a fixed number of hours of operation per year and an onboard pilot).

10 Essential Air Service Program, American Association of Airport Executives

11 Seat Capacity Selection for an Advanced Short-Haul Aircraft Design, Ty Marien, NASA Langley

12 NASA Strategic Framework for On-Demand Air Mobility, NASA Aeronautics Mission Directorate

13 Essential AIr Service Program, American Association of Airport Executives

14 Design Studies of Commuter Aircraft with Distributed Electric Propulsion, Alex Stoll et al., Joby Aviation

The 2016 commuter aircraft study highlighted other opportunities to reduce commuter aircraft costs. One of the main underlying assumptions in the study was a utilization of 1,500 hours per year, as listed in the requirements provided by the commuter airline. Utilization refers to the number of hours the aircraft is operating and determines the impact of costs that do not vary or vary little with the number of hours flown, known as fixed costs – insurance, interest, etc. – on the overall hourly operating cost of the aircraft. One of the challenges with regional aircraft is that utilization is generally lower than for larger aircraft that can keep a steady pace of flights throughout their operating lifetimes, stopping only for fuel, cargo/passenger loading, and any required maintenance. A modern 150-passenger class airliner may see a utilization of 3,500 hours or more per year – a pretty impressive sum that reduces the impact of fixed costs on the hourly operating cost of these transports. While the route structure of regional aircraft involves less time in the air than these larger workhorse transport aircraft, finding innovative business and operating models that increase utilization is a key component to reducing the impact of fixed costs. Using the 2016 commuter aircraft design study as a guide, doubling utilization could help reduce total costs by 10-15% from interest and insurance savings alone. As well, as the RAM model is proven, it will become more popular, attracting more customers as time goes on. RAM's convenience and other positive attributes will eventually speak for themselves, thus reducing costs even further.

One final aspect of the 2016 study was the impact of the cost of the pilot, which accounted for an additional 10-15% of total operating costs. Regulations governing the minimum number of flight crew onboard an aircraft correspond to the number of passengers. The study in question considered nine-passenger aircraft, with a minimum required crew of one pilot. The compensation for the single-pilot flight crew on that aircraft is only divided by as many as nine seats – as compared to a 150-passenger airliner, with a required crew of five (two pilots and three flight attendants), which can amortize crew costs over far more seats. Technologies that reduce the required flight crew, or perhaps eliminate the need entirely, can further reduce this impact on the bottom line. These crew reductions do not have to initially target passenger operations – instead, repositioning and cargo flights are good candidates for opportunities to tackle these costs.

Altogether, these studies point to some salient themes that will be explored in this paper:

- As costs go down, the market favors smaller seat classes of aircraft, which can serve more airports. Serving more airports means compatibility with runway field length restrictions, limited terminal facilities, and proximity to local communities that may be more averse to disturbances.
- Near-term technology options, such as electric propulsion and reduced crew operations, can reduce hourly operating costs for regional aircraft.
- Operating models that increase utilization beyond that of current commuter airline operations, for example through a mix of services such as passenger and cargo, can have a substantial impact on reducing operating costs.

Not in My Backyard (NIMBY)

Large portions of the population can benefit from enhanced access to RAM. From cargo solutions to on-demand flights to other applications that may emerge from these capabilities, the potential within the RAM vision presents new and innovative ways to utilize air travel so that it is convenient, environmentally responsible, and financially viable.

However, airports sometimes attract negative attention from local residents – generally due to noise and emission concerns. Despite advances in technology and more stringent regulations regarding noise and emissions, increasing operations at local airports with today's aircraft may accelerate the negative perception of living close to an airport for many residents. It is exceptionally important for RAM to be a good neighbor. As discussed later, new propulsion technologies, aircraft capabilities, and operating practices will help operations blend into the background of the local environment. RAM will operate aircraft so quiet and unobtrusive, and provide services so accessible and useful, that stakeholders will want RAM flights in their communities.

On-Demand Service

Travelers have long been able to charter aircraft, opening up access to the full range of local airports in the United States. Others may have access to a privately owned aircraft, either as individuals or through their business. When available, private aircraft offer exceptional freedom to travel across the nation – the freedom to explore a vast number of destinations on a schedule dictated by the traveler. For a variety of reasons, this mode of transport has not traditionally extended to the majority of the public.

Developments in recent decades have sought to democratize access to on-demand air travel services. Fractional ownership and airplane sharing services have tried to increase the utilization of smaller aircraft. In 2002, NASA's Small Aircraft Transportation System (SATS) envisioned the use of modern general aviation aircraft to enable a network of personal on-demand air transportation that would be more widely available to the general public.[15] Other entities have tried to seize on the SATS vision as new technologies were developed to

15 Small Aircraft Transportation System Concept and Technologies, Bruce Holmes et al., NASA Langley

connect people in new ways. ImagineAir and FlyOtto attempted to provide ride-sharing services to reach consumers who may not otherwise be aware of on-demand aviation services. Today, there are several emerging companies such as FLOAT, Surf Air Mobility, JetSuiteX, and others that continue this vision. As connectivity technology has improved, so too has the ability of on-demand air service providers to reach new travelers.

Zip Aviation Study

The Zip Aviation Study, funded by NASA's aeronautics strategy office, considered the implications of introducing electric, highly automated, small aircraft into a business model analogous to Zipcar.[16] The concept assumed that automation could be introduced into the aircraft so that individuals could obtain certification for safely operating these highly automated aircraft with only a weekend of training. Then, these individuals would be able to quickly and easily rent an aircraft from their local airport to take a trip by air, similar to how Zipcars are rented.

The potential market for trips in these on-demand aircraft was projected with Virginia Tech's Transportation Systems Analysis Model for a range of estimated cost levels. Findings revealed that if flight ticket costs could be reduced by 50% or more, there would be a large jump in demand, making the entire Zip model viable. The study focused on trips with a 300-mile range limit, on average, and found that with enough interest, these trips would only cost a traveler roughly two times what it would cost to operate a car the same distance; but the actual time saved, and with it headaches and stress, could prove immeasurable.

Midwest Market Analysis

Researchers at Purdue University, in collaboration with NASA, conducted a study to understand the impacts that electric propulsion technologies, increasing levels of autonomy, and improved operational capability may have on regional transportation systems.[17] The study focused on the Midwest region of the United States as a case study. It estimated the reductions in travel time and/or cost that could be achievable through the broader use of small aircraft for regional transportation. The study showed that RAM will be most successful as regional airports become better equipped with appropriate charging/fueling and maintenance capabilities to give travelers as many potential destination options as possible. Additional infrastructure would not be necessary until the current number of small airports became saturated. Most importantly, the study found that the ride-sharing economy and autonomy are the two biggest enabling factors to regional transportation systems. This analysis clearly presents the potential of combining new technologies and business models to develop a transportation system that everyone can afford.

Scheduled Service

Regional scheduled air passenger service today accounts for approximately 3% of total air traffic.[18] As noted earlier, the economics of serving these routes is challenging with the aircraft and operational models that have been used in the past. However, the RAM concept can take some lessons from previous regional operations, both in their successes and failures.

One of the challenges with connecting passengers on longer routes is simply getting them to a major airport in the first place. There are currently nine U.S. airports that are considered capacity-constrained, meaning too many people and planes are trying to use the same limited resources at the same time.[18] This number is projected to grow to at least

16 High Speed Mobility Through On-Demand Aviation, Mark Moore et al., NASA Langley

17 Future RAM Analysis Using Conventional, Electric, and Autonomous Vehicles, Satadru Roy et al., Purdue U.

18 National Plan of Integrated Aiport Systems, 2021-2025, Federal Aviation Administration, p. 7, 15

Advanced aircraft designs can creatively be reconfigured to carry cargo, along with passengers, without the latter feeling like cargo themselves.

eleven by 2030, with an additional six considered to be at risk of reaching constraints in this time period. Nearly all of the major "hub" airports are on the capacity-constrained list, meaning that airports will be restricted in how many new flights, if any at all, can be added. The capacity of an airport to handle flight operations is largely independent of aircraft size, meaning that a small aircraft and a traditional airliner take up the same runway capacity, even if the latter serves over a hundred more passengers. This would seem to eliminate small regional aircraft from consideration at these major airports.

However, the nature of these smaller regional aircraft generally means they can operate from much shorter runways than their large jet transport brethren. This opens up possibilities – several major airports have smaller, secondary runways that can serve regional traffic. Many have crossing runways that are limited in use due to the wind configuration. However, regional aircraft may be able to make use of Land And Hold Short Operations (LAHSO) to use runway capacity that may not otherwise be usable by larger aircraft that need more runway. This unique approach has been used in the past – for example, in the 1980s, Ransome Airlines used LAHSO operations to squeeze in extra flights at National (now Ronald Reagan National) Airport in Arlington, Virginia.[19]

Though the economics can be challenging, there are still several operators of small regional aircraft today. They may be partially subsidized through programs such as EAS and are able to find niche markets that are not otherwise well served by both major air carriers and ground transportation options. They may even work in collaboration with these carriers through code-share agreements. Some of these carriers have spurred the development of new regional aircraft. For example, Cape Air, whose aging fleet of Cessna 402 aircraft have been out of production for decades, served as the launch customer for Tecnam Aircraft's new P2012 Traveler. RAM offers the potential tipping point for a large-scale shift in regional transportation towards smaller passenger classes.

RAM for Improved Cargo Transport

Regional aircraft have been a staple of air cargo for decades. Their ability to land at small, unimproved airstrips gives them unique access and range, particularly when the alternative is ground travel that may not be practical or even feasible. For example, FedEx operates more than 200 single-engine Cessna 208 Caravan aircraft, which can carry up to 3,000 pounds of cargo and land on short runways. Recently, FedEx served as the launch customer for the twin-engine Cessna 408 SkyCourier, which is expected to enter service this year.[20]

The overnight parcel shipping business built by UPS and FedEx has become one of the most profitable segments of their business model and is an enormous part of national and worldwide commercial air traffic. Amazon Prime and Walmart are also driving the need for next-day delivery. Amazon already offers same-day/one-day service to 72% of the U.S. population.[21] Using RAM technologies to reduce costs and increase utilization will further increase access – lowering costs to the population that already enjoy this service and enabling access to the remaining 28% of the market.

The infrastructure to support next-day delivery depends on population density and geography such that population drives sales-per-region and the size of the region drives the delivered cost of the sale. Clearly there are many details to consider, but when discussing Regional Air Mobility and its likely usefulness, RAM systems may be the only means for rapid delivery to remote locations. Technologies, such as autonomy and electric propulsion, can drive down the price of transporting cargo and provide a low-risk, revenue-producing test case to ensure reliability of these technologies before transporting passengers.

An aircraft sitting idle or underutilized, just like a machine tool or a tractor, is losing money. The more time a plane spends working, the more revenue it generates. The addition of cargo flights to passenger flights (or vice versa) will help decrease RAM costs because cargo transport enables an airplane to be flown both day and night, not just during peak hours when passengers generally prefer to fly. And, using the same aircraft for both passengers and cargo means that even if the flight doesn't sell all of its seats, it can still operate profitably thanks to cargo on board. All major commercial airlines already take this hybrid approach to flying passengers as well as cargo, as do operators in states like Alaska that already have a robust RAM operation in place. RAM applications that match passenger travel needs with aircraft may also include cargo demand so that RAM aircraft can accommodate both.

Point-to-point flights originating from smaller airports will not have passenger/cargo demand density as high as hubs. Some flight segments may only be able to fill a few of the available seats, and demand for cargo can help cover costs and add revenue. Advanced aircraft designs can creatively be reconfigured to carry cargo, along with passengers, without the latter feeling like cargo themselves. Demand for passenger flights to remote locations and/or locations more convenient than the hubs currently utilized by commercial airlines will be a hallmark of RAM service, but that demand will vary, so loading flexibility will help maximize the utility of the aircraft. Furthermore, combining passenger and cargo operations can increase the utilization of RAM aircraft, reducing the impact of fixed costs on total operating costs.

19 A Brief History of Ransome Airlines, David Laird, Clipper Pioneers, Inc.

20 FedEx Express Introduces New Feeder Aircraft, FedEx Newsroom, November 28, 2017

21 Amazon can already ship to 72% of US population within a day, this map shows, Eugene Kim, CNBC

The Customer Journey:

1

Book It

Book spontaneously, even while on your way to the airport, or schedule in advance.

2

Hop On

Never miss a beat. Get dropped off right next to the plane or walk through a small building or gate.

3

Sit Back

Relax or be productive – no need to keep your eyes on the road.

4

Hop Off

Go directly to an automatically arranged waiting rideshare or parked car.

Your Travel Experience

Booking for Seamless Travel

The prevalence of online and app-enabled services has changed consumer behavior on the ground (think Airbnb and Uber), and innovative companies are trying to modernize air travel by bringing the same conveniences and efficiencies to the skies. Most of us are familiar with how Uber car service works: A user downloads the app, attaches a payment system to it, and orders a class of car on demand. The future of air travel could look similar if we begin to normalize mid-distance air travel. Several companies, such as FlyOtto, ImagineAir, FLOAT, and Blackbird, have already begun to modernize how we book aircraft in this market. RAM does not need to reinvent this process, but rather provides a more cost-effective option to book on the various platforms that have already been developed to provide a more seamless booking experience. By employing the 5,000+ local airports that already exist within the United States, coupled with advancements in smaller, lighter, and potentially autonomous aircraft, new technologies enable a seamless travel experience.

Renewed Passenger Experience

As RAM grows, consumers will begin to see the amenities we have come to expect at larger hub airports available at local airports, such as long-term car parking, lounge and waiting areas, secure access to the tarmac, and food and beverage options. And, if you are flying out of a smaller regional airport with no terminal, users will often be able to park near the plane itself. RAM will grow to feel like a VIP private jet experience but accessible to far more people. Even as RAM becomes increasingly popular as a regional mobility solution, the demand for regional travel will be distributed across 5,000+ airports, instead of 30, creating less potential for bottlenecks.

Furthermore, noninvasive security screening will be available in cases where it's required, and passengers will be able to carry their luggage (and water bottles and other liquid-based products) directly on board—no conveyor belts, no baggage carousel wait times. Companies such as JetSuiteX, Blade, and UberAir have already developed this experience for air travel. Once again, a new experience does not need to be invented; RAM will simply leverage existing investments and operation models to provide a seamless experience for the regional traveler.

Getting You There

The "last mile" is a term used in transportation planning to describe the movement of people and goods from a transportation node (e.g., airport) to their destination. RAM works best when travelers have several options to get to their final destination from the airport. Uber, Lyft, or other rideshare platforms will likely play an important role, and studies show that even electric scooter companies are open to placing bikes and scooters at the airports for arriving passengers.[22]

Billions of dollars of investment, from both the public and private sectors, are already being poured into electric grid upgrades. RAM can integrate into the electric infrastructure not just for the aircraft but to allow for innovative last-mile transportation options as well (e.g., autonomous cars).

Electrifying RAM

Many of the ideas discussed in this paper are not some future concept. They already exist and will become more cost effective as time goes on. As shown above, there is a market for smaller, lighter aircraft, and once new technologies are successfully integrated with operational models, RAM's potential can be realized.

When the Wright brothers first demonstrated powered flight in 1903, they used the thrust from two propellers linked to a small gasoline-powered engine of just a few horsepower to help push their machine through the air. In the decades that followed, aircraft propulsion systems largely consisted of piston engines driving propellers to generate thrust. Both the engine and propeller became increasingly sophisticated, and by World War II, aircraft had engines capable of producing several thousand horsepower, powering aircraft that flew hundreds of miles per hour and could carry many tons of payload.

World War II also kicked off what would become a revolution in aircraft propulsion: the jet engine. Though initially unreliable and incredibly fuel-hungry, the jet engine would be refined within a few short decades to become the dominant source of propulsion for many aircraft roles. Today's gas turbine engines are a far leap from the early jet engines developed during World War II – more reliable, more powerful, and more efficient than ever. If you are a passenger on an airplane with more than about ten seats, chances are it is using a gas turbine engine of some type.

Electric motors have been around for longer than piston or gas turbine engines. They have generally not been used for aircraft propulsion because of challenges associated with their weight, the amount of power they produce, and how the electricity is stored or generated on the aircraft. Recent developments in electric motors, spurred on by huge investments in electric ground vehicles, have allowed electrified aircraft propulsion to become a reality. Today, electric motors have been successfully demonstrated on test flights and even certified for commercial use. New designs generate several hundred horsepower at weights that are comparable to turbine engines in the same power class. Continued investments in both the public and private sector indicate that safe, reliable, lightweight electric motors capable of producing thousands of horsepower will be available in the near future. Electrification of the propulsion system aligns well with RAM for the following reasons:

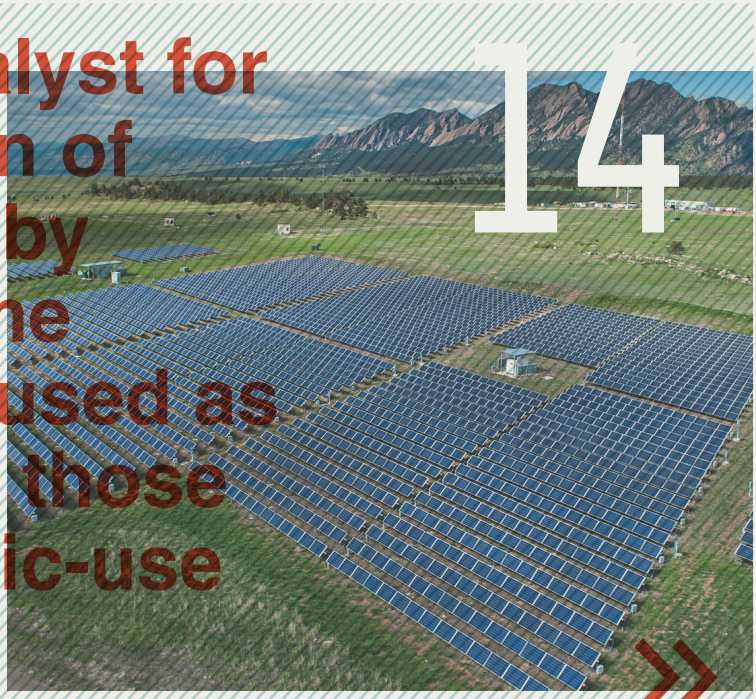
- Improved efficiency: Electric motors use far less energy than their combustion counterparts. Unique and more efficient aircraft designs are possible because electric motors present new design options for improved performance. These designs are particularly well-suited to the smaller aircraft size classes which enable widespread RAM.
- Reduced lifecycle emissions and compatibility with the future electric grid: Focusing operations at small regional airports brings in a new, large electricity customer that can impact capital investment decisions for airport-scale renewable power generation. In the near-term, these aircraft could leverage existing investments in the grid; in the long-term, this reduces the total lifecycle emissions for these aircraft operations.
- Reduced noise and maintenance compared to current aircraft with combustion engines: Engine noise can be virtually eliminated, and electric motors have far fewer moving parts, reducing maintenance needs. The ability to turn propellers slower and climb faster also contributes to reduced aircraft noise in a surrounding community.

Efficiency

One of the benefits of electric motors over their gas-powered contemporaries is efficiency. On a piston or turbine-powered aircraft, anywhere from half to two-thirds of the energy stored in the fuel goes right out the tailpipe. A modern electric motor will convert more than 90% of electricity provided to it into mechanical power. This means that an electrically powered aircraft may not need to store – or waste – as much energy to produce the same amount of mechanical power as a gas-powered engine. This efficiency benefit is especially important, since fuel is a large portion of an aircraft's total operating cost. In addition, the lower efficiency of gas-fueled engines is directly traceable to the environmental impact of aircraft operations.

22 More than 82% of the US population — upwards of 268 million people — lives in an area where Uber operates as of 2018. Uber Across the United States, Jonathan Wang, Uber, Medium

RAM can be a catalyst for enhanced adoption of renewable energy by leveraging the same locations that are used as landing facilities – those thousands of public-use airports.



Unfortunately, the means for storing electric energy are quite heavy. A modern battery suitable for aviation applications may contain less than 1/50th of the energy stored in gasoline or jet fuel for a given weight. This results in aircraft with far shorter range, or that are far heavier for a given range, and therefore require more power.

So, why bother? The answer is that the improvements in electrified aircraft propulsion are opening up new opportunities while also revitalizing existing ones. The hobby aircraft and drone industry very quickly adopted battery-electric propulsion as the dominant choice about two decades ago. Despite the increased weight of the batteries, the lightweight, powerful electric motors proved to be far more reliable and simpler to operate. This was one of the key components of the explosion in the small UAS (i.e., drones) market. Those same trends apply to slightly larger aircraft as well. Many aircraft that use gas-powered engines today do not need the long ranges that their fuel of choice affords. Rather, they may be involved in very short missions – pilot training at the local airport, short flights to local airports, aerial sightseeing – where increased reliability and lower operating costs are more important than long range capabilities. It is these missions, which are generally too expensive for most of the public to consider, where electrified aircraft propulsion architectures will first shine.

Environmental Impact

Electricity is not necessarily emission-free, as approximately two-thirds of the electricity produced in the United States is generated from processes that involve greenhouse gas emissions. If the electrical energy is generated onboard the aircraft from an energy-rich fuel, such as may be for hybrid aircraft, then those engines are subject to the same physics of the gas-powered propulsion systems the hybrid system replaces, meaning that the gas-powered portion of the hybrid system will still put half to two-thirds of the stored energy out the tailpipe.

In the past few decades, there has been a global trend towards cleaner energy generation. Recent national mandates have been considered to further increase the amount of “clean(er)” electricity generation in the United States, so, over time, the balance of emissions generated by electricity production will improve. Regardless of a national mandate, RAM can be a catalyst for enhanced adoption of renewable energy by leveraging the same locations that are used as landing facilities – those thousands of public-use airports.

These airports typically consist of hundreds to thousands of acres of public-use land that, for safety reasons, is fairly sparse, undeveloped, and flat. A small fraction of most

airport land use is devoted towards the operation of aircraft. Megawatts of solar energy fall on large storage and maintenance buildings, passenger facilities, parking lots, clearway fields, and other areas daily, and most of it is unharvested for local use. While airport solar farm projects have expanded in the past decade, they are typically limited in size. This is due to the return on investment associated with these projects, since they are limited by the local consumers of electricity, which may be airport operations or the needs of the surrounding community. By introducing another large consumer of local energy, either directly as electrical power or other energy storage products that leverage airport renewable power, RAM can dramatically improve the return-on-investment potential for local airport renewable generation projects - without causing some of the headaches associated with moving or storing peak renewable power elsewhere on the grid. NASA is currently investigating how much airport-generated solar could offset or even eliminate regional aircraft electrical loads from the national power grid.

Aircraft Design and Integration

Design advancements due to electrification are already taking a toehold in aviation. Pipistrel, winner of the 2011 Green Flight Challenge, recently brought a two-seat electric training aircraft to the market, with other entrants such as Bye Aerospace close behind.[23] Harbour Air, a regional seaplane service, is developing electrically powered retrofits of its floatplanes to reduce operating and maintenance costs for its otherwise short routes. Mokulele Airlines is partnering with Ampaire, developer of a hybrid-electric retrofit aircraft, for its passenger operations in Hawaii.[24]

Electrified aircraft propulsion is also enabling entirely new aircraft designs and missions. Unlike most gas-powered engines, the power-to-weight ratio and efficiency of electric motors is far less dependent on their size. In general, smaller gas-powered engines are less efficient or less powerful for a given weight, so it is desirable to use fewer piston or turbine engines on an airplane for a given power level to reduce weight or increase efficiency. Since this is less true for electric motors, airplanes with far more motors than the public is used to seeing are being developed. NASA's X-57 Maxwell is a flight demonstrator for distributed electric propulsion technology, with the final variants of this aircraft using up to 14 electric motors to enable a more aerodynamically efficient aircraft in cruise flight.[25] Aircraft such as Joby Aviation's S4 use six electric motors to enable efficient cruise while also providing vertical takeoff and landing (VTOL) capability.[26] Wisk's Cora aircraft uses dedicated electric motors for VTOL, and then shuts these down for cruise flight.[27] These are but two of the many different electric VTOL (eVTOL) aircraft now in development and offer a glimpse of the new types of aircraft that electrified propulsion can enable.

23 The 2011 Green Flight Challenge Sponsored By Google, CAFE Foundation

24 Island Hopping with Mokulele Airlines, Ampaire

25 X-57, NASA

26 All-Electric Air Mobility, Joby Aviation

27 Discover the Future of Urban Air Mobility, Wisk

The more energy efficient the aircraft, the further operating costs can be reduced and the sooner you will be able to fly at a lower cost from your local airport to your desired destination.

Another critical element of electrified aircraft propulsion concepts is the huge reduction in noise that is possible. Electric machines themselves have no high-pressure exhaust or mechanical imbalances that can lead to excess noise. They can produce exceptional torque at lower motor speeds than combustion engines, enabling them to spin propellers at slower speed but still generate high thrust levels. Propeller tip speed is a large contributor to propeller noise. Electric motors can produce the same amount of power regardless of altitude or air temperature, which means the aircraft can climb faster and higher, even from hot, high locations. Climbing faster is very important for noise, since airplanes that are higher up produce less noise on the ground. Furthermore, the ability to use multiple, purposeful motors like the X-57 means that future electric aircraft may have more thrust during takeoff, greatly increasing current aircraft climb rates. Tomorrow's aircraft may be able to climb fast enough and use quiet enough motors and propellers that the "noise footprint" of the aircraft – the region where someone on the ground can hear the aircraft – is contained within the airport boundary.

Electrification Pathways

The approach taken to electrify RAM aircraft may be accomplished with any or all of the following:

- Retrofit existing aircraft with new electrified powertrains by swapping out traditional combustion engines.
- Gradually replace entire fleets with aircraft that are specifically designed to take advantage of the unique benefits of electric propulsion (e.g., better aerodynamically designed aircraft), capable of using nearly all existing runways.
- Introduce electric short takeoff and landing (STOL) aircraft making electric aircraft valuable in rural, suburban, and even urban areas that may have constrained landing facilities or are otherwise not already served by a local airport.

Integrate Electric Motors into Existing Aircraft

The lower cost of electric energy and the mechanical simplicity of electric motors both lend themselves to overall cost reductions. These propulsion systems have fewer moving parts and lower part counts and are therefore much easier to manufacture and maintain. Based on an early electric propulsion demonstration project in California, a two-seat training aircraft's energy costs were reduced by 85% and annual inspection costs were reduced by 50% compared to the traditional piston engine variant of the same aircraft.[28] Similarly, a plug-in hybrid version of a six-seat aircraft is demonstrating close to 50% reduction in energy costs compared to the base aircraft while covering the same distance in the same amount of time. Electric aircraft can also reduce environmental impacts through zero or reduced-emission operations, enabled by renewable energy sources and lower noise levels.

New Aircraft Designed for Electric Power

Unlike combustion engines, electric motors are highly efficient regardless of their size. This allows aircraft designers to strategically situate electric motors on the aircraft to provide both aerodynamic and propulsive benefits. Therefore, electric propulsion aircraft can be designed to use even less energy than both electric retrofits and conventionally fueled aircraft. As these benefits are realized, electric aircraft of the future may look distinctly different from those flying today. The more energy efficient the aircraft, the further operating costs can be reduced and the sooner you will be able to fly at a lower cost from your local airport to your desired destination.

Electric Short Takeoff and Landing (STOL) for Access

Short takeoff and landing (STOL) capability enabled by electrified aircraft propulsion will spur future growth of RAM markets by connecting high-value locations without airports (such as city centers), where a new short takeoff/landing strip could be added into the existing regional airport network. Traditional STOL aircraft can require up to 2,000 ft of runway. Augmented with electrified propulsion, eSTOL aircraft may require as little as 200 ft.

This runway length reduction comes from a "blown wing" design, where propellers blow a sheet of high-velocity air over a large portion of the wing. This increases the aircraft high-lift capability, allowing them to fly at very low forward speeds and therefore take off and land in much shorter distances than conventional airplanes.

Electric motors are able to change power more quickly than engines, allowing them to be used effectively for approach flight path control. This will allow electric aircraft to more easily land on shorter runways, especially when combined with improved approach guidance, control technology, and pilot assistance systems.

STOL aircraft are not required to operate off the existing network of regional airports. However, there are near- and far-term ways in which they are beneficial to the development of a RAM system. Near-term value comes from the ability to use "stub" (i.e., shorter) runways at large airports as well as noise reduction thanks to STOL aircraft's ability to reach higher altitudes before leaving airport grounds. Far-term value will be realized in reduced infrastructure costs (shorter runways use less pavement and land, requiring less maintenance) and improved access, especially for residents of more densely populated areas.

28 Sustainable Aviation Project, Joseph Oldham

Autonomous Systems

Pilots do more than control an airplane – they are integral to flight safety. The FAA establishes that "the pilot in command of an aircraft is directly responsible for, and is the final authority as to, the operation of that aircraft" and that during any "in-flight emergency requiring immediate action, the pilot in command may deviate from any rule." The heroic efforts of the entire flight crew on US Airways Flight 1549 (the "Miracle on the Hudson") in 2009, along with the actions of the rescuers quick to respond to the scene, resulted in all 155 passengers and crew surviving what could have been a catastrophic event. This is one of many examples where the actions of the flight crew saved lives.

However, in the past decades, pilots have not necessarily been on board the aircraft they are operating. In the post-World War II era, many surplus aircraft were converted into remotely piloted drones and mostly used for target practice. This too saved lives – it enabled the military to test new systems, including those used to defend against adversaries, without putting an aircrew needlessly in danger. As the military capabilities progressed, so too did the missions of its Remotely Piloted Aircraft (RPA) – no longer simply "drones" – to tackle missions dubbed too "dull, dirty, or dangerous" for onboard aircrew. RPAs such as the General Atomics MQ-9 Reaper and Northrop Grumman RQ-4 Global Hawk have become modern staples for the U.S. Department of Defense.

The idea of remotely piloted or fully computer-controlled aircraft is now commonplace in civil aviation as well. Small, consumer Unmanned Aerial Systems (UAS) - often known as "drones" to the general public – burst onto the scene earlier this century. This was spurred on by a convergence of technologies. Huge industry investments in smartphones led to the development of low-cost microprocessors, solid-state accelerometers and gyros, high-bandwidth wireless communication, and lighter-weight, higher-capacity batteries. Development of cheaper, high-efficiency brushless electric motors, along with further developments in lighter-weight rechargeable battery technology, transformed the hobby aircraft industry seemingly overnight from combustion engines to electric powertrains. This paved the way for the consumer UAS industry – "hobby drones" – to explode into the market.

Today's consumer UAS industry continues to push boundaries. Commercial UAS operations include mapping, aerial surveys, and remote monitoring. Several companies have plans to introduce cargo services on these aircraft, including delivery to a customer's front door. As these aircraft become ubiquitous, they will need to be operated safely and responsibly, both with respect to people and property on the ground and other aircraft in the air. Regulators have introduced new rules for these systems, ranging from how they participate and are identified in the National Airspace System to how the aircraft themselves are built and tested.

These small UAS systems have further evolved from needing a remote pilot "hand-flying" the aircraft to the aircraft now automatically flying itself -- known as autonomous operation. In the simplest case, some degree of automatic action is required when remotely piloted aircraft lose link with their remote pilot, such as pre-programmed actions executed to maintain the required level of safety. More sophisticated autonomous systems make decisions, execute contingency plans, and otherwise complete a mission with little or no control input from a crewmember. The path towards increasingly autonomous aircraft operation involves the

In all cases, the ability to demonstrate safe operation – for those on the ground or in the air – will set the pace for adoption of autonomy.

inevitable increase in sophisticated UAS operations as well as increasingly simplified controls for aircraft with onboard flight crew. In the former case, autonomous operations for cargo-carrying UAS are increasing in scope and frequency, which will help drive development of fully autonomous operations. In the latter case, passenger-carrying flights, particularly those driven in the Urban Air Mobility space, see a path for simplified onboard operator requirements as a pathfinder for eventual autonomous operations with passengers. In all cases, the ability to demonstrate safe operation – for those on the ground or in the air – will set the pace for adoption of autonomy for operation of different missions and associated aircraft.

Simplified Piloting

The modern aircrew executes functions that are colloquially known as "aviate, navigate, and communicate." Aviate refers to maintaining control of the aircraft and its support systems – keeping it stable, in control, and with all systems operating in their normal limits. Anything that threatens the control or continued operation of the aircraft is dealt with under this function. Navigate refers to planning for where the aircraft will go next – understanding the necessary flight path, altitudes, weather, airspace restrictions and outages, the impact of these on vehicle performance and endurance, and other factors that will influence decisions in the future. Communicate refers to participation in the airspace system among other users – providing others with accurate knowledge of the aircraft's position, intent, and status, as well as gathering information on other aircraft and airspace conditions.

Advancements in technology have helped simplify some of the tasks that fall under "aviate, navigate, and communicate," enhancing an aircrew's effectiveness by allowing them to focus on fewer, more critical tasks. The aviation industry refers to novel technology that makes aircraft easier and safer to operate as Simplified Vehicle Operations (SVO). The introduction of SVO technology will make becoming a pilot more accessible to more people and ultimately accelerate RAM.

Existing and Near-Term Flight Crew Aids

Systems that provide the pilot better situational awareness about the aircraft surroundings, such as accurate weather conditions, obstacles, and other airplanes, are invaluable.

Convergent Autonomy Pathways:

	1	2	3 Autonomous Air Transportation
SVO:	Reduce pilot workload and increase safety	No longer "pilot," but simply "operate" the airplane	Move operators to ground control centers to monitor flights
UAS:	Demonstrate aircraft safety over unpopulated and remote areas	Expand operations to more congested airspace and over populated areas	Replace cargo with passengers

Many systems that help the aircraft avoid dangerous situations already exist and have been shown to reduce most major causes of accidents.

Many systems that help the aircraft avoid dangerous situations already exist and have been shown to reduce most major causes of accidents. This also allows the pilot's workload to be significantly reduced. In short, pilots do not have to do as much other work as they did before and can focus on flying the airplane.

"Operate" instead of "Pilot"

Today, pilots need special ratings to fly different types of aircraft and in different kinds of conditions. A pilot needs to be trained differently to fly an aircraft with two engines vs. one engine, or in clear conditions vs. clouds. Future SVO systems could help to consolidate inputs and manage these differences so that they are no longer relevant. Just like a modern driver's license allows someone to drive many types of cars in many conditions, future pilot certification could make more seamless transitions between types of aircraft and operations.

Essentially, airplane automation will be increased to a level where more people can obtain a pilot's license because the training requirements and associated costs are less.

Operate Remotely

As the functions of the pilot become automated, the aircraft can safely be controlled from anywhere by a remote operator. In case of emergency or loss of connection with the ground, the aircraft will have all the necessary information to safely land at the most suitable airport. Progressively, operators will be able to monitor more than one aircraft at the same time.

No Longer Just a Drone

In this construct, existing or newly developed large drones are upgraded until they are safe enough to carry passengers. From the outset, the aircraft is designed to be operated from the ground without a pilot on board. The objective is to demonstrate that autonomous aircraft can safely and efficiently share the airspace with piloted traffic.

UAS Operations in Low-Risk Environments

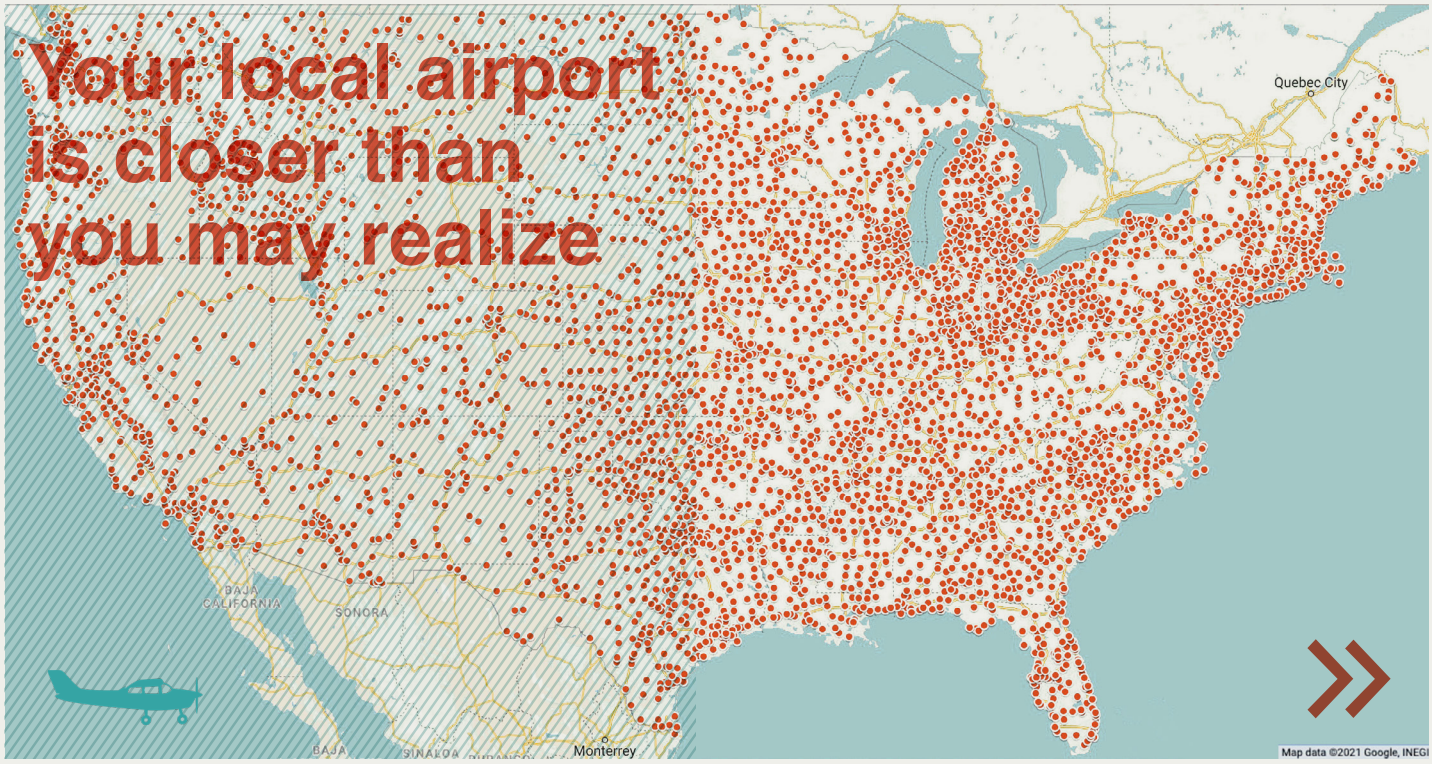
The drone systems are upgraded to meet crewed aviation standards. The software is certified to meet the appropriate design assurance levels, system safety analyses are built to ensure that failures are appropriately mitigated, and the aircraft is equipped with necessary navigation and communication systems that will integrate it into the airspace. Once approved, commercial operations to carry cargo or for surveillance purposes (e.g., pipeline monitoring, land surveys, etc.) are conducted in airspace with little traffic over unpopulated areas, including in inclement weather conditions. As accident-free flight time is accumulated, the operational envelope is expanded.

UAS Operations in Higher-Risk Environments

The operational envelope progressively includes busier airspace, flight over densely populated areas, and flight into large/international airports. All aircraft components get certified, and extensive failure injection tests and system responses are evaluated. Contingency and emergency procedures are validated. Flights are performed in all weather conditions.

UAS for Passenger Operations

The vehicle and its integration have been thoroughly tested in all relevant operating conditions. All of the aircraft systems have been certified to meet manned aviation standards. The aircraft and its ground control center are ready to transport passengers.



Infrastructure Landscape

In 1946, Congress gave the Civil Aeronautics Administration (CAA) the task of administering a federal-aid airport program aimed exclusively at promoting development of the United States' civil airports. Called the National Plan of Integrated Airport Systems (NPIAS), this program created the first general aviation (i.e., local) airports and ensured they were built alongside upcoming cities to encourage more flight traffic into local communities. In fact, the goal was to situate airports so that all of the United States' population would live within 20 miles of one.

As has been repeated in every National Airport Plan since 1946 (almost 75 years ago), the goals listed below are still representative of the potential air transportation system that will be enabled through RAM.[29]

- Airports should be safe and efficient, located at optimum sites, and developed and maintained to appropriate standards.
- Airports should be affordable to both users and Government, relying primarily on user fees and placing minimal burden on the general revenues of local, state, and Federal Government.
- Airports should be flexible and expandable, able to meet increased demand, and accommodate new aircraft types.
- Airports should be permanent, with assurance that they will remain open for aeronautical use over the long term.
- Airports should be compatible with surrounding communities, maintaining a balance between the needs of aviation and the requirements of residents of neighboring areas.
- Airports should be developed in concert with improvements to the air traffic control system.
- The airport system should support national objectives for defense, emergency readiness, and postal delivery.
- The airport system should be extensive, providing as many people as possible with convenient access to air transportation, typically not more than 20 miles travel to the nearest location.
- The airport system should help air transportation contribute to a productive national economy and international competitiveness.

These airports were originally intended to be commercial centers of aviation activity that would bring economic development to their regions. However, the advent of the jetliner meant that most planes needed longer runways for takeoff, an option only available at larger airports. Thus, a small handful of airports evolved into commercial aviation hubs and regional airports became largely unused for commercial services.

29 Field Formulation of the National Plan of Integrated Airport Systems, Federal Aviation Administration, p.3

While large jet airliners offer many advantages (e.g., economies of scale and long range), their inability to leverage smaller, regional airports also meant unforeseen strain on the US highway system. The result? Short- and mid-distance air travel became nonviable options and were essentially erased from the travel landscape for the general population.

Community Energy Hubs

Airports can make great hubs for synergistic generation and/or storage for alternative energy, such as solar and hydrogen, for ground vehicles, community users, and Regional Air Mobility aircraft. Indeed, 146 airports across the country have already begun a total of 225 renewable energy projects.[30] The largest current airport-based solar farm utilizes 183 acres at Indianapolis International Airport and produces 36.1 million kilowatt-hours per year, enough to power 3,650 homes.[31] Ground vehicles are being electrified, and billions of dollars invested in electric vehicle charging and electric grid upgrades will support them. Airports in many parts of the country are rapidly deploying this infrastructure, in some cases through state regulation, which will support efforts to reduce greenhouse gas emissions from transportation sources.[32]

This electric infrastructure provides immediate airport and community benefits while paving the way for expansion of alternative-energy-based flight. Because airports can serve (and are served by) a multitude of ground vehicle types, including electric, RAM can utilize the same resources, and when airports plan for the needs of alternative energy aircraft while upgrading infrastructure for other uses, the costs for these upgrades can be shared. This planning can help reduce barriers to new Regional Air Mobility services that are introduced as electric aircraft enter the market.

Solar solutions can also bring energy to remote airport communities by utilizing portable solar powered units. As a part of the Sustainable Aviation Project in Fresno, CA, an adapted portable solar charger has been shown to serve both ground vehicles and aircraft, proving that viable infrastructure options already exist and are ready to support an increasingly electrified transportation system.

As more electric aircraft are revealed to the public, state and local governments around the country are evaluating the potential of this technology to improve connectivity, reduce greenhouse gas emissions, and generate new economic activity. Tests continue to be performed by various private companies and non-profit organizations, and RAM is showing promise of lowering the cost of operation for aviation businesses that, in turn, can expand commercial opportunities at underutilized airports benefiting local communities.

Airspace Integration

Just as the national highway road system is the primary infrastructure that cars use, airspace management is the primary infrastructure that governs the skies. The National Airspace System (NAS) has specific rules and regulations regarding onboard equipment requirements, air traffic control clearances, two-way communication, and weather and visibility requirements in order to be allowed to fly in the NAS. Since RAM aircraft share the airspace with all other existing users, they need to comply with these same rules and regulations.

Today, communication between air traffic control (ATC) and aircraft is accomplished primarily by means of voice over two-way radio – a system that has been in place since 1930 when the first radio-equipped control room was established in Cleveland, Ohio. The system in place today provides a safe environment for RAM operations to take flight, but this method does limit scalability in dense environments. Instructions and responses can only be communicated at a rate that humans can clearly understand. Each instruction must also be read back to ensure it was accurately understood.

Many essential components of airspace modernization are currently under development. The FAA's NextGen program to modernize ATC includes digitization of communication.[33] Future RAM vehicles will feature increasingly complex and data-rich systems, including redundant navigation and collision avoidance systems, which are not supported by the present voice-based air traffic management (ATM) system, especially at scale.

The expansion of RAM will be progressive, as will the modernization of airspace. RAM will not initially be inhibited by existing systems and instead will be able to integrate with them. New technologies on board will automatically detect and safely avoid other flying vehicles without need of human intervention. New vehicles will be equipped with systems and processes that augment and eventually replace the voice-based system. One day, autonomous vehicles could communicate with each other to coordinate airspace decisions to ensure the skies remain safe for everyone. As technology is deployed both on the airborne side as well on the air traffic control side, intermediary steps, such as an operator overseeing unmanned aircraft and interacting with ATC, can help enable the proliferation of RAM. This isn't simply a wish list of potential technologies that would help RAM, these are technologies that are in the final stages of development and are ready to be deployed in this emerging market.

30 Airport Renewable Energy Projects Inventory and Case Examples, Airport Cooperative Research Program

31 IND Solar Farm, Indianapolis Airport Authority

32 Zero-Emission Airport Shuttle, California Air Resources Board, California Environmental Potection Agency

33 Modernization of U.S. Airspace, Federal Aviation Administration

The expansion of RAM will be progressive, as will the modernization of airspace. RAM will not initially be inhibited by existing systems and instead will be able to integrate with them.

Future air traffic control models could look quite different and may include elements of the Unmanned Traffic Management (UTM) system developed to support small drones. In contrast to conventional voice-based ATM, UTM is a digitized system in which commands and responses flow between vehicle and control station through data links.[34] UTM operates as a separate, yet complementary, system to the traditional ATM system and may even serve as a model solution for the NAS – an environment that handles about 10,000 aircraft airborne over the United States at any given time and for which the Federal Aviation Administration (FAA) employs approximately 10,000 air traffic controllers. Many of the building blocks for higher capacity airspace have already been considered within the FAA's NextGen program, and additional required new technology includes remote identification of aircraft, data exchange protocols, performance requirements, and standardization. Each of these technologies will enable more effective RAM services to take to the skies.

Advances in Airworthiness

Commercial aviation boasts an impressive safety record. Worldwide, the fatal accident rate for commercial aviation in 2019 was about one accident per two million flights.[35] This enviable record is due to many factors, including high standards for certification of airline operators and aircrew, as well as stringent airworthiness requirements for the design, manufacture, and maintenance of aircraft.

Despite these exceptionally high standards, challenges do remain, particularly as new technology is introduced. Certification often focuses on how a technology may break and what happens when it does, rather than how it works nominally. Newer technologies do not have the same experience base as older approaches that are proven and therefore must "earn" the trust of regulators and operators alike. In the past two decades, several high-profile aviation accidents have been the result of technologies designed to help the aircrew maintain control of the aircraft, but instead led to further compromise of control between the aircrew and aircraft. Other issues include energy storage systems that did not have adequate safety features to prevent propagation of fires. These incidences have led to important changes in how aircraft with newer technologies will be certified.

Recently, aviation regulators in the United States and Europe adopted new rules for airworthiness in an attempt to maintain aviation's high level of safety, but allow for faster, smoother adoption of new technologies that may enhance performance and accessibility.[36] One of the key features of these new airworthiness rules is the adoption of consensus standards – standards jointly developed by government regulators, industry producers and operators, researchers, and members of the flying public – as a means to show the aircraft meets the stringent safety rules established by law. These rules apply to smaller aircraft, which include fixed-wing airplanes up to 19,000 pounds that carry less than twenty passengers. This change is a critical enabler for adoption of some of the technologies outlined in this paper – it enables a regulatory environment that is permissive of new technology but also demands a very high level of safety.

34 What is Unmanned Aircraft Systems Traffic Management?, NASA, January 30, 2020

35 Aviation Safety Network releases 2019 airliner accident statistics, Aviation Safety Network, Janaury 1, 2020

36 Small Airplanes: Regulations, Policies & Guidance, Federal Aviation Administration

Parallel Trends

One of the most challenging parts of putting together a vision for the future is to accommodate every future possibility. It is clear that, while compelling, the ideas associated with RAM will evolve in concert with other technologies and trends. RAM can provide value in a host of different futures, but this also requires that early efforts are executed with an appropriate appreciation for other activities that, at first blush, may seem competitive with RAM, or otherwise could inhibit development of key RAM operations or technologies.

Virtual Presence

One of the strongest recent trends has been the explosion of virtual presence in place of physical travel. Improvements in communication technologies have made more robust telepresence options available, and the COVID-19 pandemic caused a dramatic disruption across the air transportation market. As the world hunkered down to "slow the spread," many of the prior stigmas associated with working from home have been disproven or disappeared entirely. Meetings, reviews, and even happy hours have gone virtual. Travel will return once the virus is contained, but in what form?

Businesses and workers alike may celebrate the cost savings and convenience associated with virtual presence, but personal and leisure travel demand will remain. People still want to visit their families, explore new places, and feel the sand between their toes. Furthermore, the growing acceptance of "work from anywhere" may in fact push people to take more trips – working during the day and enjoying a new setting in the evening – just for a change of environment.

One other notable feature of the recent pandemic has been the explosion in e-commerce. More people than ever are ordering goods online that they previously purchased from a brick-and-mortar store. As e-commerce continues, so must cargo delivery. RAM may not be able to get a package to your doorstep, but it could quickly get it to your remote community, where another modality will take it "the last mile."

Virtual presence has arrived and is likely here to stay, lowering business travel demand and increasing reliance on e-commerce. To be successful in this environment, RAM needs to aggressively target technologies to lower operating costs so that prices can be kept low to attract personal and leisure travel. A RAM operator will want to include cargo as part of their portfolio. RAM operators may even try to solicit innovative partnerships with pleasure and leisure destinations.

Advances in Automobiles

The personal automobile has been a staple of the American household for generations. It is also by far the most preferred form of transportation for regional trips today – it offers flexibility, convenience, and generally low cost as compared to other travel options. Modern highways and roadways snake throughout the country such that just about anyone in the continental US has a route to travel, if they have the time.

The challenges with regional travel by automobile are well-known, and in fact these challenges are some of the major targets for which RAM is the solution. However, improvements in automobile travel are being pursued, principally along three major themes: lower operating cost and emissions through electric vehicles, lower ownership cost and greater convenience through ridesharing, and increased safety and improved operator experience through autonomous technologies. Of these, the first two (electric vehicles and

Advanced automobiles will help with the development of RAM technologies and will be a key component of getting travelers to and from local airports.

ridesharing) are already a growing part of the market, and companies are investing billions of dollars into more autonomous operations ("self-driving cars").

The good news is that these advancements are not necessarily competitive to RAM. Industrial-scale investment in automotive electric powertrains and energy storage will help mature and reduce costs associated with electric aircraft architectures, though the two domains will not be directly compatible. Ridesharing and even self-driving vehicles help to dramatically increase accessibility to local airports – solving the "first and last mile" problems of any airport transfer.

RAM still has advantages over advanced automobiles. RAM's infrastructure is far from capacity constrained, whereas today's roadways are highly congested, and their expansion requires expensive investments and possible acquisition of land through eminent domain – an idea that is generally unpopular. Travel by air, particularly without numerous transfers, should be faster than by the ground on many regional routes. Self-driving vehicles may help to increase safety, speed, and throughput – but America's roadways will still be, at best, a mix of autonomous and personally driven vehicles for decades to come.

Advanced automobiles will help with the development of RAM technologies and will be a key component of getting travelers to and from local airports. For long distances and/or congested ground travel pathways, RAM should still be a preferred option for regional travel, given that low-cost, community-capable aircraft are part of the solution.

High-Speed Rail

One of the most efficient ways to transport cargo or passengers over long distances is via rail. The railways of the United States are primarily used to transport cargo – in fact, over a quarter of all freight is moved via rail. Passenger rail is not used in the United States as much as in other countries, though light rail mass transportation options are available in many major urban areas, particularly in the northeast.

High-speed rail systems have been proposed for the United States as one solution for low-cost regional transportation. These systems serve densely traveled routes, with limited stops that enable mode transfer to a traveler's final destination. The cost to develop these systems can be high, given that new rail networks will likely be needed rather than improving existing railroads that favor more moderate speeds. Still, should such systems gain wider favor, they could provide the American traveler with a safe, low-cost, low-emission, convenient form of regional travel. Travel by rail is also one of the most weather-tolerant methods of transportation.

Should travel by rail become more prevalent in the United States, via new routes or other policy-based methods, rail service will most certainly be more cost-effective than air travel on the same routes. However, if demand on a route is high enough to justify ground infrastructure, it's likely high enough for existing commercial airline service. Therefore, rail threatens airliners and big highway arteries more than it threatens the potential of RAM. Given that RAM is a node-based system rather than a path-based system, RAM can easily adapt to changes in travel patterns as new rail systems or other travel opportunities are available to the public.

Should rail travel increase, regional airports could also be reasonable candidates for rail stations, serving as transfer points for both passenger and cargo rail lines. Airports encompass large swaths of municipal land that can be used for storage depots, parking lots, warehouses, and other facilities needed for rail stations, without getting into issues associated with eminent domain in order to acquire more space. Such an arrangement could also provide RAM operators with a new source of passenger and cargo demand.

RAM operators should monitor and encourage development of rail stations at key airports. The potential loss of revenue for RAM on a specific route may be offset by the passenger, and especially cargo, service transfer points that could occur at a local airport. If travel by rail increases, then America's airports are unique resources available to the regional traveler – they offer a multitude of potential mode transfer options.

Advanced Transport Aircraft

At first glance, a modern jetliner may not look all that different from the transports that dominated air travel in the 1960s. However, huge advances have been made in jet transports – new materials, digital systems, and leaps in turbine engine technology have occurred since jetliners first took to the skies. A modern jet transport consumes half as much fuel as it did in the late 1960s. These modern aircraft are more efficient, quieter, and safer than ever before. These advances have come at a steady pace, as manufacturers and operators continually invest in raising an already high bar.

Future transport aircraft will continue to push the boundaries for increased efficiency and safety. Manufacturers are investing in hybrid-electric technology and associated integration of propulsion into the airframe for more efficiency improvements. Flight crew aids akin to SVO, and even autonomy, are areas of continued investment. Manufacturers and operators have recognized that bigger is not always better and have targeted a portfolio of aircraft sizes that includes smaller passenger counts than today's larger passenger aircraft. Some of these smaller aircraft in particular could be competitive for RAM operations.

Overall, RAM should be able to complement these advances in larger transport aircraft. Today, commuter airlines "code share" with major airlines at several different hub airports, expanding the customer base of the airlines and enhancing the experience and options for the commuter passengers. The smaller commuter aircraft that cross over with RAM can operate at some major airports without impacting capacity constraints, using "stub" runways or LAHSO.

While aviation in general is responsible for only a small percent of global carbon emissions, the sector is projected to make up a larger portion of total emissions in the years to come. Governments and concerned members of the public are increasing pressure, in the forms of policy, revenue, and consumer movements towards lower emissions. These actions will push aircraft operators to invest more heavily in lower-emission aircraft and routes. The smaller size and generally shorter range of RAM aircraft makes them ideally suited to low-emission or even zero-in-flight emission electrified propulsion solutions, which could paradoxically increase reliance on RAM in a future where aviation emissions are heavily regulated.

RAM aircraft will have fewer than twenty passengers, which means they will be certified under a more flexible set of airworthiness standards than larger transports. RAM can serve as a pathfinder to certification of larger aircraft – and emissions-reducing technologies such as hybrid-electric or all-electric propulsion systems will first cut their teeth in RAM. Some of these technologies will eventually move up towards the larger transport aircraft.

Advanced transport aircraft technologies will be synergistic with RAM operations. RAM should drive customers to the major airlines and their larger transports at larger airports. If RAM can be competitive with ground travel, these aircraft could become a larger segment of air travel than the current regional market. The advanced propulsion architectures of RAM aircraft will also work to drive down fleet emissions, which can be very helpful in situations where aircraft emissions are heavily scrutinized by policy or the public.

Urban Air Mobility

The idea of UAM has been around in some form for decades, but the most recent development in this space was catalyzed by the 2016 release of Uber's Elevate white paper.[37] Since this paper was published, billions of dollars of capital have been invested into a dozen or more credible electric vertical takeoff and landing (eVTOL) aircraft designs, as well as into efforts to develop urban vertiports that allow for quick intracity travel. The investments and markets have been scrutinized by both pundits and skeptics, and while the future is far from certain, there is a tantalizing market potential at stake.

37 Uber Elevate: Fast-Forwarding to a Future of On-Demand Urban Air Transportation, Uber, October 27, 2016

At their core, both UAM and RAM share many similarities. Both recognize that advanced electrified propulsion architectures, increased utilization, and SVO/autonomy will dramatically reduce the costs associated with operation of these aircraft. Both recognize that community acceptance is a key component to near-ubiquitous operations. Both look to displace travelers from automobiles into the skies.

UAM and RAM diverge in terms of markets served and infrastructure requirements. UAM operations tend to focus on eVTOL aircraft, giving them great access to urban cores via newly constructed vertiports. RAM leverages the plethora of existing, underutilized airports throughout the United States, obviating the need for vertical takeoff and landing. This latter characteristic means that RAM aircraft will have more payload capability and/or range, and generally be cheaper to operate, than a comparable UAM aircraft. However, the RAM aircraft will not be able to fully serve lucrative markets of the many short trips in urban cores.

VTOL aircraft could serve shorter-range RAM markets, though a dedicated RAM aircraft will be able to serve the same mission for less cost due to the high power and energy demands of vertical takeoff and landing. VTOL UAM aircraft would have the advantage of being able to directly access some urban core areas that RAM aircraft could not, which could drive more market share towards UAM-for-RAM missions. Ultimately, the market will decide if shorter-range RAM markets will favor the increased access of VTOL UAM aircraft or lower-cost RAM aircraft.

As energy storage technologies mature, the range of both UAM and RAM aircraft should increase, and/or the cost of operation should decrease. Eventually, the flexibility of UAM aircraft with longer ranges will be very competitive with the lower cost but more limited takeoff and landing capability of RAM aircraft on shorter RAM routes. It is quite feasible that longer-range UAM aircraft could displace RAM aircraft on some shorter routes. That said, a successful RAM operator may find their increased range leads to new markets that could not previously be served at an appropriate cost.

RAM and UAM both rely on similar core technologies, and both RAM and UAM will benefit from the investment already occurring in these technologies. RAM should target routes that would not otherwise be served by near- or mid-term UAM. UAM and RAM should be able to synergistically interact – a RAM user could shift modes to a UAM aircraft at a regional airport for travel into a busy urban core or other remote area without an adequate RAM landing facility. In the far-term, combined UAM and RAM operations may be able to compete with routes currently dominated by larger transport aircraft – the RAM aircraft could serve non-capacity constrained airports on longer-range routes, with UAM aircraft bringing customers to and from these regional airports.

The local airport you may not have even known existed will soon be a catalyst for change in how you travel.

Conclusion

The local airport you may not have even known existed will soon be a catalyst for change in how you travel. It will be a gateway from your doorstep to the rest of the world. It will be a hub for local, renewable energy. It will make sure that your community has rapid access to convenient commerce options and critical supplies. Best of all, it doesn't rely on miraculous technology or infrastructure advancements - the groundwork is already in place.

1. The United States currently has over 5,000 public-use airports, which are within 10 miles of 60% of the population and 25 miles of 95% of the population. Only about 500 are served by commercial flights today, but community-compatible aircraft, autonomy, a seamless passenger experience, and high utilization will enable RAM to become a reality for far more of those airports. Best of all, substantial operational growth at these airports is easily within reach: only 17 of all US airports are projected to be capacity-constrained by 2030.

2. A key requirement for widespread RAM is to dramatically reduce the operating cost of small regional flights. When the cost savings occur, adoption explodes. A NASA study found that a 40% reduction in operating cost compared to today's regional aircraft pushes the market to a huge expansion in small regional flights serving far more airports.

3. Aircraft operating cost reductions of more than 50% are possible for RAM aircraft through (1) reduced energy and maintenance costs with electrified aircraft propulsion; (2) lower fixed costs through efficient high-rate production and increased utilization, e.g. by combining passenger and cargo operations, and (3) reduction of flight crew and/or reduction of flight crew workload through remote piloting and autonomous operations. These cost reduction estimates will be realized in cargo and repositioning flights first and include impacts of near-term technology; further reductions are possible farther term.

4. Electrified aircraft propulsion enables friendlier operations to the community. These technologies themselves reduce noise and in-flight emissions substantially and enable new designs with increased climb performance that can keep noise within the airport footprint.

5. The presence of electrically powered aircraft provides a catalyst for renewable generation at the local airport. Every community has an airport, so every community has a publicly subsidized swath of land that is ripe for placing renewable sources, such as solar panels, on the property. RAM aircraft serve as a new customer of energy at the airport, which can impact payback periods and lead to greater initial capital investment in larger systems. This also reduces potential infrastructure burden on downstream grid components – something that challenges renewable projects today. Overall, this pushes the United States power and transportation sectors towards lower emissions.

6. Local airports aren't some major travel hub – the trip from your door to the airplane will be far more painless than your current trip to board an airline at a major airport. Parking, security, and even getting on and off the airplane will be far smoother and require less time. Advancements in ridesharing mean that you won't be stranded – your trip to or from the local airport is now easier than it's ever been and will only continue to get better.

7. RAM is not waiting on some major breakthrough, but instead leverages trends and developments that are ongoing. The airports and air traffic system needed to execute these flights exist today, and improvements to air traffic management are already in the works for other future aircraft operations that will only add to RAM's capability. Multiple groups are investing in electric powertrains, energy storage, and autonomy, from automobiles to drones to UAM to transport aircraft. Many communities have already recognized how their local airports can be renewable energy hubs, and there are existing mechanisms in place for local and federal funding of these projects. Finally, the safety certification approaches that apply to the class of aircraft suitable for RAM operation has recently been overhauled to allow for faster, safer adoption of new technology.

8. While developments are occurring on many fronts that will improve RAM, not all of them are required to be in place before some operations start to make sense. Operators are already finding new and innovative ways to bring air travel to more communities, and this will accelerate as RAM catalysts continue to advance.

9. RAM can thrive in the presence of advances in other forms of transportation or transportation substitutes – enhanced telepresence, self-driving/electric cars, high-speed rail networks, advancements in large transport aircraft, and urban air mobility. In all of these cases, RAM can provide value to the consumer and to the other advanced transportation architectures.

This paper articulates a vision for how Regional Air Mobility will transform how we travel. Targeted investments and policy decisions will accelerate the adoption of the RAM vision. These include maturation of technologies for advanced electrified aircraft and automated aircraft operations specific to RAM applications, policy initiatives that enhance regional airports and expand their operational and energy generation capabilities while ensuring that RAM operators are good neighbors, and development of approaches to ensure that RAM users have nationwide access to a safe, affordable, and convenient transportation or delivery experiences. Now, it is up to all of us – as consumers, investors, policy makers, researchers, or simply citizens of our planet – to help realize this vision.

Operators are already finding new and innovative ways to bring air travel to more communities, and this will accelerate as RAM catalysts continue to advance.

Appendix

This white paper covers a range of topics to help clarify what Regional Air Mobility (RAM) is and why it matters. It should not be construed as the final, defining source of all knowledge when it comes to possibilities and best ways forward as they relate to RAM initiatives. Rather, the paper is intended to start a conversation with the communities that will be participants in what is an evolving RAM process.

Frequently Asked Questions

We fully expect that you, the public, will have many questions. The following list of FAQs and answers should help further the RAM discussion.

Q Are autonomous aircraft safe?

A RAM must be safe to be commercially viable. Those offering RAM vehicles and services are well of aware of this, creating a strong safety incentive. Additionally, there will be robust oversight from the FAA and other regulators, as well as from safety-conscious stakeholders. Also, autonomous and unmanned aircraft will begin as cargo flights only. Once the safety and reliability of the technology is proven with no passengers on board, the public will feel more receptive to passenger flights that operate in the same way.

Q I still love my car. Will we all give them up one day?

A This is not an either/or situation. You can still be a car or motorcycle enthusiast, but for the average person who requires a practical and efficient way to travel a few hundred miles, RAM is the answer. RAM capabilities actually give you more freedom than your car, enabling you to travel farther and to more diverse places, in less time than ever before.

Q My car gives me the convenience of door-to-door service. Will I feel burdened by the multi-modal trip that RAM will create (i.e., traveling from car to plane and back to car)?

A A critical mass of RAM systems will solve this. Multi-modal journeys are much more convenient today in many locations due to 82 percent of the U.S. population having access to ridesharing.[38] And, that convenience will just extend to smaller, regional areas as rental car agencies and ridesharing rise to meet the business opportunity. Furthermore, it is expected that the RAM experience will be enhanced with the reliability of autonomous ground vehicles as a last-mile solution.

Q As a citizen taxpayer, will I end up footing the bill for the RAM program?

A Just like other transportation modes that utilize public infrastructure (e.g., car travel), costs are paid directly by users and indirectly through taxes and fees. Every state is different, but each of their regional airports are, and will continue to be, supported by a mix of federal, state and local funding – just as they always have been.[39] In other words, there is already significant investment being made on maintaining this infrastructure and RAM will simply allow more people to utilize it.

Q How long will electric grid upgrades at airports take to implement?

A The electrification of the automobile industry has happened almost overnight. In 2010, there were 541 electric charging stations in the United States; in 2019, there were 78,301.[40] If lessons learned from this expansion are employed for developing airport charging stations, the 5,000+ airports could be quickly electrified.

Q Will increased air traffic create more noise and road traffic in areas surrounding the airport?

A Automated aircraft will be able to fly more precise noise reduction flight paths. As we've seen in the auto industry, electric propulsion will also be much quieter than current aircraft. In many of the early tests of electrically powered aircraft, the aircraft blends into the background of a typical suburban neighborhood. As for road traffic concerns, the overall benefit of having a functional regional airport close by far outweighs the perceived negatives. Just think, RAM gains you convenient access to over 5,000 airports nationwide. You can start your journey from the little airport near your house without fighting your way through parking, ticketing, and security lines at the major hubs. As well, more functional airports will more evenly distribute airport traffic, so less travelers are vying for highway space and parking at major hubs like LAX and JFK.

Q How often will the average person use RAM each month/year? Is there potential to use it daily?

A There is a large scope of potential applications for RAM. Leisure travel, business trips, and super-commuters (~4 million Americans travel >90 minutes to work) are all near-term opportunities that will allow users to use this transportation solution daily, monthly, or occasionally.[41]

Q How competitive will RAM's affordability be in comparison to other modes of regional transportation?

A Current operators are charging $29 for a one-way 75+ mile trip.[42] As autonomy, a seamless ecosystem, and community-compatible aircraft are introduced to this transportation option, the costs will reduce significantly to the point of being affordable to nearly everyone.

38 Uber Across the United States, Jonathan Wang, Uber, Medium

39 Voluntary Airport Low Emissions Program, Federal Aviation Administration

40 U.S. Alternative Fueling Stations by Fuel Type, Alternative Fuels Data Center, U.S. Department of Energy

41 The surging ranks of super-commuters, Jonathan Berr, CBS News

42 $1,250 per month subscription with ~22 workdays per month, FLOAT Shuttle

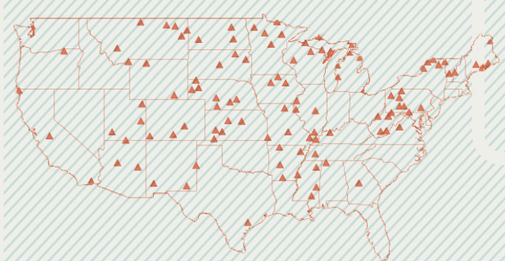
Regional Air Mobility
A Brief History

Regional Air Mobility: A Brief History

1946

The Federal Airport Act allows for the construction of some 6,000 airports. The Act helps foster the growth of air transportation by providing as many people as possible with convenient access to air travel. An airport is now only 16 minutes away from the average American.

1978



The Airline Deregulation Act removes price and route restrictions. The Essential Air Service program is created to subsidize air carriers on certain otherwise unprofitable routes to ensure small, remote communities maintain a minimum level of air service.

1979

Ransome Airlines operates commuter flights into capacity-constrained National Airport (DCA) by leveraging "stub" runways and the short takeoff and landing capability of their DHC-7 aircraft.

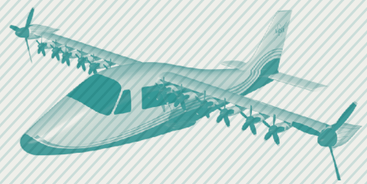
2005

NASA casts a vision to revitalize the U.S. Small Aircraft Transportation System (SATS) by completing focused research and technology demonstrations.

2011

A 4-seat, electric-powered aircraft designed and produced by Pipistrel proves to be 4X more efficient than a commercial airliner at the NASA / Google Green Flight Challenge.

2012



Tecnam develops an all-new 9-seat passenger aircraft, the Tecnam P2012, designed specifically for the needs of the RAM market.[43]

2016

NASA announces plans to develop the all-electric X-57 Maxwell to further advance the design and airworthiness process of electric propulsion technology for RAM aircraft.

2017

FedEx Express works closely with Cessna on a clean-sheet design targeted at small- and medium-sized cargo markets served by RAM operations.

2018

Reliable Robotics completes first fully automated gate-to-gate remotely operated flight of a 4-seat aircraft.

2019

The world's first all-electric, commercially focused seaplane takes flight in British Columbia. It is a 6-passenger float plane powered by magniX and operated by Harbour Air. magniX special conditions published by the FAA.

2020

FLOAT (Fly Over All Traffic), an air shuttle service, begins providing daily flights between general aviation airports around Southern California.

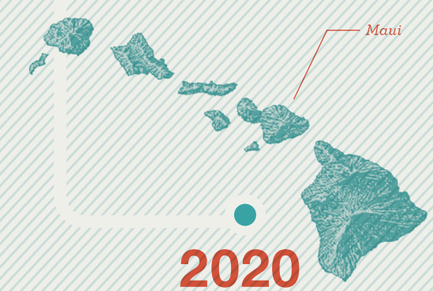
2020

Pipistrel's Velis Electro achieves type certification in Europe – the first for an all-electric aircraft.[44]

2020

Xwing completes a fully automated flight of 730 miles with 700 lbs of school supplies and personal protective equipment for the Navajo Nation.

2020



Ampaire partners with Mokulele Airlines to demonstrate the value of hybrid-electric aviation in Hawaii. Ampaire initiates their first test flights of the Electric Eel on the island of Maui, flying from Kahului to Hana.

43 Photo by N717JG, CC BY-SA 4.0, bg removed, recolored.

44 Photo by Andrejcheck, CC BY-SA 4.0, bg removed, recolored.