NASA Strategic Framework for On-Demand Air Mobility

A Report for NASA Headquarters
Aeronautics Research Mission Directorate

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Executive Summary

The Aeronautics Research Mission Directorate (ARMD), NASA Headquarters, requested an analysis of the strategic framework and public value proposition for On-Demand Mobility (ODM) vision and concepts, to support decisions on research and technology development investments by the agency. This report responds to that request, and provides a high-level view from a team of subject matter experts experienced in all aspects of aviation innovation: aircraft, airspace, airports, operations, policy, regulation, technology, strategy, partnerships, and finance.

The strategic framework team reached the following distilled conclusions and related high-level recommendations:

- The vision for ODM of enabling the ability “…for anyone to fly from here to there, anytime, anywhere…” creates a compelling public value proposition that could result from a Federal R&D investment that would be vastly leveraged by the private sector.
- An ODM vision requires a national policy, informed by a technology strategy, to align the regulatory, partnership, and investment elements necessary to initiate new and accelerate current activities to keep pace with both national needs and advancing technologies.
- The convergence of technologies from outside and from within the aviation sector create new paths to solving long-standing challenges in aviation safety, efficiency, performance, and affordability through ODM.
- NASA investments in ODM research and technology development would provide the means of delivering air mobility products and services that would support a uniquely significant advancement in American quality of life, economic opportunity, and standard of living.
- These investments would preserve the Nation’s global leadership in aviation and emerging transformations in transportation and distribution systems.
- NASA should create an ODM-centric project and strategic thrust that leverages current project investments in airspace, safety, autonomy, and UAS, and manufacturing and materials activities.
- The current NASA ODM Roadmapping activities, while highly effective in assembling an industrial and academic community of practice with a shared vision, require additional components related to secure cyber-physical aircraft connectivity; comprehensive airspace accessibility and services; and air portal infrastructure systems.
- Current and proposed ODM technology investments will have significant synergistic benefits to smaller unmanned aerial systems as well as larger general aviation and commercial passenger aircraft.
- Achieving the ODM vision represents significant cultural changes for America and establishing a sharing of that vision is essential to long-term success.
- The commercial emergence of the ODM vision represents a significant cultural change in America and its achievement requires a shared vision, which NASA is in a position to facilitate.
- NASA is in a unique position to play a leadership role in the formation of one or more Innovation-Public-Private Partnerships (I-PPP) to aggregate and leverage the necessary resources from both sectors toward a common public value in future mobility.

The findings and recommendations in this paper serve to propel bold, forward-leaning actions and acceptance of risk that will accelerate and materialize the ODM vision for all stakeholders, investors, beneficiaries and contributors in government and industry.
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Chapter 1 – Introduction and Strategic Context

Prelude

“No flying machine will ever fly from New York to Paris.”
Orville Wright

“About forty miles away from Paris, I began to see the old trench flares they were sending up at Le Bourget. I knew then I had made it, and as I approached the field with all its lights, it was a simple matter to circle once and then pick a spot sufficiently far away from the crowd to land O.K.”
Charles Lindbergh

Our aeronautics heritage is filled with unimaginably intimidating challenges that, once met, raised the expectations of ourselves to ever higher levels. The vision for On-Demand Mobility (ODM), embraced by a large and growing global community of practice, imagines a future for transportation of people and goods, anytime, anywhere, for productivity, or pleasure, with levels of safety and affordability we take for granted in our automobiles today.

1. Introduction

NASA and Industry Perspectives

The NASA Aeronautics Research Mission Directorate (ARMD) vision for aeronautical research for the next 25 years and beyond encompasses a broad range of technologies to meet future needs of the aviation community, the Nation and the world for safe, productive, efficient, flexible and environmentally sustainable air transportation. NASA’s analysis of global trends has led ARMD to identify the following three “Mega-Drivers,” shaping the requirements for aeronautical research in the coming years:

- Mega-Driver 1, Global Growth in Demand for High-Speed Mobility: Reflects rapid growth in traditional measures of global demand for mobility.
- Mega-Driver 2, Global Climate Change, Sustainability and Energy Use: Presents severe challenges in maintaining affordability and sustainability.
- Mega-Driver 3, Technology Convergence: Points of convergence occurring in industry sectors such as materials, manufacturing, energy, and information and communication technologies that will transform aeronautical capabilities.

NASA has incorporated six Strategic Thrusts into the Strategic Implementation Plan (SIP), which is the program initiative for ARMD’s response to Mega-Drivers as they affect aviation:

- Strategic Thrust 1: Safe, Efficient Growth in Global Operations
- Strategic Thrust 2: Innovation in Commercial Supersonic Aircraft
- Strategic Thrust 3: Ultra-Efficient Commercial Vehicles
- Strategic Thrust 4: Transition to Low-Carbon Propulsion
Within this structure, NASA has requested assistance with development of a strategic framework supporting its research and technology investment portfolio in the domains of On-Demand Mobility (ODM) transportation systems. The term ODM encompasses the use of smaller technologically advanced aircraft for widespread public use in transportation of people and distribution of goods, to virtually any destination accessible by air. ODM aircraft employ advances in electric propulsion, increases in vehicle autonomy, advances in airspace automation, and advances in materials and manufacturing as well as vehicle acoustics and emissions improvements. The international community of practice who are making leading ODM systems innovations express confidence that a new generation of both Vertical Takeoff and Landing (VTOL) and Conventional Takeoff and Landing (CTOL) aircraft will be brought to market with levels of affordability and safety that rival those in automobiles.

Whereas scheduled air transportation addresses the needs for travel between large centers of population, a significant demand exists for travel of people and goods between many other locations where population is less concentrated and thus unlikely to attract scheduled air service. The vision for ODM creates new opportunities for economic expansion, improved standards of living, and enhanced quality of life for vast portion of the Nation that are not served by the scheduled air carrier system.

Concepts addressing On-Demand Mobility are responsive to all three Mega-Drivers, and the applications of technologies from Thrusts 1, 3, 4, 5, and 6 are logically relevant to ODM vehicles and airspace opportunities. The purpose of this report is to present a narrative with supporting evidence of the public-good and value to the nation that would result from the collective technological impacts from industrial and governmental applications of NASA’s SIP-inspired investments to the ODM domain. The report also provides NASA with several recommendations regarding technology strategies, public-private partnering options, and policy) for fostering the achievement of the ODM vision.

NASA has chartered three technical ODM roadmap teams, in the following arenas:

1. Simplified Vehicle and Airspace Operations
2. Hybrid Electric Propulsion
3. Manufacturing, Vehicle Systems Integration and Community Acceptance

These three roadmaps have evolved from almost two years of collaborative deliberation by government, industry and academia toward development of a “community of interest” among technical and management leaders in the ODM arena. The roadmaps represent the beginning alignment between the appropriate roles for NASA’s technology leadership and industry’s ability to transfer those technologies into commercial applications. Further, the NASA roadmaps provide technical strategies for reducing the risks that are, for the most part, beyond the time, cost and technical risk boundaries of industry. Implementing ODM also requires risk mitigations in commercial adoption, public safety, market acceptance and related domains that are the purview of industry. These roadmaps focus on pre-competitive technologies representing common, industry-wide interests in technology advancements that are typically beyond the ability of any individual company to undertake.

Typically, these pre-competitive interests develop within three areas related to ODM:
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1. Common industry design guidelines for aviation systems that involve safety, productivity, efficiency and environmental goals.

2. Standards for systems and architectures that demand industry-wide acceptance.

3. Regulatory satisfaction requirements and certification standards that are relevant to industry involvement.

Finally, the roadmaps include content of value for international collaborations between U.S entities and the increasing number of companies as well as regulators from abroad with common interests in the three Mega-Drivers listed above.

This report proposes that the public will benefit in multiple ways from industrial applications of NASA’s support for ODM technology development. These outcomes result from direct technical payoffs (i.e., through commercial partner commitments to applications) in both scale-up effects (from smaller ODM aircraft upward to larger aircraft) and scale-down effects (from ODM aircraft down to aircraft in the smaller classes of Unmanned Aerial Systems (UAS)). In addition, the report offers evidence and logic supporting indirect public value, derived from ODM implementation of NASA Strategic Implementation Plan (SIP) for the Nation’s quality of life, economic opportunities, standard of living and environmental considerations, made possible through new means for accessibility and mobility enabled by ODM concepts.

In the absence of a formally declared national aviation policy or aviation transportation policy, we make the following assumptions that create the framework for strategic thinking regarding the ODM vision and related objectives:

1. ODM technology investments by NASA must fit within NASA’s charter in research, technology development and technology transfer.¹

2. NASA’s role includes multiple activities to create a shared pool of pre-competitive R&D outcomes for non-government, commercial adoption.

3. NASA’s role also includes the creation of information and knowledge supporting regulatory satisfaction (certification) of aviation products, services and operating capabilities.

4. NASA’s role includes generating data and engaging with Federal and state government organizations responsible for public safety.

5. NASA’s role includes generating data that identify and quantify the public benefits of ODM.

6. While NASA’s role has been traditionally limited to aeronautics technology-specific missions, the case for ODM calls for NASA to consider a broader role in championing the ODM vision, beyond the technology domain, to include promoting the public value proposition and national policy. It is noted, at the same time, that NASA’s technical results create significant value for investors in their decision-making.

7. At the corporate decision-making level, industry is informed by the results of NASA’s research and technology in creating advanced products and services.

¹ PL 111-314, NASA Space Act, as Amended, Dec. 18, 2010, Sections 102, (d), Objectives of Aeronautics and Space Activities, Subsections, d.2, d.5, d.8, d.9.
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8. **NASA’s role is limited in satisfying constraints and considerations in intermodal connectivity and infrastructure as well as in accessing environmental factors that require engagement of Federal, State, and Local Governmental and non-governmental organizations.**

Because some of these objectives required to support the realization of the ODM vision are outside the scope of NASA’s charter, we will focus on areas that we understand to matter for informing NASA’s strategic thinking within the ARMD investment portfolio.

This report is organized in seven chapters as follows:

1. Executive Summary and Introduction
2. ODM Market Demand
3. Enabling Technologies, NASA Roadmaps and Gaps Analysis
4. Organizational Contributions and Roles
5. Public/Private Collaboration Options and Resource Alignment
6. Policy and Regulatory Considerations
7. Stakeholder Outreach Plan

The intended audiences for this report include the new Congress and Administration of 2017, prospective industry and government partners, and internal NASA organizations, as viewed through the lenses of a team of independent domain experts with significant experience in the fields of aeronautics strategy, technologies, policy, regulation, partnerships, finance and aviation operations.

**Universal Challenges**

Our nation and others around the planet face daunting challenges in meeting evolving demand for movement of people and goods across the spectrum of transportation modes, while mitigating costs and impacts. These challenges involve intercity transportation, especially for underserved communities with markets too small for scheduled air carrier operations, as well as domestic and intercontinental commercial air services. NASA and U.S. industry are in a unique position to contribute to game-changing solutions across all domains of aviation, including commercial airlines, business and charter aviation, air taxi and commuter services, personal aviation, public safety and special services flying, and emerging Unmanned Aerial Systems (UAS) operations. Air transportation innovations require complex consideration of factors including the following:

- Future consumer behaviors
- Airspace capacity and efficiency
- Community accessibility
- Global climate considerations
- Regulatory satisfaction
- International considerations
- Airspace system infrastructure
- Societal and demographic shifts
- National, regional and local economics
- National policy alternatives
Multiple opportunities and concerns frame the future of the global transportation enterprise and shape the context in which NASA is uniquely positioned to contribute in the ODM domain.

1. The safe, productive and efficient mobility of people and goods facilitates economic development and enhanced quality of life. Thus, transportation technologies that respond on-demand to society’s needs for mobility offer broad, transformational opportunities to improve the wellbeing of U.S. citizens through enhanced domestic and international commerce.

2. In the U.S. and EU, scheduled air carriers are consolidating services toward larger aircraft, serving larger markets, flying longer legs. In the process, a vacuum in smaller community service exists, thereby diminishing economic opportunity and quality of life for increasing numbers of communities.

3. The growth of congestion in large cities and so-called megaregions has vastly outpaced the ability of highways to meet demand. The consequences in lost productivity and congestion-induced carbon emissions create both a challenge and an opportunity for airborne concepts.

4. Globally, as the need for transportation by air increases, commercial aviation is trending toward being one of the largest contributors to future carbon emissions among industrial sectors. As non-aviation industries reduce their carbon footprints, the relative effects of aviation’s emissions appear headed toward being a larger part of the global challenge.

Let us delve into these areas, starting first with opportunities that NASA technologies enable, and concluding with issues of aviation and climate. We make the case that through NASA’s leadership and public-private collaboration enabling ODM innovations, the prospect exists for accelerated advancement and deployment of commercial systems that capitalize on opportunities and mitigate concerns on a shorter time-scale.

**You Can’t Get There from Here**

Community access, economics, and quality of life are compelling issues of importance. As domestic air carriers continue to consolidate their market networks, many of the nation’s airports are increasingly left with declining quality of service, or none at all. Nationally, over the past decade, the effects of these moves by the airlines have resulted in diminished connectivity for more than 25% of U.S. cities [1]. As the nation’s highway system has matured and filled, beyond capacity in many places, the cost in excess time and energy expended in ground travel continues to rise. The highway capacity issues affect both urban and intercity mobility. The lost economic opportunity through the increasing numbers of communities that are without convenient and affordable air access diminishes the nation’s economic performance. The increased numbers of communities with declining air access represents a diminished quality of life for citizens living out of reach of major airports. Connectivity, access, and mobility by all modes of transportation represent a most essential element of our nation’s standard of living, including GDP per capita and other connectivity, and other well-being factors.

This report focuses on the role that NASA technology strategies could play in establishing the use of smaller aircraft and advanced technology to provide significantly greater mobility throughout the nation and elsewhere. Furthermore, there is significant merit in using smaller aircraft to prove

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the viability of ODM concepts as feasible, economical and applicable to both larger and much smaller aircraft. Finally, solutions developed for domestic consumption are exportable to address global challenges in mobility.

**Easy Access to Multiple Markets—the Power of Social Networking Personified**

More so than connecting via the Internet, people meeting face-to-face generate multiple dimensions of economic activity. Reducing the time of delivering goods also improves a region’s economy. Thus, facilitating On-Demand Mobility increases a region’s productivity.

*This report offers a strategic framework for development of technologies enabling smaller technologically advanced aircraft and their transportation services, coupled with business model innovations for inter- and intra-urban mobility.* The benefits will extend to contributions to the accelerated scale-up of such solutions to the global commercial air carrier industry, as well as the scale-down of technologies for intra-urban and other mobility scenarios such as with UAS for an ever-expanding scope of applications. We have seen these effects in play before. The NASA AGATE, SATS and ERAST projects discussed in more detail in Chapter 5, provided industry with the means to deploy new technologies in Code of Federal Regulations 14 FAR Part 23 aircraft, for example, as well as others (e.g. UASes) that rapidly led to applications of some of these technologies in larger (FAR Part 25) aircraft.

**Dude, Where’s My Flying Car?**

The need is great for mobility solutions at all scales—from personal to public and from scheduled to on-demand—that are affordable, efficient, clean and safe. In Chapter 2 of this report, we provide extensive evidence of the demand for ODM transportation domestically; the projections of that demand are compelling. Domestic and international investments aimed at enabling more widespread use of localized air portals, expanded airspace utility and innovative aircraft concepts, including vertical flight, are accelerating. The emergence of electric propulsion, automation of air traffic management, autonomy of vehicles, air-to-air and air-to-ground broadband WiFi, Trajectory-Based optimization of flight path economics and safety, new manufacturing and materials technologies, and innovations in vehicle configurations all illustrate a convergence of essential ingredients leading to the potential for highly beneficial airborne solutions to the growing need for mobility. Many of these technologies will both contribute to and benefit from the emerging “self-driving” automobile capabilities, including consumer acceptance.

The estimated costs of congestion in U.S. metroplexes alone are growing: In 2013, traffic congestion robbed the U.S. economy of an estimated $124 billion. Without significant action to alleviate congestion, this cost is expected to increase 50 percent to $186 billion by 2030 [2]. The cumulative cost over the 17-year period is projected to be $2.8 trillion, the same amount Americans collectively paid in U.S. taxes in 2013. Furthermore, the growth in cost for maintaining the much stressed U.S. Roadway Infrastructure represents a heavy burden on the economy [2]. Failure to fully explore alternatives to that burden represents a threat to the nation’s future growth as well as to losses in quality of life and standard of living. *The prospect appears both credible and valuable that industry investments in electrically propelled and autonomous intra-urban air taxis could contribute to solutions to metroplex congestion and carbon footprint in the nearer term. They also could lay the foundations for scale-up of the technologies to global air carrier implementations in the longer term.*
Aviation and 1.5 Degrees C

Significant international attention to climate change is affecting the future of commercial aviation. Recent studies indicate that even if international aviation meets all targets for alternative fuels, technology advancements and airspace efficiencies, the industry will have consumed about 12% of the global carbon budget to achieve the target of < 1.5 degrees C global temperature increase by 2050\(^3\). Should the industry fail to reach this target, its share of the carbon budget could exceed 25% for all global carbon contributors [3]. Nearer-term strategies to mitigate these effects are already beginning to become part of the public conversation. The approaches being debated include constraining demand through pricing and other market controls [4]. While the motivations for proposing such draconian-sounding demand constraints are understandable, they are not forward-looking through a lens of innovation and technology strategy. A forward-looking strategy would support investments that lead to means for satisfying, rather than for constraining demand. This report offers a strategic framework for productive approaches to the domestic and international debates on the future of air mobility.

External Strategic Context

- Demographic trends: A declining proportion of the population have drivers’ licenses [5][6]. The statistics are stark:
  - For 16- through 44-year-olds, there was a continuous decrease in the percentage of persons with a driver’s license for the years examined. For example, the percentages for 20-to-24-year-olds in 1983, 2008, 2011, and 2014 were 91.8%, 82.0%, 79.7%, and 76.7%, respectively.
  - For 45-through-69-year-olds, there was an increase in the percentage of persons with a driver’s license from 1983 to 2008, followed by a continuous decrease from 2008 to 2014. For example, the percentages for 60-to-64-year-olds in 1983, 2008, 2011, and 2014 were 83.8%, 95.9%, 92.7%, and 92.1%, respectively.
  - For those 70 years and older, there was an increase in the percentage of persons with a driver’s license from 1983 to 2011, followed by a slight decrease from 2011 to 2014. The percentages for 1983, 2008, 2011, and 2014 were 55.0%, 78.4%, 79.2%, and 79.0%, respectively.

The reasons for these shifts appear from surveys [6] to be linked to competition for time, cost and sharing options: “…not enough time to get a license” (37%); “…cars are too expensive” (32%); and “…can ride with others” (31%). It seems an appropriate hypothesis that the dominant use of public transportation or walking in larger cities [7], coupled with the increasing availability of shared-ownership, shared-use models, and on-demand ground travel (CarToGo; ZipCar, Uber, Lyft, etc.), have coupled to drive these changes in consumer behavior. While the significance of society’s changing attitudes toward owning an automobile, and becoming a licensed driver are yet to be fully understood, ODM research needs to address those demographic changes as well as what implications ODM strategies may have on future consumer demand. Today, aircraft are expensive to own and operate, in part because the user base for personal and business aircraft is relatively small (compared with automobiles). Increasing ODM accessibility through sharing models is

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3. The UN’s climate body, which was responsible for the Paris Agreement adopted in December 2015, set < 1.5 degrees global temperature rise as an aspirational goal for 2050.
likely to have a positive effect on demand, thus lowering acquisition and use costs.

- Competing modal developments: Self-driving cars will provoke a change in travel modal distributions by distance. The current cross-over distance for which drivers choose to fly is about 400 miles (about 8 hours) because the time required for flying and driving is about the same for airline trips requiring a hub-and-spoke connection. Driverless cars will likely cause a shift this to a longer distance since traveling by car should be less fatiguing for occupants and travel time can be used more productively. (Studies to validate and quantify these effects will be valuable.) The adaptation of self-driving car technology into ODM applications appears to be a reasonable expectation, if the certitude standards for air vehicles can be met. Research into the adaptation of technologies for self-driving/flying cars and aircraft would likely produce both leveraging and acceleration of investment outcomes for both domains. Encouraging developments in this arena include the establishment by the General Aviation Manufacturers Association of an industry-government committee to begin the process of advocating for such standards, including for simplified vehicle operations and electric propulsion systems. A second encouraging feature of this landscape is the participation by the FAA regulators in this committee, along with the transition by the FAA from a “prescriptive” regulatory framework to a “consensus standards” approach to certification of technologies, which will be applied to ODM vehicles, autonomy and automation in general.

- The convergence of aviation and non-aviation technologies include the following is a list of technologies from both the aviation and non-aviation domains that combine to serve as a foundation for transformational advancements in ODM aircraft, airspace, “airports,” and related operating capabilities and requirements:
  
  - High energy-density batteries
  - Fuel cells
  - High power-density electric motors
  - Additive (3D) manufacturing
  - Hydrophobic material coatings
  - Rich broadband air-to-ground, air-to-air, and orbit-to-air digital, bi-directional, IP connectivity
  - Military-, or Bank-grade cybersecurity systems
  - Trusted autonomous systems
  - Multi-function materials and structures
  - Advanced material systems (increased strength-to-weight properties)
  - Artificial Intelligence
  - Biometric identification, registration and authorization
  - Wearable and virtual or enhanced reality display systems

Through a focused research effort, led by NASA in collaboration with the FAA, industry and academia, these emerging technologies could combine with existing aviation system advancements to accelerate and amplify the improvements needed in ODM systems performance and cost to enable a fundamentally new market in air mobility.

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4 Airports is in quotes, since the term has specific meaning in today’s aviation infrastructure that may not apply to the future of “air portals, vertiports, or vertistops” for VTOL ODM vehicles, or to roadable aircraft, for example.
Participants and Contributors

The nature of ODM vision and solutions commands attention from a wide field of stakeholders, participants and contributors from both public and private sectors. Two of the more recent public announcements about ODM innovation initiatives from industry include those from Uber\(^5\) (posing system requirements and benefits for on-demand aviation), and from Airbus\(^6\) (offering a vehicle solution to the Uber requirements). As more fully explored in Chapter 4, there are as many as 30 publicly and non-publicly announced industrial initiatives in the ODM arena.

International Initiatives

The U.S. General Aviation industry, in numbers of operations, pilots, and aircraft deliveries, has been in decline for three decades or more. While the factors that affect these trends are manifold (GDP, energy prices, disposable incomes, and demographic trends to name a few), the fact is that over the past decade, the U.S. has invested less significantly in research and technology development for this segment of aviation than foreign governments and industries. Without a “storehouse” of foundational technologies, in particular those that derive from government labs such as at NASA and the FAA, we can expect these downward trends to continue. In contrast, the EU and China, for example, have been active over recent years in technology development benefiting innovation the ODM domain.

In the EU, under the Seventh Framework Programme (20078-2013)\(^7\), the European Commission funded a lengthy series of studies and research efforts conducted under a variety of projects referred to as P-Plane (Personal Plane)\(^8\), SAT (Small Air Transportation)\(^9\), EPATS (European Personal Air Transportation System)\(^10\), conducted by consortia of government, industry, and academic organizations. The result of these efforts has been to catalyze the EU small aircraft industry to invest in very advanced thinking about the role of such aircraft in public transportation in the EU and the related public value proposition for solving 21\(^{st}\) century transportation challenges at less cost, less carbon, and more productivity than can be achieved through ground-based solutions.

In his recent book, China Airborne\(^11\), James Fallows outlines the bold, patient, long-term strategy embraced by the Chinese government toward becoming an international leader in all aspects of aviation. Most of the world’s airport construction today is in China. The largest rate of growth in airline service today is in China. This relatively new dimension of the aviation landscape poses both threat and opportunity for U.S. ambitions in the future of aviation. China has recently announced their investment in the General Aviation Alliance in Zhongguancun near Beijing\(^12\). The mission of the organization is to become a bridge between China and the U.S. on General

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5 http://www.uber.com/elevate.pdf
6 https://vahana.aero/welcome-to-vahana-edfa689f2b75#.1vedu2n27
7 http://ec.europa.eu/research/fp7/index_en.cfm?pg=understanding
8 http://www.pplane-project.org
10 http://epats.eu
11 https://www.theatlantic.com/china-airborne/
Aviation issues and will provide Chinese aviation enterprises with more international co-operation opportunities.

India has recently released a report on their strategic planning related to regional connectivity by air\textsuperscript{13}. According to the press information from the Government of India, Ministry of Civil Aviation:

Airport Authority of India will be the implementing Agency for the Scheme. The RCS route would have to include un-served airports i.e. airports where there is no scheduled commercial flight or under-served airports i.e. airports which have 7 or less scheduled commercial flights per week. The RCS routes would cover a length between 200 to 800 km. But this criterion would not apply to hilly areas, islands, North-east region and for helicopter operations.

Based on the scheduled air carrier operating experience in the U.S., in markets that are too small or irregular in demand for financially sustainable scheduled service, the ODM concept (both the CTOL inter-urban and VTOL intra-urban vehicles under consideration in NASA studies) would be relevant in the markets of interest in India. The movement by India in these directions could represent an opportunity for U.S. manufacturers of ODM products and services.

2. Summary

This document focuses on the non-traditional air mobility innovations that emerge in the context of this convergence and provides an overview of the need for solutions, the technological underpinnings for solutions to these challenges, demand data illuminating the compelling market case for solutions, collaboration and partnership criteria and options, as well as strategic thinking about the policy needs regarding the value of advanced personal mobility solutions within a diverse and effective multimodal system.

The current NASA-led ODM Roadmaps are an excellent starting point for engaging the U.S. and international community of interest in on-demand mobility. *The convergence of autonomy, automation and connected vehicle technologies along with the ever-increasing demand for increased mobility and decreased congestion, pose an opportunity for our nation to be the global leader in the transformation of transportation through ODM advancements*. The effect of these advancements in fomenting “creative destruction,” in Schumpeter’s terms, has the potential to be transformational.

The implications discussed are mainly positive, but solutions have a negative potential as well. The innovations underway in new forms of air mobility involving autonomous aircraft flying in automated airspace management systems may have unintended consequences and unpredictable paths of development. Much the same as it was difficult to foresee the positives and negatives of the Internet or mobile telephony, so it will be challenging to foresee the facets of more widely distributed air mobility available to more consumers between more origins and destinations than we could imagine in the last century. With adequate attention to security and malfeasance considerations surrounding these advancements, the outcomes in new industries, jobs, wealth, quality of life and standard of living could be profoundly good for the nation.

\textsuperscript{13} http://pib.nic.in/newsite/PrintRelease.aspx?relid=146715
3. Findings and Recommendations

The following is a series of findings and recommendations supported by the assessments of this chapter:

**Finding 1.1** – There is a pressing national need for the U.S. to invest in advancements in ODM-related technologies if we are to maintain a competitive international posture in products as well as in regulatory standards.

**Finding 1.2** – The public value proposition posed by the ODM vision includes raised levels of standards of living, productivity, and economic opportunity that derive from an increasingly networked and connected public and their personal and business transport needs.

**Finding 1.3** – The opportunity and timing for achieving the ODM vision is significantly enhanced by the convergence of aviation and non-aviation technologies affecting propulsion, autonomy, safety, efficiencies, environment, and affordability.

**Recommendation 1.1** – NASA should organize an ODM-centric project, strategic thrust, and partnership plan to address the full breadth of technology domains required for this disruptive innovation to flourish.

**Recommendation 1.2** – NASA leadership and championship of the ODM vision including the role of partnerships is vital to the success of the concept.
Sources Cited


Chapter 2 – ODM Market Demand

1. Introduction and Summary

This chapter centers on the probabilities of demand for air travel given reasonable assumptions of consumer behaviors and service offerings (speed, range, payload, cost). We specifically evaluate the demand for inter-urban air travel in markets that have insufficient travel activity to support scheduled, financially sustainable, commercial airline operations. We refer to this class of service as “Thin-Haul.” For purposes of this study, we address air service classified as the “thin-haul” form of “on-demand mobility” (ODM). This demand is for markets of between 150 and about 600 nm in segment length flown by Conventional Takeoff and Landing (CTOL) aircraft. We address this segment of ODM air service in two categories of aircraft: CTOL Air Taxi (a 3-4 passenger aircraft) and Thin-Haul Commuter (a 9-10 passenger aircraft). These aircraft are piloted (single-pilot) in 2016 and autonomous in 2035. This market segment fits within the NASA Statement of Work, but notably, does not include the intra-urban ODM demand which we call Urban VTOL. The differences between intra- and inter-urban ODM are important for future studies.

Section 2 of this chapter is a literature review of the subject. The conclusions from this review indicate that there is very little research specifically aimed at the thin-haul or ODM sectors of air travel options. While ample attention is paid to aspects of commercial scheduled air travel, there is virtually nothing written on the smaller market segments served by ODM or thin-haul. (In Section 7 we examine alternative data sources that could be amplified to meet these important data needs, and to provide more precise understanding of the behavior of the air travel customer in these segments of the industry.)

In the absence of documented market performance data on ODM demand, there is a reasonable approach to the travel demand estimation and its allocation to modal segments of the industry, including thin-haul ODM service. This approach utilizes advanced analysis of the relationship between key components of the economy (level of economic activity, fuel price, population, history) and the generation and distribution of air travel trips by whatever means between city pairs. This advanced analysis leads to the ability to probabilistically describe the travel behavior of an individual traveler based on their specific value of time, value of money, and value of comfort and convenience when combined with the available options that are provided with known costs, time attributes, and comfort features. Specifically, we can determine the following: 1) the estimated number of individuals that want to travel between geographic locations of sufficient size and heterogeneity to generate potential air travel; and 2) the probability that any individual will choose a specific travel option from a set of travel options that include all available air modes, including ODM modes, as well as alternative modes such as auto or scheduled ground service.

The methodology that supports this approach is described in some depth in Section 3 of this chapter. Its first application is presented in Section 4, where we define what we mean by ODM and thin-haul demand. Special emphasis here is placed on the desired departure/arrival times of possible air travel options, which is key to understanding how such demand can be economically supported.

In Section 5, we offer estimates of ODM and ODM-only demand globally, for the United States and for India. These estimates are provided for both 2015 and 2035 to give some idea of how demand trends will move over time. Section 6 estimates the so-called direct and connection demand for a specific CTOL thin-haul commuter aircraft as an example of how demand for this
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mode can be estimated in general. Section 7, as mentioned above, contains a discussion of new data that might aid in creating better estimates of air travel demand in the future.

Finally, there are four appendices to this chapter, which are presented at the end of the report. Appendix 1 is a listing with summaries of the literature reviewed for problem. Appendix 2 is a more detailed description of the models and data used to estimate the demand. Appendix 3 provides a brief review of the structure of the AirMarkets Simulator tool, which is used to create the estimated values of demand. Appendix 4 offers a closer look at the stochastic pricing curve found in the air travel industry.

A very important conclusion of this chapter is that despite the lack of current data that can be used to make reasonable inferences about future air travel needs, or the ability of any specific technology to meet those needs, we provide findings from our methodology that illuminate the significant demand for ODM consumption. In order to produce demand insights of higher fidelity we need better data to model future human consumers making transportation modal choices among options.

2. Literature Review

A lack of available U.S.-based data on long distance travel is the main hindrance to long distance travel research. As a result, not many people have conducted research on long distance travel within the U.S. ... Most [studies] have made use of either the 1995 ATS or the 2001 NHTS which are the most recent long-distance travel data or past NTS surveys conducted by the U.S. Census Bureau.\(^\text{14}\)

A literature review was conducted to determine what data and research had been conducted related to on-demand mobility for air travel and long distance mode choice (with a focus on auto and air trade-offs). The literature review was conducted by using multiple keyword searches. Results were sorted in terms of “relevance.” Some searches returned a very large number of results (7,000+). For these cases, we examined articles until the results became largely irrelevant. The keyword search terms, number of results returned, and number of results examined are shown in Table 2.1 below:

<table>
<thead>
<tr>
<th>Search Term</th>
<th>Number Returned</th>
<th>Number Examined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long distance and travel</td>
<td>9,369</td>
<td>500</td>
</tr>
<tr>
<td>Mode choice and air</td>
<td>327</td>
<td>327</td>
</tr>
<tr>
<td>“Thin-haul”</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>“Air travel” and demand</td>
<td>7,994</td>
<td>200</td>
</tr>
<tr>
<td>“On demand mobility” and air</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 2.1: Search Terms Used in Literature Review

In addition, in early 2016, the Airport Cooperative Research Program (ACRP) of the Transportation Research Board (TRB) released a call for proposals to address “Air Demand in a Dynamic Competitive Context with the Automobile.” As part of this call, several recent reports produced by TRB that were noted as relevant resources were reviewed as well. Finally, relevant papers presented at the 2016 AIAA Aviation Conference in Washington, DC were identified.

To date, there has been little research that has been conducted to help evaluate the role of the automobile as a competitor in intercity or intracity travel. We do not have a clear understanding of the characteristics and variables affecting passenger choices between airline travel versus automobile travel, and the way those choices are expressed within the competition between air and automobile. Several programs, including the Airport Cooperative Research Program (ACRP), the National Cooperative Highway Research Program (NCHRP), and the National Cooperative Rail Research Program (NCRRP) of the Transportation Research Board (TRB) and the Federal Highway Administration (FHWA) are currently or have recently funded research to explore one or more aspects of intercity travel. Table 2.2 summarizes recent studies of long-distance demand conducted by ACRP, NCHRP, NCRRP and FHWA.
### Table 2.2: Recent Studies of Long-Distance Demand

These reports provide insights into the state-of-the-art in long-distance travel demand modeling and common challenges that have been faced in developing air travel demand, particularly as they relate to available data.

Some of these studies, such as ACRP Web-Only Document 22 or ACRP Report 03-36, provide useful background information, such as passengers’ value of time for different parts of an air travel trip and / or conduct comprehensive reviews of prior air passenger studies. This information will be valuable for agent-based simulation studies (such as the AirMarkets simulation results produced as part of the current project). Other studies, such as ACRP Report 31, note that there are strong geographic differences in air travel in the U.S. (i.e., West Coast and East Coast trip generation rates are substantially different). This finding is particularly relevant in the context of predicting ODM trips and suggests that a national-based survey should be used to capture regional differences.

<table>
<thead>
<tr>
<th>Study</th>
<th>Key Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACRP Report 31, <em>Innovative Approaches to Addressing Aviation Capacity Issues in Coastal Megaregions</em></td>
<td>Strong geographic differences in air travel: West Coast Megaregion (population 38 million) generates about twice as many internal air trips than the East Coast (population 29 million).</td>
</tr>
<tr>
<td>ACRP Web-Only Document 22, <em>Passenger Value of Time, Benefit-Cost Analysis, and Airport Capital Investment Decisions</em></td>
<td>Provides passengers’ value of time for parts of an air travel trip, including ground access time, terminal access time, other times in the airport, flight time, egress time, and flight delays. These surveys and values of time could be useful for agent-based simulations of air travel behavior.</td>
</tr>
<tr>
<td>ACRP Report 03-36, <em>Using Disaggregate Socioeconomic Data in Air Passenger Demand Studies</em></td>
<td>This project, currently in progress, reviewed more than 100 air travel demand studies with a focus on how socioeconomic data has been used in air demand studies.</td>
</tr>
<tr>
<td>ACRP Report 118, <em>Integrating Aviation and Passenger Rail Planning</em></td>
<td>Rail does not usually replace air feeder flight roles; final destination of trip is critical to choice (rail tends to terminate in city centers and air outside city centers).</td>
</tr>
<tr>
<td>ACRP Report 142, <em>Effects of Airline Industry Changes on Small and Non-Hub Airports</em></td>
<td>Used focus groups and case studies to complement data analysis. Flight reliability cited as a reason to bypass a smaller airport for hub; some airports respond by initiating van service to hub airports.</td>
</tr>
<tr>
<td>NCHRP Report 750, Volume 6, <em>The Effects of Socio-Demographics on Future Travel Demand</em></td>
<td>Reviews sociodemographic trends and technology changes applicable to air travel demand.</td>
</tr>
<tr>
<td>NCRRP Project 03-02, <em>Passenger Rail in the Context of Dynamic Travel Markets</em></td>
<td>Conducts online survey that includes passenger attitudes and values. Results showed differences in attitudes towards safety, privacy, and other factors by sociodemographic groups.</td>
</tr>
<tr>
<td>FHWA, <em>A Tour-Based National Mode System to Forecast Long Distance Passenger Travel</em></td>
<td>As price or cost increases, individuals are more likely to change destinations (traveling somewhere closer to home) than modes.</td>
</tr>
</tbody>
</table>
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differences. In addition, ACRP Report 118 and the FHWA Report on a Tour-Based National Model to Forecast Long Distance Passenger Travel find that trip characteristics (such as trip costs and whether the final destination is in the center city, and trip costs) impact not only mode choice but destination choice. This suggests that a highly detailed survey with “actual” trip origins and trip destinations (not just the airport locations) should be used to understand mode choice. The latter will be particularly important for intracity trips, as these trips have the shortest distances and “other factors” such as access time and trip reliability (for commuting) are likely more important in determining mode choice. In addition, these results suggest that a joint destination and mode choice model may be needed to forecast ODM trips, particularly for leisure/discretionary trips where multiple destinations may be substitutable (e.g., different golfing or beach destinations).

Finally, several other studies such as NCRRP Project 03-02 and NCHRP Report 750, Volume 6 provide insights into how demand for long-distance trips varies as a function of individual traveler characteristics, including attitudes, values, sociodemographic and socioeconomic factors.

The ACRP, NCHRP, NCHRP, and FHWA reports discussed above offered a common message: a new data collection effort is critical for the development of long-distance demand models that accurately captures how individuals make travel decisions today – not 15 to 20 years ago. It has been decades since a nation-wide survey of long-distance behavior was conducted for the U.S. However, much has changed since the 1995 American Travel Survey (ATS) or 2001 National Household Travel Survey (NHTS), the most recent national-based studies, were conducted. As shown in Figure 2.1 below, which compares mode choices immediately before and after the events of 9/11, there was a shift in mode shares for long-distance trips, with a larger proportion of intercity trips being taken by automobile (shown as POV on the Figure) versus air. This is another motivation for why it is critical to collect new data to support ODM demand forecasting. However, we should note that the relationship between air travel and auto travel as a function of distance is nearly linear, except for the very short range in the Post 9-11 diagram. In the absence of any data to the contrary, we must assume this linearity holds.

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Figure 2.1. Auto (POV) vs Air Travel Mode Split, Pre- and Post-9/11/2001. Curves on left are based on 1995 ATS data and curves on right are based on 2001 NHTS data.

There have been several more regional- or state-focused surveys that have been conducted since the 1995 ATS and 2001 NHTS national-based surveys. These more recent surveys may prove helpful for the current research project and can inform future data collection surveys. Table 2.3 summarizes travel surveys that the ACRP, NCHRP, NCRRP, and FHWA studies discussed above. This list is not comprehensive of all the surveys that may be available, but is representative of those that have been used in the prior studies in Task 1. There are several key points that are evident from the review of surveys included in Table 2:

- The number of long-distance travel surveys is relatively small, particularly relative to the number of intracity household travel surveys.
- Household travel surveys conducted by metropolitan planning agencies (that primarily support intracity demand modeling) often include a limited number of long-distance intercity trips; however, combining data from these surveys may be challenging if survey instruments are not similar.
- Some metropolitan planning areas have invested in long-distance surveys.
- More recent long-distance travel surveys have primarily focused (and been funded) to support analysis of the Northeast and California high speed rail corridors.
- There is a lack of recent data for many areas of the U.S., particularly for the Central and Southeastern US.
Table 2.3: Travel Surveys Cited in ACRP, NCHRP, NCRRP and FHWA Reports

<table>
<thead>
<tr>
<th>Source</th>
<th>Description</th>
<th>Coverage Area / Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995 ATS and 2001 NHTS</td>
<td>Most recent national survey of long-distance trips (all modes)</td>
<td>All U.S.; 2001 NHTS used as primary source to develop FHWA long-distance multimodal passenger travel modal choice model</td>
</tr>
<tr>
<td>2014 survey conducted by New England Transportation Institute and University of Vermont</td>
<td>Includes SP trade-off questions for multiple modes</td>
<td>2,560 responses from Mass, New Hampshire, Maine, Vermont</td>
</tr>
<tr>
<td>NCRRP 2015</td>
<td>Includes SP trade-off questions among train, car, automobile, bus</td>
<td>513 responses from Cascade corridor and 5,112 from Northeast corridor</td>
</tr>
<tr>
<td>California High Speed Rail Study</td>
<td>Survey including SP mode choices</td>
<td>2,678 long-distance trips used for CA High Speed Rail study</td>
</tr>
<tr>
<td>Caltrans statewide survey</td>
<td>Survey of long-distance travel in California</td>
<td>2,820 long-distance trips used for CA High Speed Rail study</td>
</tr>
<tr>
<td>Southern California Association of Governments (SCAG)</td>
<td>Metropolitan-based travel survey</td>
<td>343 long-distance trips used for CA High Speed Rail study</td>
</tr>
<tr>
<td>San Francisco MTC</td>
<td>Metropolitan-based travel survey</td>
<td>723 long-distance trips used for CA High Speed Rail study</td>
</tr>
<tr>
<td>Sacramento Association of Governments</td>
<td>Metropolitan-based travel survey</td>
<td>318 long-distance trips used for CA High Speed Rail study</td>
</tr>
<tr>
<td>NE Corridor Intercity Bus Study</td>
<td>Survey of intercity bus travelers</td>
<td>Northeast U.S.</td>
</tr>
<tr>
<td>NE Corridor Auto OD Study</td>
<td>Survey of intercity automobile drivers</td>
<td>Northeast U.S.</td>
</tr>
<tr>
<td>2015 ACRP Air Value of Time Study (ACRP Web-Only Document 22)</td>
<td>Survey of 1,260 travelers; focus on air travel only</td>
<td>U.S. (172 origin and 148 destination airports)</td>
</tr>
<tr>
<td>2001 NHTS add-ons from New York and Wisconsin; 2003, 2010, and 2014 household travel surveys from Ohio, Colorado, California</td>
<td>Surveys used for model calibration (not estimation)</td>
<td>New York, Wisconsin, Ohio, Colorado, California; Used for calibration in FHWA long-distance travel model</td>
</tr>
</tbody>
</table>

The insights from this limited review are consistent with the experience of the researchers who developed the FHWA long-distance multimodal passenger travel choice modal choice model. Specifically, the FHWA (2012) report notes that “although there do exist other travel surveys that have some data on long-distance travel, the literature review found that they lack the richness and
size of the ATS or NHTS.” Therefore, there is a critical need to collect new data in support of better understanding demand for ODM markets.

Finally, it is important to note that since the last national long-distance travel survey in the U.S. was conducted in 1995, there have been numerous technology and other changes, such as cell phones, smart phones, location-based navigation devices, real-time traffic information, in-seat DVD players in planes and cars, body scanning technology at airports, and the emergence of lower-cost travel alternatives such as Airbnb, and Uber and Lyft. In addition, the substantial increase in passenger and baggage screening time has added significantly to airport access and processing times. These changes and innovations can influence consumer choices in a variety of ways - from making travel more productive and/or more affordable; making travel more onerous (e.g., long security lines); and expanding travelers’ knowledge about potential destination sites. These and other key technological trends likely influence consumers’ long-distance choices. Any future data collection plan should be designed to provide insights into how travelers are using technology when planning or taking their long-distance trips. It is also possible that non-traditional data sources, such as cell phone data, could be used to quantify and predict current demand for long-distance trips by air and automobile.

In summary, a better understanding of these factors, along with an understanding of potential changes in demographic and other factors that will affect how this competition expresses itself, will enable decision-makers to make more informed judgements and results. Forecasting and planning models are widely used to provide decision-makers with a view of future conditions. Although these models can be complex, they work only as well as is permitted by the model design, assumptions and input data. Thus, a goal for the improved analytical framework should be to contribute new types of information regarding intracity and intercity travel mode choices. We see two major thrusts for this research: 1) defining the important tangible and non-tangible factors that influence fly vs. drive decisions, enhanced by case studies; and 2) updating the choice framework using these variables with ones that vary by region and airport location, to serve as a footing for future choice predictions that can apply to all airports, also enhanced by case studies.

3. The Quantitative Estimation of Air Travel Demand

Except for a few individuals who fly aircraft as a profession or hobby, travel demand is a derived demand. People travel so they can do something else – take care of business, visit family, go on vacation, or see things they’re curious about. Moreover, travel demand is a stochastic quantity. By that we mean that the actual demand that arises in any given period (e.g. a day or week) cannot be deterministically established, and hence has an associated probability distribution. The concept of expected demand is thus meaningful only if there is a probability distribution function that empirically establishes how likely any number of individual trips would originate in the origin and terminate at the destination during a specified time span, given values for other travel attributes such as price, travel time, or comfort. The subject of this Section of our discussion is to describe these stochastic properties as represented by the AirMarkets Simulator, an agent-based model of air travel. The mathematical details of these properties are presented in Appendix 2, while the AirMarkets Simulator program is examined in Appendix 3.


We use a traditional formulation for the estimation of air travel demand between an origin and destination. We first model the generation of trips from a specific city, and then model their distribution to all other cities. The first part, called the Trip Generation Model (TGM), estimates the per-capita air trips originating in a specified geographic area per unit time, based on independent variables such as population change, unemployment rates, fuel costs, and local economic activity. The second part is called a Trip Distribution Model (TDM), and it allocates the TGM estimated demand to specified destination cities. The TDM is a modified gravity model, which relates demand to the origin and destination populations (rather like the mass of two planets) and the distance between the two. In the air travel case, distance, price and something referred to as network impedance replace the simple distance of a gravity model. Network impedance is a measure of the travel costs associated with a specific network configuration and competing modes or itineraries of travel.

The result of the application of these two models is an estimate of the total trips for a specified time interval between an origin and destination, given price, alternative transport modes, and air network impedance structure.

The initial forms of these models were developed using data from the United States scheduled air travel bank settlement plan (BSP). The precise model structure is the result of extensive theoretical work, while the coefficients of the model are estimated using ticketing data. The econometric theory implemented in the AirMarkets demand model is a result of extensive research into OD demand modeling in the United States: examining alternative forms, different independent variable combinations, and various aggregate and disaggregate properties of several model structures. For details, see Parker et al. (2007) and Parker (2010).

The third stochastic model used in the AirMarkets Simulator is the passenger Mode / Itinerary Choice Model, or just the Choice Model. It estimates the probability that a traveler going from a specific origin city to a specific destination city will choose each of the possible ways of making that trip. The AirMarkets Simulator generates a form of model called a Random Utility Discrete Choice Model (DCM) for each passenger in the simulation. During a specific simulation, it generates a random number which is applied to the discrete distribution of available choices. This approach, for example, accommodates the dynamics inherent in the booking process that precedes the departure of a scheduled airline flight. The DCM is fairly complicated, and is examined in detail in Appendix 2.

With these three components, and their values estimated for a specific origin-destination city pair, we can have a reasonably good estimate of the demand to go from one to the other, (and we have a logically consistent structure for the estimation of the accuracy of that demand estimate).

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16 A bank settlement plan, or BSP, is an organization that handles the money associated with the purchase of an airline ticket through a travel agent. There is one such organization covering any geographic area, and at last count some 165 such plans existed throughout the world. The BSP for the United States is a company that used to be called the Airline Recording Corporation, now known simply arc.
The AirMarket Simulator is based on bottom-up, agent-based logic. To get an idea how it works and to illustrate some of the complexities associated with the estimation of air travel demand, consider a network of scheduled flights traveling in a set of cities up and down the U.S. West Coast. Suppose there is a flight coming from Anchorage, Alaska (ANC), stopping at Seattle (SEA), then again at San Francisco (SFO), and finally turning around at Los Angeles (LAX) airport and heading back the way it came to Anchorage. This flight serves six markets on its southbound journey: ANC>SEA, ANC>SFO, ANC>LAX, SEA>SFO, SEA>LAX, and SFO>LAX. Suppose there are 100 seats on the airplane, all priced the same for travel in the same market (i.e. there is no revenue management in effect for the fare structure), and there are at least 300 people per day wanting to travel in each individual market. Finally, assume there are at least two other flights in each of the six markets served by this one, but served by airplanes with a different capacity than the aircraft supporting our flight.

Ticket booking occurs over time in all six markets, and the booking in one market is independent of the booking in any other market. Empirically, the ticket booking period extends at least 120 days before departure. This means that the expected maximum utility generated by the passenger choice model depends on when prior to flight departure that quantity is calculated because as the departure date of the flight approaches, more and more seats on available flights have been taken and are not available for future patrons. Which of the 18 flights serving these six markets is the first to fill up is governed by choices made by independent agents, which themselves are random variables.

The rates of booking over the time prior to departure are reasonably consistent throughout the world. In Figure 2.2, two graphs illustrate the time dimensionality of the network utilization. These graphs are based on detailed data from AirMarkets Simulation runs, which includes all markets with non-zero weekly demand in the world.

In each graph four data series are shown. First is the fraction of total successful bookings as a function of days before flight departure. The second variable is the fraction of passengers for which no affordable flight option is available, so they are unable to undertake the journey. This fraction is closely aligned with the successful booking curve since affordability does not affect when a booking is attempted. The third variable is the accumulating fraction of attempted bookings where no itinerary at any price is available. As we would expect, the lack of availability is near zero until around 15 to 10 days before departure, where this lack of availability begins to climb rapidly as flights fill up and fewer and fewer alternative air travel options are still available. For comparison purposes, the fourth data series is an accumulation plot of the number of charter ODM service options purchased by passengers in a selected U.S. market.

Figure 2.2 show the data in accumulated form. That is, the total bookings up until a specific day before departure are plotted against the day before departure index for that day. In Figure 2.3 the same data are shown, except that each day shows only the bookings/no affordability/no availability/ODM for that particular day. As expected, the number of bookings starts quite small and rises at first slowly, but more rapidly as departure approaches. It should be noted, as well, that the curve for ODM service acquisition stays quite close to the availability curve. This suggests that, to a reasonable degree, ODM use increases at the same rates as the loss of availability of

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17 This is evident from looking at the rate of ticket sales for thousands of markets throughout the world. In no case was it found that even a single aircraft had sold all of its seats any further in advance than 120 days.
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other, scheduled flights. (By the way, the reason the ODM series in Figure 2.3 is jagged while the other series are smooth is because the ODM series contains relatively few passengers.) Indeed, the total demand is the total booked trips plus the total trips that did not have availability plus trips desired by not affordable, which equals 48,839,000. The total number of successful bookings worldwide is 40,566,000 for the standard week of the simulation run. While about 3,857,000 passengers could not afford any of the options available, 4,416,000 (nearly 10.8% of all passengers) have no availability by the time the day of departure arrives. In other words, 85% of the demand is assumed to be met by the currently available scheduled network.

![Accumulated Fraction Per Day Before Departure](image)

**Figure 2.2: Accumulated Total Bookings by Days before Departure**

Could the remaining 15% be considered as latent demand? Certainly, if the price were lowered, a larger share of the 3.86 million passengers who could not afford current itineraries would be served. Therefore, if more flights were available, either with more seats on each or more frequent service, the 10% who have no available option during the booking period would be more successful. It seems further simulation research in this area would be beneficial in arriving at a suitable method for measuring latent demand.
4. The Definition of ODM and Thin-haul Service

An essential part of understanding travel demand as it relates to the scheduling of travel services to meet that demand is understanding when individuals want to travel. Like the reason for travel itself, when the travel is needed is independent of the mode of travel. A travel service that fits desired travel times will do better than one that does not. The AirMarkets Simulator produces, as part of its agent-based simulation output, a distribution of when travel is desired across a week of time (from 00:01 AM on Monday to 24:00 PM on the following Sunday). Because the characteristics of the agents used in AirMarkets were derived from empirical research that did not rely on observed passenger behavior, but rather on preferences stated by survey respondents (thus allowing the investigation of hypothetical travel options), the empirical results are not conditioned on available travel opportunities. This capability is essential to enable the positing and evaluating options that do not now exist.

The immediate value of this approach is shown in Figure 2.4. This is a plot of the desired departure time of all simulated agents in a specified market across a period of time referred to as the standard week,\(^\text{18}\) which is generated as a product of the AirMarkets Simulator. The general shape of a desired departure time curve across a specific day is a double-peaked curve, with a morning and afternoon high. Each day has a somewhat different total demand, so the curves have different heights and valleys for different days of the week. In addition, due to individual city characteristics

\(^{18}\) This standard week is the second week in August, which was selected for simulation runs because it is the week with the highest average air travel demand, while least likely to have some special occasion (e.g. a holiday) during the week. In general, annual demand can be estimated from standard week demand by multiplying the week estimate by 35.1728 since this represents the share of annual demand usually observed in the August standard week.
NASA Strategic Framework for On-Demand Air Mobility

and time zone changes, every pair of cities and the associated two directional markets generate a different desired departure curve. For example, the data in Figure 2.4 are from the Seattle-Las Vegas market, which helps explain the larger proportion of desired flight times on Friday, Saturday and Sunday. Other markets, such as Chicago-New York, have smaller proportions on the weekend.

Figure 2.4: Typical Distribution of Desired Departure Time

However, not everyone travels alone. The behavior of a passenger in the choice of travel departure time and itinerary evaluation, in fact, often reflects the behavior of more than one individual person. Thus, if we are interested in the number of persons flying as a function of time (e.g., ideal departure time), then we need to accommodate the reality that more than one individual may wish to depart at the same time. The travel group size is the appropriate unit of demand measurement for all travel, but especially air travel, where vehicle capacity is a vital parameter in the definition of scheduled service vs. on-demand service. In the AirMarket Simulator, the agents that represent the passengers are called pags. This is short for passenger agents, which signifies that groups of passengers traveling together are being emulated, not individual passengers. Of course, in roughly 40% of cases the group contains only one individual, but in the remaining there can be two, three or more. In the graph shown in Figure 2.4, it the ideal departure time of pags that are being plotted, not the ideal departure time of individuals themselves. Therefore, the probability that a given number of individuals will want to travel in a specified time span is not only dependent on the probability distribution of the desired departure times, but also on the probability associated with how many people are traveling in each associated travel group.

In most markets, there are other options for travel besides airplanes, including private automobiles, for-hire cars, trains, buses and boats, and a collection of airlines that provide scheduled service. In other words, the passenger has a choice of one of many options, and this fact is an important consideration when scheduling of an air travel option is being considered. The choices for a travel party that wants to go from a specific origin to a given destination are reasonably represented by a
discrete choice model, as mentioned earlier. Such a model provides an estimate of the likelihood that an individual traveler will select a particular option of the possible available choices to make the trip, given attributes of the travel option and characteristics of the traveler.\textsuperscript{19}

In terms of scheduling air travel service, the most relevant variables in the discrete choice model are the departure and arrival times of the service carrying the passenger. This feature of a travel option is referred to as the \textit{ideal schedule delay} variable, (not to be confused with the term schedule delay as it applies to the difference between scheduled departure and actual departure caused by weather or traffic congestion). Ideal schedule delay could be associated with either of two time variables – ideal \textit{departure} time or ideal \textit{arrival} time. One, however, implies the other for a given travel option, and so we need only to consider departure time as the ideal schedule delay value, since arrival times for given choices imply a known departure time.

Empirically, the closer to the traveler’s ideal time a travel choice is, the more utility that choice has, and thus the probability becomes higher that the traveler will select that choice.

Given these stochastic conditions, what is the maximum expected demand for any specific departure time for a scheduled flight? If that demand is sufficiently large, then a scheduled service can be provided with a reasonable chance of sufficient revenue to support the cost of the service. If that maximum, however, is not large enough to support any scheduled time, then the market cannot be served by a scheduled air carrier.

It is readily possible to determine the minimum size of the demand in any city pair market and for any aircraft proposed to support scheduled air service. This configuration leads directly to an operationally useful definition of on-demand mobility only service, to wit: a market is defined as \textit{On-Demand Mobility only} (ODM only, or just ODM) if it cannot support scheduled service, as defined above, by any available aircraft.

It should now be clear how to design the air service to meet the needs of any city-pair market, at least from the perspective of the passengers buying tickets. Operational constraints, such as maintenance time and cost or pilot and crew considerations, often dictate when air service will be available. But if the availability does not meet the needs of the air travel customer, then the service cannot be sustained, and any attempt at providing scheduled air service will fail.

This analysis also creates an interesting opportunity for considering scheduled service with smaller aircraft. If low operating costs can be maintained, then smaller aircraft can serve a market more frequently than larger planes, thereby enhancing the desired versus the actual departure time relationship. Such more frequent flights of smaller aircraft might also garner higher fares. Exploration of that option would seem vital to our understanding the long-term viability of small aircraft engaged in scheduled service.

This scenario leads to a natural definition of the term \textit{thin-haul}. Using the demand time profile above, we can reasonably define the market demand for any size of aircraft. We will refer to a market as being \textit{thin-haul of degree x} if an aircraft with capacity of \(x\) passengers is the smallest aircraft that can support scheduled service in that market. Also, as a matter of convention, we will consider air service as \textit{scheduled} if at least one flight per week departs the origin city for the destination city at the same time of day and day of the week. As a practical matter, however, in

\textsuperscript{19} We assume the values of travel attributes held by the individuals in the same traveling group are all the same.
the United States and other developed countries, it is reasonable to expect scheduled service to be offered no less than daily and usually at the same time each day.

5. Estimates of Demand for ODM Service

Two aircraft are used to illustrate the estimation of ODM and thin-haul market demand for this study. For the ODM case, a four-passenger airplane with typical range, speed and cost is assumed. For the thin-haul case, a 9-passenger electric aircraft is assumed in the example. In the ODM case, estimates of demand worldwide, for the United States and for India are portrayed, and annual demand estimates are offered for 2015 (the latest year for which necessary data are available) and for 2035, using accepted forecasts of population growth over the next 19 years. For the thin-haul demand estimate, the subject aircraft is the electric vehicle, but only the continental United States is used as the geographic area. This is because the network configuration for scheduled air service can be quite complex, and detailed descriptions and analyses of all possible such configurations is beyond the scope of this study. The Thin-Haul demand estimate will be examined in greater detail when the thin-haul estimate is described in Section 6.

In this Section, we consider the case of ODM. Table 2.4 shows the assumed aircraft attributes, passenger characteristics, and fare of a four-passenger aircraft used by the AirMarkets Simulator in the simulation of ODM demand. These parameters are based on current knowledge of existing aircraft, and on reasonable assumptions regarding expectations in the future year estimate of 2035. (One of the research topics that needs to be addressed is how well these assumptions fit the expected air travel circumstances twenty years from now.)

The definitions of these attributes, characteristics and fare variables are summarized below:

1. Aircraft Attributes: Physical feature of the airplane
   a. Maximum Passengers: The capacity of the aircraft, not counting crew.
   b. Maximum Range: The maximum range of the aircraft without stopping.
   c. Range Reduction per Passenger: How much the maximum range is reduced by the presence of each passenger.
   d. Cabin Comfort Level: A coefficient used to express aspects of cabin comfort – noise, privacy, physically comfortable seating, compared to a first-class seat on a commercial aircraft.
   e. Cruising Speed: The speed of the aircraft at cruising altitude.
   f. Time to Cruising Altitude: How long it takes for the aircraft to reach cruising altitude from takeoff.
   g. Time from Cruising Altitude: How long it takes for the aircraft to go from cruising to landing.

2. Passenger Characteristics: Passenger attitude and time effects
   a. Aircraft Acceptance: The probability that an air traveler will consider traveling in a smaller aircraft given his perception of the safety and comfort of small airplanes.
   b. ODM Availability Awareness: The probability that the passenger will be aware that there exists charter ODM service in the market where his seeks to travel.
   c. Mean Commercial Access Time: The average time requirement to go from initial origin (home, office, etc.) to the nearest airport with commercial service in the market under consideration, go through airport security, and eventually depart for the destination, and go from the airport on arrival to the passenger’s final destination.
d. Mean ODM Airport Access Time: The same time as 2.c above, except for the airport supporting the ODM service.

3. Fare Structure: How much the travel party will be charged for the ODM service. (Note that it is assumed only one travel party will fly in an ODM aircraft at a time, and the fare is the same no matter how many are in the travel party.)
   a. Base Fare: The charge for the ODM service regardless of the specific market being served.
   b. Per Mile Fare: The added charge for the ODM service per nautical mile of distance being travelled.

We stress the importance of the Passenger Awareness variable in this ensemble of properties of potential ODM service. Although we do not have empirically sound research to support it, anecdotally it appears that the number of air passengers that consider ODM service is very small. Indeed, most air travelers do not know it exists, how it can be accessed, or how much it costs relative to other available air services. The values used for this analysis are based on observed charter flights versus commercial flights as recorded by the FAA. Consumer awareness and acceptance look to be an area of most productive areas of future ODM use research. The values for these attributes and characteristics used in this analysis are shown below in Table 2.4.

<table>
<thead>
<tr>
<th>ODM Demand Analysis: Aircraft Attributes, Passenger Characteristics, and Fare</th>
<th>2015</th>
<th>2035</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aircraft Attributes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum Passengers</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Maximum Range</td>
<td>600 nm</td>
<td>600 nm</td>
</tr>
<tr>
<td>Range Reduction per Passenger</td>
<td>45 nm</td>
<td>45 nm</td>
</tr>
<tr>
<td>Cabin Comfort Level</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Cruising Speed</td>
<td>3.0 nm/min</td>
<td>3.0 nm/min</td>
</tr>
<tr>
<td>Time to Cruising Altitude</td>
<td>6 min</td>
<td>6 min</td>
</tr>
<tr>
<td>Time from Cruising Altitude to Landing</td>
<td>6 min</td>
<td>6 min</td>
</tr>
<tr>
<td><strong>Passenger Characteristics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aircraft Acceptance</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>ODM Availability Awareness</td>
<td>0.1</td>
<td>0.7</td>
</tr>
<tr>
<td>Mean Commercial Air Access Time</td>
<td>240 min</td>
<td>240 min</td>
</tr>
<tr>
<td>Mean ODM Airport Access Time</td>
<td>70 min</td>
<td>70 min</td>
</tr>
<tr>
<td><strong>Fare Structure</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ODM Base Fare</td>
<td>$25.00/trip</td>
<td>$25.00/trip</td>
</tr>
<tr>
<td>ODM Fare/nm travel distance</td>
<td>$0.91/nm</td>
<td>$0.62/nm</td>
</tr>
</tbody>
</table>

Table 2.4: ODM Attributes, Passenger Characteristics, and Fare Assumptions.
The ODM demands were generated using the AirMarkets Simulator on the hypothetical ODM aircraft. It should be noted that intraurban ODM aircraft options are not considered in this analysis. As revealed by the literature search, there is little empirical data to support the anticipated mode split between autos and aircraft, so exploration of this capability in the context of this study is inappropriate. Further discussion is needed before such can be undertaken.

The results of the simulation are presented with nine values generated by the AirMarkets Simulator. These measures are as follows:

1. **Total Markets Using ODM Service:** As each passenger agent is processed in the simulator, an assumption is made about what fraction of the agents are aware of the existence of ODM service in that market. This fraction is applied to markets where that awareness is the case in the specific simulation run. Over time, awareness fraction is increased to 100% by 2035.

2. **Total ODM Trips:** Total number of trips booked by the simulated passengers in all the markets characterized by 1 above.

3. **Total ODM Passengers:** Number of passengers that the bookings in item 2 represent. Each passenger agent contains one or more individual passengers.

4. **Total ODM Revenue:** Total revenue generated by the booked passenger agents in item 3. Note that the fare for ODM service is the same regardless of how many passengers are in the travel party.

5. **Total Markets Without Nonstop Service:** Total number of ODM markets that do not have nonstop scheduled service.

6. **ODM Only Markets:** Total number of markets counted in item 1 above that are *ODM-only* markets. That is, these are markets where there is insufficient demand to support financially sustainable scheduled service with a 4-passenger aircraft.

7. **ODM Only Trips:** Number of trips in the ODM-only markets that are counted in item 6.

8. **ODM Only Passengers:** Number of passengers carried by the trips counted in item 7.

9. **ODM Only Revenue:** Revenue generated for the ODM only trips.

Each value is the annual result expressed in 1,000s.

These demand simulations have been carried out for three geographic regions: the entire globe, the United States, and India. These regions are defined as follows:

1. **Global Region:** Represents the entire world, and any air travel in any city pair market in the world that could be served by an aircraft with the listed properties. It does *not* represent all the air travel that could exist.

2. **United States:** Represents the air travel that originates in a city inside the geographic limits of the United States, including Hawaii and Alaska. It does not include, however, U.S. possessions such as Puerto Rico.

3. **India:** Represents air travel in the country of India. However, air travel in India is growing at a rapid pace and airports are being built all the time, thus opening new market possibilities. India’s data should be considered only as a baseline for this country since “current” population and economic data for India are still several years old when they become available for simulation use. By 2035, we would expect this problem to disappear.
The demand analysis for 2015 is shown in Table 2.5 below. Table 2.6 gives the estimated results for 2035. The only differences between 2015 and 2035 are population changes and a sharp increase in ODM awareness, from 0.1 to 0.7, a significant increase.

**Table 2.5: 2015 ODM Demand Estimate**

<table>
<thead>
<tr>
<th>Annual Expected ODM Demand (1,000’s) -- 2015 Demand Year</th>
<th>Global</th>
<th>US Origin</th>
<th>India Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Markets</td>
<td>722</td>
<td>239</td>
<td>12.89</td>
</tr>
<tr>
<td>Total Trips</td>
<td>13,657</td>
<td>3,570</td>
<td>212</td>
</tr>
<tr>
<td>Total Pax</td>
<td>20,880</td>
<td>5,452</td>
<td>324</td>
</tr>
<tr>
<td>Total Revenue</td>
<td>$3,076,866</td>
<td>$902,536</td>
<td>$41,599</td>
</tr>
<tr>
<td>Total Markets Without Nonstop Service</td>
<td>398</td>
<td>178</td>
<td>5.17</td>
</tr>
<tr>
<td>ODM Only Markets</td>
<td>343</td>
<td>136</td>
<td>3.97</td>
</tr>
<tr>
<td>ODM Only Trips</td>
<td>564</td>
<td>218</td>
<td>5.94</td>
</tr>
<tr>
<td>ODM Only Pax</td>
<td>865</td>
<td>334</td>
<td>8.89</td>
</tr>
<tr>
<td>ODM Only Revenue</td>
<td>$145,965</td>
<td>$56,731</td>
<td>$1,717</td>
</tr>
</tbody>
</table>

Intraurban markets not included

**Table 2.6: 2035 ODM Demand Estimate**

<table>
<thead>
<tr>
<th>Annual Expected ODM Demand (1,000’s) -- 2035 Demand Year</th>
<th>Global</th>
<th>US Origin</th>
<th>India Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Markets</td>
<td>1,342</td>
<td>480</td>
<td>28.16</td>
</tr>
<tr>
<td>Total Trips</td>
<td>116,577</td>
<td>29,008</td>
<td>2,770</td>
</tr>
<tr>
<td>Total Pax</td>
<td>186,237</td>
<td>46,292</td>
<td>4,425</td>
</tr>
<tr>
<td>Total Revenue</td>
<td>$19,023,605</td>
<td>$5,198,547</td>
<td>$415,570</td>
</tr>
<tr>
<td>Total Markets Without Nonstop Service</td>
<td>873</td>
<td>403</td>
<td>51.08</td>
</tr>
<tr>
<td>ODM Only Markets</td>
<td>924</td>
<td>367</td>
<td>15.22</td>
</tr>
<tr>
<td>ODM Only Trips</td>
<td>4,477</td>
<td>1,737</td>
<td>62.18</td>
</tr>
<tr>
<td>ODM Only Pax</td>
<td>7,165</td>
<td>2,797</td>
<td>98.12</td>
</tr>
<tr>
<td>ODM Only Revenue</td>
<td>$830,483</td>
<td>$324,193</td>
<td>$12,957</td>
</tr>
</tbody>
</table>

Intraurban markets not included
well. However, as shown in Figure 2.6, about one-fourth of all ODM market traffic occurs in the United States, somewhat less than other form of air travel, while a significantly higher proportion of the global ODM only air traffic (up to nearly half) is found in the US. Data for India compared to the global or U.S. totals were not considered in this analysis, given the inadequacy of such information for India.

![Figure 2.6: Comparison of ODM and ODM Only Trips: U.S. versus Global (2015)](image)

In Figures 2.7 through 2.9 the distributions of the length of the ODM trips is shown for each of the three geographic areas. The left-hand graph shows the histogram of the frequency of ODM trips for each length span, expressed in 50 statute mile units. On the right, the cumulative distributions of the trip length are shown. *The results indicate that the international demand for ODM services is vastly larger than the demand in the U.S. This result provides compelling indications of the value of U.S. leadership in developing the ODM industry base and market opportunity.*

These graphs are only for estimated ODM trips in 2015. We have not produced similar analyses for 2035 because that would have required a rather extensive analysis of the projected geographic growth of the area under study. We don't know today what the geographic layout of the world will be in 2035. While the U.S. geography may not change much in the next two decades, such stability in population distributions may not be the case with India and parts of South America, China and Africa, where substantial improvements in infrastructure can be expected. Estimating the geographic distribution of the populations and wealth in these countries, or to even identify and extract existing estimate, is beyond the scope of the current project.
NASA Strategic Framework for On-Demand Air Mobility

Figure 2.7: Global Distribution of Demand by Trip Length (2015)

Figure 2.8: U.S. Distribution of Demand by Trip Length (2015)

Figure 2.9: India Distribution of Demand by Trip Length (2015)
6. Estimated of Demand for Thin-haul Scheduled Service

The demand for travel in thin-haul markets depends specifically on the aircraft being considered. For the purposes of this analysis, a prototypical electric aircraft is used to explore this demand. From a passenger perspective, the fact that it is an electric-motor powered vehicle as opposed to a petroleum-based fuel airplane is largely irrelevant to its potential utilization. (Of course, the climate change and social impact of the implementation of an electric-powered airplane has the potential of being quite dramatic. However, those implications are outside the scope of this exploration.)

The demand for air travel in thin-haul markets must also be expressed differently than that for ODM service because thin-haul service is scheduled service, so it is competing with other scheduled services that might exist in a market. In addition, because the service is scheduled, the specific departure time required by the definition of ‘scheduled’ means that the service will be suitable for some, but not for others, depending on the passenger’s ideal departure time.

Furthermore, while it would be appropriate to estimate the demand necessary to support a specific aircraft, market demand significantly higher than the capacity of that airplane would suggest a larger aircraft would be more suitable. Consequently, two boundaries for demand in a specific market exist. One is a low demand value, below which there are not enough expected passengers to provide sufficient revenue at reasonable prices to support the service; and the other a high demand value, above which there is not enough space on the aircraft to meet the service demand.

A complete analysis of even these simple parameters takes us into a much more complex air travel environment: because we would have to specify other competing scheduled air and ground services and describe significant operational details of the proposed service (aircraft schedule, size, fares, routing, etc.). Such a complex analysis is beyond the scope of this study, primarily because there are literally thousands of possible combinations that can be accommodated.

To best accommodate the challenges of estimating thin-haul demand under these conditions we make a series of simplifying assumptions that fit the properties of the aircraft defined by NASA while meeting reasonable conditions for a scheduled service. We believe that the data provided by NASA and the use of these data in the AirMarkets Simulator provide valuable probabilities of demand for inter-urban ODM service under the assumptions available.
Table 2.7: Attributes, Characteristics and Fare for 9-Passenger Electric Aircraft

Table 2.10 gives the attributes, characteristics and fare parameters associated with the hypothetical electric airplane mentioned above. There are several assumptions made with this data. The first is that the Availability Awareness, which is the probability that a travel party will know of the existence of the service, is now set to 1.0. This is because scheduled air service is automatically incorporated into all schedule information mechanisms now available, such as Expedia. It is thus reasonable to consider awareness of any scheduled service, regardless of source, to be universal among potential air travelers.

A second consideration is that since the service is scheduled, tickets will be sold on a per-person basis for this form of air travel (like all other scheduled services), as opposed to the situation with ODM or ODM-only air travel, where the fare is the same regardless of the number of individuals in the travel party. Therefore, the per-ticket fare is the sum of the base fare plus the fare per nautical mile for each passenger on the flight. The passenger willingness-to-pay for scheduled service has been the subject of extensive research by AirMarkets Corporation. After the examination of more than 18,000 city pair markets around the world, the distribution shown in Figure 2.10 seems to fit most markets. The graph in this figure shows the percent of tickets sold at or below the fraction of the maximum price given on the horizontal axis. For example, the sharp rise at about 0.15 price fraction is where economy class tickets are priced in the market. The slowly rising, almost horizontal part of the graph in the upper right represents the very expensive seats, including first class sold at the last minute. In many cases, the maximum price is as much...
as 20 times the average price. (This distribution is referred to as a modified Frechet probability distribution, and is described in more detail in Appendix 5).

Figure 2.10: Distribution of Tickets for Air Service as a Function of Maximum Ticket Price.

Assuming this ticket price distribution holds in markets that have sufficient demand to support thin-haul scheduled service, then the per-passerenger price would need to conform to this fare distribution. This means it is necessary to adjust the demand to accommodate the price structure implicit in the aircraft fare assumptions and the increased cabin comfort level.

Another consideration is that, for scheduled service, the maximum range for a specific route can be no longer than the maximum range of the aircraft fully occupied. Scheduled air service implies that the scheduling cannot depend on the airplane load factors. (Of course, it is theoretically possible to use an aircraft with a given capacity as a scheduled aircraft in any market of any length, up to the aircraft maximum, by limiting the number of allowable passengers on a scheduled flight, but that probably is not a wise business policy.)

As discussed above, we also need to specify a minimum and maximum expected market demand. The maximum is straightforward: nine passengers in the 2015 estimate and ten in the 2035 estimate. The difference is that in 2035, the aircraft is assumed to be operated autonomously, thus providing an additional passenger seat. For the minimum market size, we shall use five passengers. Below this number we are at the demand levels used for the ODM analysis earlier, and thus the thin-haul demand would be, in a sense, complimentary to the ODM analysis.

Finally, we need to make a distinction for scheduled service between direct market demand and connection demand. In the ODM analysis, we considered only direct demand between an origin city and a destination city. There were no stops assumed to occur between the two. It is natural to assert that a small scheduled service would have as a major component of its utilization the movement of individuals from more sparsely populated areas to commercial airports in larger
cities, from which a passenger could continue his journey to other destinations beyond the range of the thin-haul service. In fact, within the continental United States, there is no general aviation airport that is more than 375 nautical miles from a major facility that has commercial air service. Once passengers are at any of the world’s commercial airports, they can book flights and connections (although not necessarily convenient ones) to reach any other commercial airport in the world. In other words, the world’s commercial air travel is everywhere connected. This means that, unlike the ODM service, a significant portion of the demand for thin-haul will arise from the need to go to or from a commercial airport. We shall refer to this demand as connection demand.

Thus, there are two forms of demand relevant to the thin-haul case: direct demand, which is the expected number of pags (passenger groups traveling together) moving from a fixed origin to a fixed destination via the thin-haul service; and connection demand, which is all other demand originating or terminating in a specific city that must move through a nearby commercial air facility.

For direct demand, it is assumed that the scheduled time for the service is the optimal time of day, yielding the highest expected travel demand in that market. This expectation can be estimated by application of the ideal schedule time probability distributions that result from the DCM and ideal schedule delay functions that support the AirMarkets Simulator. All other demand is considered connection demand.

Table 2.8 shows the estimated direct and connection demands for the continental United States. This geographic area was selected because the availability of other modes of travel, specifically private automobiles and bus/rail scheduled services, exists virtually universally in the 48 contiguous states. This, then, allows the AirMarkets DCM to be extended to these other modes with reasonable validity, and thus provides supportable estimates of the demand probabilities associated with estimated direct demand. Also, note that the estimates for ODM demand were in units of 1000, which is not the case here.

<table>
<thead>
<tr>
<th></th>
<th>2015</th>
<th>2035</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Markets</td>
<td>484</td>
<td>458</td>
</tr>
<tr>
<td>Direct Market Annual Demand Estimate</td>
<td>952,544</td>
<td>928,499</td>
</tr>
<tr>
<td>Direct Market Daily Demand Estimate</td>
<td>2,609</td>
<td>2,544</td>
</tr>
<tr>
<td>Connection Origins</td>
<td>650</td>
<td>684</td>
</tr>
<tr>
<td>Connection Annual Demand Estimate</td>
<td>3,019,880</td>
<td>3,340,601</td>
</tr>
<tr>
<td>Connection Daily Demand Estimate</td>
<td>12,275</td>
<td>13,579</td>
</tr>
</tbody>
</table>

**Table 2.8: Estimated Thin-haul Demand, Continental United States**

The reader will note a reduction in the direct market demand in 2035, even though the capacity of the aircraft increases by 11%, and there is an overall population (hence demand) increase of about 13% in the U.S. from 2015 to 2035. This is because the range of the aircraft is reduced from 400 nm to 375 nm (due to the load increase). Note that for the connection demand, however, the 2035
7. Potential for Using New Data Sources to Model Air Travel Demand

As the literature review revealed, most current models and studies of air passenger demand rely on data that are obtained from traditional data sources and data collection techniques. Traditional survey data that provide the mode detailed data on air passengers are often expensive to collect and infrequently collected. Given the explosion of modern digital data sources (such as credit card transactions, cell phone traces, etc.) it may be feasible and cost-effective to use alternate data sources to model air travel demand. These data can potentially complement (or, depending on the application, replace) air passenger surveys.

For example, AirSage is a company that works with a cell phone provider to generate cell-phone data from spatial and temporal perspectives. AirSage data have been successfully used in the past to model intricate demand (across multiple modes of transportation). Specifically, AirSage has modelled the number of vehicle and air trips taken in the Atlanta – Charlotte corridor (This was for a high-speed rail feasibility study in the area). AirSage has also worked with one of the airports in the Washington DC area to develop a catchment area, thus identifying the departure locations of residents using their airport.

At a high level, the AirSage data are just a series of “location points in time.” The locations are determined by triangulations from cell phone towers. (Depending on where you are in the “triangle” for the cell phone towers, you may have different accuracies). There are some parts of the U.S. that have higher accuracies than other areas (higher accuracy is typically seen where towers are close together, as in dense urban areas). There are various ways that a “location point” can be generated. Basically, if you do anything with your cell phone (check for mail, make a phone call) a location point is generated. If you have your cell phone on “automatic” mode, (meaning you automatically receive emails) then location points are generated several times a minute.

AirSage has developed several algorithms that apply to these data to identify home and work locations. For example, if you see a cell phone at the same location every evening for eight hours at a time, you can deduce that is a home location. Similarly, if you see a cell phone at the same location during weekdays for more than five or six hours, you can be reasonably certain it is a work (or school) location. AirSage has developed several “data extraction tools” that can be thought of as coding logic they apply on the raw data to support specific modeling applications. In the case of long distance travel, they have developed “stop logic” that identifies places in which individuals likely stayed overnight or points of interest they visited during a long-distance trip. AirSage can also identify the “furthest location” that was visited. In this application, the company may have begun by identifying the population they were studying (e.g., all people with home locations in the Atlanta areas). They then “drew a GIS boundary” around this population (e.g., a boundary that was say 250 miles away) and identified any points that crossed this boundary (indicating a long-distance trip). Different stopping logic is usually applied depending on the application. In this case, for a trip of four hours by car one way (assuming at 60 mph), a criterion is needed to determine whether a stop was likely longer than a 15-minute rest stop or one hour lunch break, versus an overnight stop or a several-hour visit to a tourist site.
NASA Strategic Framework for On-Demand Air Mobility

The “stopping logic” can be customized (and often must be) depending on the problem application. The above logic is for vehicle trips, but now consider air trips. By using Zip Code or other data, it is possible to characterize people arriving at an airport as either resident or visitor. It is also possible to determine if residents if they came to the airport from home, work or another location. The trip to the airport is a “drop off” if the cell phone passes through a “GIS boundary” (in this case, curbside at the airport or potentially cell phone lots) and leaves within a short period of time. Distinguishing between airport employees and travelers by noting which cell phones regularly stay in the airport might be problematic since it could be difficult to separate pilots and flight attendants, for example, from frequent travelers.

The scenario just presented illustrates how new emerging data sources can be used to model air travel demand. As with any data source, there are important limitations to keep in mind. Cell phone data are intentionally not accurate to a level that would allow for identification of a specific GIS point (or home). AirSage can only give location data at a “census level,” which is more detailed than zip code positioning but is not at the street level. Note, however, that detailed location information and socio-economic information can be obtained through the passenger surveys. Also, while it is possible to obtain cell phone data for different time periods, to maintain confidentiality, the cell phone identifier is scrambled every 30 days (or month). Thus, the AirSage data should be used as a cross-sectional dataset, or “separate” datasets that can be pulled for different months. They cannot be used for time-series analysis (outside of a month). These restrictions are some reasons why cell-phone data are likely to complement, but not replace, traditional air passenger surveys. See [10, 11] for additional information on how AirSage has used cell phone data for modeling long-distance trips across modes. The important features of improved data on consumer behaviors include such parameters as preference for traveling individually or in groups as a function of age cohort; the preference for use of telepresence as a substitute for travel; the preference for air versus ground as a function of availability of self-driving cars and trip distance, for examples.

8. Forecast Results

Autonomous CTOL Air Taxi ODM

Assuming it is useful to compare future CTOL air taxi ODM aircraft production needs in the context of current technologically advanced single-engine piston aircraft, the following forecast results are offered:

- The conservative near-term demand for ODM aircraft production to satisfy projected U.S. consumer trip demand (~2,000 aircraft) is larger than the current U.S. industrial production in General Aviation (~1,000 piston airplanes) (https://www.gama.aero/media-center/industry-facts-and-statistics/shipments-billings)

- In the farther term, the very conservative demand for CTOL air taxi ODM travel increases the demand for aircraft by about 1,000% (10X), to about 20,000 aircraft.

- The global demand for trips (operations) and aircraft to service the demand is about 400% (4X) larger than U.S.-only figures.

- India would experience growth in demand from 2015 to 2035 by about 1,300% (13X) because of advancing economics and ODM technologies.
The CTOL aircraft performance required to satisfy the distribution of trip lengths appears achievable within the anticipated power- and energy-densities of electric propulsion advances underway today.

These results do not include Thin-Haul Commuter demand or urban VTOL demand for aircraft, which will increase the trip and aircraft demand levels significantly.

Autonomous Thin-Haul ODM Commuter

Thin-Haul demand modeling results need to be put into context. For example, in 2035, the FAA forecasts the U.S. commercial fleet to increase to 8,414 aircraft. Also, for 2036, the FAA forecasts about 71 million “Itinerant Airport Operations” in the U.S., which includes itinerant air carrier, commuter, air taxi, general aviation, and military operations at all airports. In this context, the following forecast results are offered:

- The expected ~4.2 million trips (operations) in 2035 by Thin-Haul represents ~6% of the forecast commercial airline fleet operations.
- The estimated Thin-Haul fleet size represents ~7% of this forecast commercial operations. This size of Thin-Haul fleet also represents about 150% of an earlier FAA forecast fleet size for regional/commuter aircraft of less than 9 passengers.
- The results do not account for growth in demand, operations, or fleet size that would be driven by advances in electric propulsion system performance and costs.

9. Summary of Findings and Recommendations

The following is a series of findings and recommendations supported by the assessments of this chapter:

Finding 2.1 – Passenger demand for air travel and the translation of that demand to numbers of aircraft required point to a significant expansion of the U.S. small aircraft manufacturing and transportation services industry.

Finding 2.2 – Significant gaps exist in available transportation consumption patterns that are needed to serve as a foundation for improved understanding of how ODM consumers might behave in the future including for example, self-driving cars.

Recommendation 2.1 – NASA should advocate that the U.S. DOT and the FAA initiate new data collection efforts to support the development of future demand models that accurately captures how individuals make travel decisions now and may in the future. The effort should include the emerging modal options such as autonomous ODM.

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22 [https://www.faa.gov/data%5Fresearch/aviation/aerospace_forecasts/2005-2016/media/Table29.PDF](https://www.faa.gov/data%5Fresearch/aviation/aerospace_forecasts/2005-2016/media/Table29.PDF)
10. References


Chapter 3 – ODM Enabling Technologies and Gaps Analysis

Prelude

New ideas pass through three periods:
1) It can’t be done.
2) It probably can be done, but it’s not worth doing.
3) I knew it was a good idea all along!
Arthur C. Clarke

NASA’s unique power in the role of advancing technologies lies in the Agency’s ability, through influence and brand, to legitimize the need for solutions to problems we never knew we had; through science and engineering capacities to provide existence proofs of those solutions; and through technology portfolio investments, to stimulate the industrial capacities to create new jobs and wealth through new products and services for society.

1. Introduction

Our nation faces daunting challenges in areas of efficiency, accessibility and affordability of intracity as well as intercity transportation. As the nation’s highway system has matured and filled, beyond capacities in many places, the excess costs in time and energy expended in ground travel continues to rise. In 2013, traffic congestion robbed the U.S. economy of $124 billion. Furthermore, the growth in cost for maintaining the much-stressed U.S. road transportation infrastructure represent a heavy burden on the economy. Failure to fully explore alternatives to mitigate that burden represents a threat to the nation’s future growth. The need is great for technology-enabled solutions for personal mobility that are affordable, efficient, clean and safe. Increased utilization and democratization of the “third dimension” in our Nation’s airspace could provide these required personal mobility solutions.

Increased utilization of our Nation’s airspace has remained limited by four major factors: requirements for extensive pilot training, cost of aircraft and fuel, accessibility to specialized airport infrastructure, and FAA airworthiness, pilot training and certification, and airspace operations regulations. Several technological advances and societal trends, coupled with enlightened regulatory changes, could help mitigate these factors in the future. Advances in vehicle autonomy, led by the automotive (e.g., Google car) and UAV industries promise to make personal air travel as simple to the user as automotive travel is today, greatly reducing the need for extensive and expensive pilot training. Advances in hybrid and electric propulsion, new manufacturing and materials technologies, innovations in vehicle configurations, as well as the economics of reduced cost through production economies of scale could lead to significant reductions in Thin-Haul, urban VTOL, and personal aircraft costs. In addition, increased adoption of smart phone, internet-based ride sharing approaches (e.g., Uber) currently in use for automobiles holds the promise to increase greatly the utilization rate of individual aircraft, thereby reducing cost per passenger mile. Advances in safe, quiet VTOL technologies such as distributed electric
propulsion would help obviate the need for expensive and expansive airport infrastructure and allow more local and distributed take-off and landing sites (e.g., utilizing neighborhood heli-pads or roadside rest areas). Increased market pressure for wide-scale use of UAVs is requiring the FAA and local governments to alter existing regulations to adapt to the inevitable democratization of the airspace. Advances in automation of air traffic management, autonomy of vehicles, air-to-air and air-to-ground broadband WiFi, trajectory-based optimization of flight path economics and safety, and sense-and-avoid technologies will enable an adaptation of future FAA regulations to new technological realities. Current NASA research includes exploration of moving airspace separation, sequencing, merging, and spacing functions from the ground to the cockpit, for example. A future FAA regulatory framework might be more similar in function to the Federal Highway Administration in certification of vehicles and defining and enforcing “rules of the road” with much of the collision avoidance decision making being distributed to the local networks of vehicles.

*Focused technology investments by the U.S. government coupled with infrastructure investments and planning by federal, state and local authorities are essential to enabling this vision. However, an enlightened, adaptive regulatory framework is perhaps even more essential to maintaining U.S. leadership in the emerging UAV and on-demand mobility fields. An ability to test the advancing technologies and vehicle configurations in the relevant National airspace would enable U.S. companies to be more likely to locate their manufacturing, testing and operations domestically to the benefit of the U.S economy and U.S. consumer, and U.S. communities.*

2. Technology Assessment Process

To develop the findings, recommendations and assessments contained in this chapter, authors of this report have conducted the following process:

a. Carefully examined NASA’s ODM Technology Roadmaps and attended the various government industry workshops that led to their development.

b. Reviewed plans for NASA’s LEAPtech, SCEPTOR, and Maxwell X-57 projects to test ODM technologies.

c. Interviewed the key NASA technical leaders and contributors to the development of the roadmaps and ODM flight projects.

d. Held discussions with key industry personnel developing ODM vehicles and technologies.

e. Researched existing and planned technology development efforts by DoE, DoT, FAA, and the automotive and UAV industry that could be leveraged for ODM applications.

f. Reviewed existing NASA ARMD technology projects that could benefit from and / or be leveraged by ODM technology development efforts.

3. NASA ODM Roadmap Development Summary and Analysis

Over the past 18 months NASA, in collaboration with the National Institute of Aerospace, has conducted a series of government/industry workshops to identify the key technologies and capabilities required to enable transformational ODM systems to be developed and deployed. The agendas, presentations and results of these workshops are all archived at the web site:

[http://www.nianet.org/ODM/roadmap.htm](http://www.nianet.org/ODM/roadmap.htm)
The initial workshop was an “On-Demand Mobility Forum” conducted in Oshkosh, Wisconsin, July 21-22, 2015. The primary purpose was to acquaint the attendees of the Experimental Aircraft Association (EAA) Oshkosh AirVenture Show with studies that illustrate how potential new technologies and approaches can enable a transformational On-Demand Mobility capability. There was significant enthusiasm expressed by over 50 attendees, excellent industry suggestions were received, and new industry members were added to the ODM community.

The second workshop was an “On-Demand Mobility Roadmapping Workshop” conducted in Kansas City, Missouri, October 21-22, 2015. The Kansas City venue allowed significant participation by the FAA Small Airplane Directorate to discuss regulatory, flight operations and airspace issues. A wide variety of small and large companies and universities presented ODM-relevant technologies under development. The group decided to begin the development of three different categories of roadmaps: Simplified Vehicle Operations and Airspace; Electric Propulsion; and Manufacturing, Integrated Structures and Community Impact. Break-out sessions were then held for each of these groups to identify relevant technologies. A series of weighted Figures of Merit for ODM systems were also developed (Figure 1), and relevant technologies were mapped to them. There were close to 100 attendees, as the ODM community of practice continued to grow. Figure 1, summarizing prospective figures of merit for ODM transportation, was presented to the government, industry and academia attendees. The purpose was to gather a sense of the community around the value of this approach to understanding priorities for ODM metrics and goals. The chart was well-received for this purpose.

Figure 1. Figures of Merit for ODM

An additional “ODM and Emerging Technology Workshop” was conducted in Arlington, VA March 8-9, 2016. The Washington, DC venue allowed significant participation by FAA and NASA ARMD senior leadership. In addition to presentations by key ODM vehicle and technology developers (as well as NASA and FAA), results of promising market studies were presented for VTOL and CTOL systems. Potential ODM system operators, such as Cape Air and Imagine Air also gave presentations that showed the possible benefits of ODM research to their business plans. NASA presented its ODM technology planning and project results, and FAA presented thoughts on regulatory, certification and airspace challenges and potential solutions. Technology roadmapping discussions were held and plans finalized for working groups to develop
roadmaps. There were over 150 attendees, with even more organizations and companies being added to the community.

The fourth and Final workshop was an “On-Demand Mobility Report Out” conducted in Hartford, Connecticut, September 29-30, 2016 in conjunction with the SAE 2016 Aerospace Systems and Technology Conference. The primary purpose of the workshop was to present the final draft of the ODM technology roadmaps and updated mission studies. The three technology roadmapping working groups were dissolved, and two new mission working groups—Thin-Haul Commuters and Urban VTOL Air Taxis—were created. These roadmaps (Figures 2, 3, 4, and 5) provide technology projects, studies, and capability developments that are time-phased to feed into several ODM flight demonstration projects. Proposed flight demonstration projects, to be closely coordinated with the FAA and performed in partnership with industry, are in support of two major mission classes: thin-haul commuter vehicles and urban VTOL vehicles.

![Figure 2. Simplified Vehicle Operations and Airspace Roadmap, Part 1](image-url)
Figure 3. Simplified Vehicle Operations and Airspace Roadmap, Part 2

Figure 4. Electric Propulsion Roadmap
Figure 5. Manufacturing, Integrated Structures, and Community Impact Roadmap

Although the current roadmaps presented above provide a useful starting point for a national ODM effort, additional immediate work along the lines presented below need to be performed prior to implementation, led by NASA, in collaboration with the FAA, industry and academia.

- Most of the individual technology projects shown on each of the roadmaps have only been mapped out at a very high level. Much more detailed project development planning needs to be performed immediately to assess the cost, timing, risks and quantitative benefits of each project.
- There has also been no detailed assessment of relative priorities based on the cost-benefit of the proposed activities. We offer an initial set of high priorities activities.
- Although the proposed set of roadmap activities is quite comprehensive, from our assessment, several gaps remain.
- Given the limited NASA budget available and the number of key stakeholders, we recommend NASA conduct an immediate analysis to determine the activities ARMD should lead vs. leverage vs. collaborate. For example, battery development will likely be funded by industry and the Department of Energy, with NASA having a role of following and leveraging developments.
- We offer initial recommendations for NASA’s roles with respect to industry and other government agencies.
- As ODM-focused efforts are integrated into ARMD’s technology development mission, careful consideration needs to be given to coordinating them in an integrated fashion and collaborating with industry. We will finally offer a few thoughts on options in this area as well.
4. ODM Technology Roadmap Assessment

In general, we find the roadmap development process, including the several workshops, to be well thought out and executed. Specifically, NASA should be commended for including so many outside organizations, companies and other government organizations in this highly collaborative process. The integrated ground and flight development projects appear to be feasible and appropriate in content and timing. This process also led to the creation of a very large and diverse community of practice that includes technology developers, vehicle developers, vehicle operators and government regulators. The organizations vary from small start-ups to the world’s largest aerospace companies, foreign and domestic, as well as several government agencies. Thanks to the efforts of NASA, the NIA, and the AIAA Transformational Flight Program Committee, this community of practice has now reached a critical mass and is attracting national and international attention as well as private capital. Now is the time for NASA to continue to lead in this expanding arena, by beginning the detailed planning and execution of these roadmaps as a primary part of ARMD’s technology development mission.

5. Priorities, Gaps and Recommendations

ARMD obviously has limited budgets available and must prioritize technology investments, partner with industry, and rely on other agencies to lead some of the activities. After carefully examining the roadmaps and understanding the mission requirements, we would recommend making the following technology and capability development activities listed below a high priority (although not all would be led by NASA):

- Airframe Integrated Distributed Electric Propulsion
- High Specific Energy Long-Life Batteries with Rapid Recharging Capability
- High Voltage Hybrid-Electric Power Systems and Range Extenders with Low EMI Interference
- Adaptive High-Reliability Electric Motor Control Systems
- Multifunctional Structures/Thermal Management/Energy Storage Systems
- Electric Propulsion Standards (Reserves, Control, Charge Management, Testing)
- Highly Augmented Flight and Trajectory Control With Efficient On-Demand Routing and Sequencing
- Highly Reliable Automated Detect, Sense and Avoid Systems That Allow Critical Human Intervention
- Beyond NextGen Airspace Systems Able to Accommodate Orders of Magnitude More Vehicles
- Certification For Autonomous Operations
- Low-Altitude Full Aircraft Parachutes and Energy Absorbing Emergency Recovery Systems
- VTOL Advanced Noise and Propeller Control Technologies and Modeling
- Damage Tolerant, Self-Healing, Smart and Morphing Structures with ISHM
- Anti-Ice Coatings and All-Weather Systems
- Flexible Robotic and Additive Manufacturing

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Gaps

Although the proposed set of roadmap activities is quite comprehensive, several gaps remain that will require additional investments in technologies and capabilities by NASA or its partners. The gaps include the following technical fields:

- Cybersecurity/Trusted Communication
- Consumer Acceptance/Human Factors Assessments – Ride Quality, Acoustics, Perceived Safety
- Vertiport / Vertistop Infrastructure – Including Rapid Charging Stations
- Smart/Reliable Sensors to Enable Autonomous Operations and Self Separation
- On-Board Weather Detection and Robust Adaptation
- Air Vehicle Design Optimization (Speed, Range, Payload) as a Function of Latent Demand Characteristics
- High-Data-Rate Connected Aircraft for Airspace Operations
- System and Subsystem Certification Requirements for automation and more autonomous capabilities (drawing on the automotive industry advancements)
- Robust Control Architectures to Engine-Out, Gusts, Weather, Obstacle Avoidance, Etc.
- Human/Machine Interfaces for Emergency Pilot/Passenger Intervention
- Intermodal Network Real-Time Optimization Architectures and Approaches
- Active Noise Control and Acoustic MetaMaterials for Cabin and External Noise Abatement
- Airspace Architectures/Flight Rules for ODM
- “Pilot” Training/Certification

Partnership Recommendations: Given the limited NASA budget available and the number of key stakeholders, we recommend NASA do an immediate analysis to determine for which activities ARMD should lead versus leverage versus collaborate. NASA’s ODM efforts will benefit from the confluence of technologies and capabilities being developed by others, such as: The DoT and automotive industry, the DoE and power industry, the UAS industry, Uber, and the traditional and non-traditional aerospace industry.

Over the past several years, automobiles have become increasingly autonomous with the advent of Google Car, Tesla, Uber, and efforts by traditional automotive companies. An entire industry of second-tier and third-tier suppliers have also emerged that develop the software, algorithms, sensors and hardware to support these systems. In addition, the Society of Automotive Engineers (SAE), the International Standardization Organization (ISO), and the DoT are developing internationally harmonized standards for autonomous systems and operations. NASA can learn from and leverage these activities by hosting workshops and partnering with these companies and organizations. They will be leading the way for the ODM industry in developing relevant sensors, algorithms, cybersecurity approaches, human-machine interfaces, connected vehicles, highly reliable architectures, path optimization within traffic networks, certification standards and approaches, and regulatory frameworks. There are many similarities in automotive and ODM autonomous system requirements, and autonomous automobiles will be developed and deployed years in advance of ODM systems, allowing great opportunity to learn lessons from successes and failures.

The DoE is funding a program to develop the technologies to enable batteries with specific energy capabilities of 500 Wh/kg. It recently selected an industry consortium, Battery500, led by the
Pacific Northwest National Laboratory (PNNL) to lead this activity. Over the past several years Tesla and other automotive companies have demonstrated the technical and market feasibility of electric automobiles with rapid recharging capabilities. Several well-funded battery companies (including Tesla) are developing technologies to achieve higher than 500 Wh/kg specific energy as well as working on rapid recharging and longer life-cycle batteries. Smart energy storage and management systems are also being developed and applied from homes to the national energy grid. Several traditional aerospace companies are developing high-voltage hybrid-electric generators and power systems for aviation applications which could be used initially in place of fully electric vehicles. These technologies have great applicability to future ODM systems and can be leveraged by NASA with the appropriate partnerships.

The Unmanned Aerial Systems (UAS) industry has rapidly grown to be an over $10 billion industry in a few years and could double again in the next few years. Integration of UAS into the national airspace is perhaps the largest constraint preventing it from growing even faster. As the FAA works with the UAS industry in solving these issues and establishing viable technological solutions and a regulatory framework, these same advanced technologies can be leveraged to benefit the ODM industry. In fact, most required ODM technologies have synergy with UAS; however, investments in UAS technologies will not be sufficient to enable ODM because of the many unique requirements of ODM systems. NASA ODM technology development can take advantage of UAS industry advancements in autonomy, sensors, algorithms, cybersecurity, electric VTOL propulsion, configuration approaches, connected vehicles, and airspace integration leadership. The FAA can also track and learn from other countries’ best practices for UAS airspace integration (e.g., Europe, Australia, China, Singapore and Israel). Hence, partnerships with the emerging UAS industry are essential.

The automotive ride-sharing company Uber recently published an excellent white paper called “Elevate” on their vision for ODM operations, including the major technical, regulatory and economic challenges (https://www.uber.com/elevate.pdf). Uber has established and funded a group to perform additional ODM studies and analyses and plan to convene a global Elevate Summit in the Spring 2017 to bring together key players to coordinate efforts. Ride sharing technologies like Uber’s will be essential to the initial deployment of ODM systems for commuting due to the high ownership costs. NASA should consider partnering with Uber for the upcoming Elevate Summit and other workshops and take advantage of their expertise in ride sharing algorithms, networks, operations economics and customer experience.

**Proposed NASA ODM Technology Development Approach**

As ODM-focused roadmaps activities are incorporated into ARMD’s technology development mission, careful consideration is required for coordinating them in an integrated fashion with other ARMD projects. Many of the identified technology needs for ODM are already being addressed to varying degrees (sometimes with different requirements) in other ARMD projects, such as: rotorcraft, structures and materials, acoustics, autonomy, etc.

Investments in many of the ODM technologies identified by the roadmaps and gap analyses will have “scale-up” benefits to larger commercial and general aviation aircraft. For example, investments in better batteries will benefit auxiliary power systems for larger commercial aircraft and provide augmentation during high-power demand (e.g., take-off and landing) so that jet engines do not have to be over-designed for maximum thrust, which would save weight and boost fuel efficiency. Distributed electric propulsion could allow wing tip propellers that reduce vortex-
induced drag, thus saving fuel. This technology could also be applied to other areas of the vehicle, including improved aerodynamic performance. The Thin-Haul ODM requirements may offer the most relevance for scale-up to larger commercial aircraft applications. The major technologies investments we identified as having significant scale-up synergy include the following:

- High Specific Energy Long-Life Batteries with Rapid Recharging Capability for Auxiliary Systems
- Hybrid Electric Propulsion/Power Systems
- Higher Levels of Autonomy for Reduced Crew Operations
- Multifunctional Structures/Thermal Management/Energy Storage Systems
- Highly Augmented Flight and Trajectory Control with Efficient On-Demand Routing and Sequencing
- Damage Tolerant, Self-Healing, Smart and Morphing Structures with Integrated Structural Health Management (ISHM)
- Anti-Ice Coatings and All-Weather Systems
- Flexible Robotic and Additive Manufacturing
- Trusted Communications/Cybersecurity
- High-Data-Rate Connected Aircraft for Airspace Operations

Similarly, investments in many of the ODM technologies identified by the roadmaps and our gap analysis will have “scale-down” benefits to small and large UAS. In fact, most required ODM technologies have synergy with UAS; however, investments in UAS technologies will not be sufficient to enable ODM because of the many unique requirements of ODM systems. NASA ODM technology development will have synergy with the UAS industry in multiple ways including autonomy, sensors, algorithms, cybersecurity, electric VTOL propulsion, configuration approaches, connected vehicles, and airspace integration. The urban VTOL requirements may offer the most relevance for scale-down to smaller vehicle applications. There will of course be different certification requirements due to the human passengers/pilots, but UAS can be used to demonstrate many of the required operational technologies.

Strategic Implementation of ODM

After a thorough review, we strongly believe that NASA ARMD’s Strategic Implementation Plan provides an excellent framework through which to organize our nation’s investments in critical aeronautics technologies. The approach to having strategic thrusts and supporting programs is very well thought out, and the current investments are highly coordinated with industry’s future needs. We noted many similarities between OMD and the Supersonics Strategic Thrust/Project:

- Promising but Untested Markets Exist
- Major Systems Certification/Regulation Issues Exist (e.g., Noise, Airspace, Propulsion)
- Technological Hurdles Exist that NASA Can Help Overcome (e.g., Noise, Propulsion, Airframe Integration)
- NASA has Unique Systems Analysis and Configuration Modeling Capability/Expertise
- Flight Test Demonstrators are necessary
- Motivated U.S. Industry Partners Exist and Want NASA’s Help
- International Competition, Balance of Trade Issues Exist

We also noted that a strategic thrust already exists for Autonomy that is highly synergistic with ODM and UAS needs, yet there has not been a focused Autonomy project effort. Instead,
autonomy-related research has been spread across multiple projects. These observations lead U.S. to recommend making a separate ODM/Autonomy/UAS Strategic Thrust and Project, like Supersonics. The ODM technology challenges have significant synergies with current and planned autonomy efforts, and all of these investments would be highly applicable to UAS as well.

6. Summary of Findings and Recommendations

The following is a series of findings and recommendations supported by the assessments of this chapter:

**Finding 3.1** – The current NASA-led ODM Roadmaps are an excellent starting point for joint technology development within NASA and the ODM community.

**Finding 3.2** – The process used to develop the NASA-led ODM Roadmaps was inclusive, collaborative and thorough, and they led to the establishment of a large, diverse ODM community of practice.

**Finding 3.3** – Several gaps exist in the current ODM roadmaps as identified in this chapter, with the most critical being in the area of cybersecurity and trusted communication.

**Finding 3.4** – Investments in ODM technologies and capabilities will have many scale-up benefits to commercial and general aviation aircraft and scale-down benefits to small and large UAS.

**Recommendation 3.1** – NASA should establish a separate OMD project and alter Strategic Thrust 6 to be an ODM/Autonomy/UAS Strategic Thrust

**Recommendation 3.2** – NASA should host a workshop and establish strategic partnerships with key automotive companies and organizations developing standards and technologies for autonomous vehicles due to the tremendous synergy with ODM.

**Recommendation 3.3** – NASA should host a workshop and establish strategic partnerships with the DoE and key battery and automotive companies developing high-energy-density battery technologies and charging systems and standards due to the tremendous synergy with ODM.

**Recommendations 3.4** – Consistent with the approaches outlined in Chapter 5, NASA should consider establishing a non-profit-led Investment Public-Private Partnership (IPPP) with key ODM-related companies and government agencies to coordinate ODM technology and system development.

**Recommendation 3.5** - Given the limited NASA budget available and the number of key stakeholders, we recommend NASA conduct an immediate, comprehensive analysis to determine which activities ARMD should lead versus leverage versus collaborate.
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Chapter 4 – Organizational Contributions and Roles

Prelude

“The real story of the automobile is more wonderful than the fanciful tale of Aladdin's Lamp. It is more romantic than “Romeo and Juliet.” It is more important than the history of anything else in the world, because it deals with the latest and by far the greatest phase of the art of transportation. Transportation has been the ladder upon which humanity has climbed, rung by rung, from a condition of primitive savagery to the complex degree of civilization enjoyed by man in the twentieth century.”

James Rood Doolittle

These words, published in 1916, could be re-purposed today as relevant to the vision for On-Demand Mobility: “... for anyone to fly anywhere, anytime, for productivity or pleasure...” Transformative leaps in quality of life, standard of living, and economic opportunity have been propelled throughout history by advances in personal connectivity, whether by transport or communication. These advances, in turn, have been enabled through investments by both industry and government in research, technologies and infrastructure. From time-to-time, a sort of convergence of synergistic technologies evolves to a critical mass at a time of societal need. Now is one of these times. There is today an unprecedented aviation innovation landscape developing. The number and diversity of innovators and entrepreneurs in this landscape have parallels in the early days of the automotive industry. These convergences have repeated themselves in shipping, rail, telephone, airline, computing, and commercial space industries. As in the past, the U.S. is in a unique position to lead in another transformative advance in personal connectivity.

1. Introduction

The U.S. created the revolution in air transportation, but today our nation is at significant risk of losing its global competitive advantage as related to transportation innovations such as posed by the vision for On-Demand Mobility. Other nations are aggressively challenging U.S. leadership in technology development, regulatory standards, business model innovation, and infrastructure investments related to innovative forms of air transportation. This chapter summarizes the stakeholders, collaborators and contributors to the ODM vision, as well as the role of international collaboration. In addition, gaps between the existing participants in the ODM vision and potential

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The capacity to achieve the vision for On-Demand Mobility requires a systemic and interdependent set of advancements by a range of participants in several domains, beginning with technology and spreading to infrastructure, business models, partnerships and collaborations, marketplace acceptance, regulation, finance and national policy. The participants include stakeholders, collaborators and contributors from federal, state and local governments; and from industry, academia, and the research and development community. Each of these domains must be engaged in strategy, advocacy and development of their respective contributions.

**Existing Stakeholders, Collaborators and Contributors**

This section summarizes existing domestic and international players and their enabling roles and responsibilities for organizations that serve as stakeholders, collaborators and contributors to the ODM value proposition.

Because of steadily advancing technologies affecting aircraft propulsion, automation, materials, manufacturing and airspace management, entrepreneurial thinkers in both industry and government have developed a spectrum of concepts and technology components that could enable the emergence of on-demand mobility using aircraft. The following organizations represent potential stakeholders, collaborators and contributors to the evolution of ODM system innovations, both domestic and international. While the list presented below is representative, it is not totally comprehensive regarding the spectrum of organizations capable of contributing to ODM system innovation and advancement. These organizations represent significant, even unprecedented, opportunities for collaboration in pre-competitive technology and policy development that would accelerate the ODM market opportunities.

**Industry Organizations**

- A³ Airbus Ventures (Vahana Sky Taxi Project), [https://vahana.aero/welcome-to-vahana-edfa689f2b75#.4jh14wicm](https://vahana.aero/welcome-to-vahana-edfa689f2b75#.4jh14wicm)
- Aeromobil (CTOL Flying Car v3.0), [http://www.aeromobil.com/#s-about](http://www.aeromobil.com/#s-about)
- Bell Helicopter, Innovation Division (Urban VTOL Vehicle and ConOps Studies), [http://www.bellhelicopter.com/company/innovation](http://www.bellhelicopter.com/company/innovation)
NASA Strategic Framework for On-Demand Air Mobility

- KittyHawk Company (Larry Page Investment – Urban VTOL),
- E-volo Company (Volocopter VC200 Project – Urban VTOL aircraft),
- Joby Aviation (Urban VTOL),
  [http://www.jobyaviation.com](http://www.jobyaviation.com)
- Lilium Company (VTOL Jet Aircraft),
  [http://lilium-aviation.com](http://lilium-aviation.com)
- Pipistrel (Hydrogen-powered Aircraft – eGenius; Electric VTOL; Regional Commuter – with Chinese investors)
- Siemens Corporation (World Record Electric Motors for Aviation),
- SkyRyse Company (Urban VTOL),
  [http://www.skyryse.com](http://www.skyryse.com); [https://angel.co/skyryse-1/jobs/204902-ai-lead](https://angel.co/skyryse-1/jobs/204902-ai-lead)
- Terrafugia Company (TF-X VTOL Flying Car)
  [http://www.terrafugia.com/tf-x/](http://www.terrafugia.com/tf-x/)
- Uber Corporation (VTOL Urban Transportation Requirements White Paper),
  [https://www.uber.com/ elevate.pdf](https://www.uber.com/ elevate.pdf)
- Zee.Aero (Larry Page Investment – Urban VTOL),
  [http://zee.aero](http://zee.aero)
- Approximately ten other ODM vehicle development projects underway globally, not yet public.
- Numerous Supplier Organizations (Motors, Fuel Cells, Controllers, Avionics, Composite Material Systems, 3D Printing; etc.)
- Note the limited participation by traditional U.S. aviation industry organizations. This is not to say they would not be involved over time, just that the disruptive innovation nature of the ODM concept creates natural business barriers to entry in this emerging space for extant industries.

Trade Associations, Professional Societies, and NGOs

- AIAA Transformational Flight Program Committee (TFPC)
- Aircraft Owners and Pilots Association, (AOPA), [http://www.aopa.org](http://www.aopa.org)
- American Helicopter Society International (AHS), [https://vtol.org](https://vtol.org)
- Experimental Aircraft Association (EAA), [http://www.eaa.org/eaa](http://www.eaa.org/eaa)
- General Aviation Manufacturers Association (GAMA), Electric Propulsion and Innovation Committee (EPIC) [http://www.gama.aero/advocacy/gama-2008-agenda](http://www.gama.aero/advocacy/gama-2008-agenda)
- Helicopter Association International (HAI),
- National Air Transportation Association (NATA), [http://nata.aero](http://nata.aero)
- National Council for Public Private Partnership (NCPPP), [http://www.ncppp.org](http://www.ncppp.org)

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- Sustainable Aviation Foundation, http://sustainableaviation.org
  http://sustainableaviation.org

**Governmental Organizations (U.S.)**
- American Association of State Aviation Officials (AASHTO)
- National Governors Association (NGA)
- National Association of State Aviation Officials (NASAO)
- National Association of County Officials
- National Association of Counties (NACo)
- Regional and General Aviation Airport Authorities and owners
- State Aviation Officials (e.g., In VA - Virginia Department of Aviation)
- State-based airport associations (e.g., VAOC in Virginia)
- State-based business aviation associations (e.g., VABA in Virginia)

**Governmental Organizations (International)**
- International Forum for Aviation Research (IFAR), https://nari.arc.nasa.gov/ifar
- Japan Aerospace Exploration Agency (JAXA - Electric propulsion FEATHER project), http://www.aero.jaxa.jp/eng/research/frontier/feather/
- Netherlands Aerospace Center (NLR – Civil Aviation), http://www.nlr.org/civil-aviation/
- Single European Skies Air Traffic Management Research (SESAR), http://www.sesarju.eu
- Sustainable Transport in China, http://sustainabletransport.org/urban-transport/

**Academic and FFRDC Organizations (including Federally Funded Research and Development Centers)**
- MIT International Center for Air Transportation, http://icat.mit.edu
2. Potential International Collaborators

This section provides recommendations on the need for pre-competitive collaborative relationships with international governmental, industrial and academic organizations involved in ODM-related technology development activities.

The value of domestic benefits from ODM is not lost on the international community the European Union and China, among others. The U.S. risks the loss of significant economic and technological leadership in the aviation domain related to general aviation. Of the more than 500 U.S. companies that China has purchased or invested in over the recent years, a predominance of U.S. and many other international general aviation companies are in the mix. A sample list of Chinese industrial acquisitions in international General Aviation follows:

- Continental Motors Corporation, http://www.continentalmotors.aero
- In addition, the China Aviation Industry General Aircraft (CAIGA) group has more than 20 aircraft project in development or in production.
- Note that Epic Aircraft Company was recently sold to Russia, http://epicaircraft.com

The point of these data is to highlight the nature of international competition as it relates to NASA’s Aeronautics portfolio in ODM. This landscape is ripe for both a strongly competitive posture by NASA in support of the emerging ODM industry in the U.S., as well as an opportunity to collaborate internationally in pre-competitive areas involving standards affecting aviation safety, infrastructure and operations.

3. Organizational Issues

The larger-scale transportation system innovations in our nation’s recent past include the Next Generation Air Transportation System (NextGen), regional High Speed Rail initiatives, and the

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25 http://www.usatoday.com/story/money/business/2013/05/29/china-shuanghui-smithfield/2369565/
26 https://www.faa.gov/nextgen/
Intelligent Transportation System of America\textsuperscript{28}. These national initiatives share common themes regarding motives, participation, value creation, and domestic benefit outcomes, as presented below:

- \textit{Initiatives are motivated by solving existing transportation system challenges and would create significant domestic benefits.}
- \textit{The innovations stimulated by the system advancements are exportable and would enhance U.S. balance of trade.}
- \textit{Existing Federal R&D organizations are uniquely capable of stimulating technology advancements that enable transformational advancements in mobility of persons and goods.}
- \textit{Federal R&D organizational leadership is needed to communicate the public value propositions and to engage all stakeholders in embracing the opportunities inherent in advancing the technologies for the initiatives.}
- \textit{The visions for these initiatives are codified in national policies. These policies enable legislators, regulators, innovators, and the public to envision a common goal, to collaborate on mutual opportunities, and to support investments leading to benefits for our nation.}

It should be noted, however, that gaps exist between the requisite roles and responsibilities available through the organizations presented above and the capabilities needed to realize the opportunities that ODM offers. A few important distinctions also exist between the themes for these past transportation system initiatives and the themes driving the ODM vision. These distinctions include the following:

- \textit{Where past transportation system innovations were largely focused on solving localized or centralized needs (e.g., NextGen is focused on airline efficiencies operating between about 35 large airports), the ODM concept envisions meeting very widely distributed challenges in mobility.}
- \textit{Where past system-level innovations were focused on existing systems (e.g., enhanced highways or rail systems), the ODM vision includes the creation of new transportation capabilities.}

Where past transportation system investments benefited from national policies, the ODM vision will be limited by the absence of a national policy affecting the requisite participants and their roles in promoting, financing, developing and operating ODM capabilities.

\section*{4. Options for Leveraging Organizational Cooperation}

Recent efforts by NASA and the FAA to craft technology roadmaps and to nurture a community of interest among industry and academia are necessary steps for a broader ODM initiative. Clearly, the ODM vision is enabled by key technologies. However, technologies alone will not enable the vision. In addition, given the systemic nature of the ODM vision, NASA’s charter is limited in this regard. Therefore, NASA should consider the following steps, in collaboration with industry trade associations, universities and NGOs, to facilitate sharing of the ODM vision:

\textsuperscript{28} \url{http://itsamerica.org}
NASA Strategic Framework for On-Demand Air Mobility

- Engage the National Council for Public Private Partnerships in developing a white paper or concept document outlining a roadmap for the ODM vision, including the roles for NASA, the FAA, other government departments and agencies, industry and academia, and the state and local organizations that are stakeholders in the ODM value proposition.
- Utilize the International Forum for Aeronautics Research (IFAR) as a venue for strategic exploration of opportunities for international collaboration in pre-competitive aspects of technology, policy and regulatory investments.
- Develop an assignment for a Roundtable under the charter of the National Academies for Science, Medicine and Engineering to host a dialogue among the emerging industry leaders, the federal and state government stakeholders, and the DOT, NASA, FAA, and other technology contributors, to assess the public value proposition as a framework for national investments in the ODM technologies, infrastructure, regulation, and policies.

5. Summary of Findings and Recommendations

The following is a series of findings and recommendations supported by the assessments of this chapter:

**Finding 4.1** – Challenges posed by international competitiveness in technologically advanced smaller aircraft for more widespread inter- and intra-urban public transportation create conditions leading to the potential loss of U.S. global leadership in aviation.

**Finding 4.2** – The opportunities posed by unprecedented industrial developments in the ODM space, combined with synergistic emerging technologies create conditions in which NASA investments in research and technology development can secure U.S. global leadership in aviation for years to come.

**Finding 4.3** – The convergence of autonomy, automation and connected vehicle technologies along with the ever-increasing demand for increased mobility and decreased congestion, present an opportunity for our nation to be the global leader in transformation of transportation through ODM advancements.

**Finding 4.4** – Technologies alone will not enable fulfillment of the ODM vision. The systemic nature of this vision commands a national sharing of and commitment to its achievement.

**Recommendation 4.1** – NASA should create a focused effort in ODM research and technology development. The need for a focused program is clear in order to maintain U.S. technological, market, and regulatory leadership.

**Recommendation 4.2** – NASA should lead in the collaborative development of ODM technology through one or more Innovation-Public Private Partnerships (I-PPP) involving industry, academia, states, regulators, operators, and investors.
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Chapter 5 – Public/Private Collaboration Options & Resource Alignment

Prelude

The courtyard of the SRI International building in Menlo Park was bathed in the soft light of fall in 1983 as 24 NASA senior managers sat in discussion circles with 17 SRI experts, brainstorming solutions on how to increase the commercialization rate and private sector investment in civil space activities. James Beggs had convened the NASA Space Commercialization Task Force with a charter to “...identify specific commercialization initiatives to...lessen barriers and increase incentives for private sector investment and involvement in civil space activities.” The Task Force had developed 11 ideas for increased collaboration and had retained SRI to develop an outreach plan, which had been done many times in NASA’s past. The Beggs’ mandate, however, had a new twist: a top-down requirement that outreach include connections with companies, entrepreneurs, venture capitalists, finance companies and insurance companies to increase commercial adoption and incentivize investment.

The brainstorming continued through the afternoon when an idea was hatched: use R&D partnerships between NASA and private companies to transfer and commercialize technology, because that mechanism automatically attracted entrepreneurs, early stage capital and institutional finance. After a few hours of hard questioning, a conclusion was reached: the use of R&D partnerships would require NASA to move beyond outreach for best efforts collaboration to committed partnerships. This approach would raise the political and performance stakes for NASA, but also deliver the technical and commercialization results sought by senior management. Another reason to support the idea emerged: the use of R&D partnerships was being championed by Dr. D. Bruce Merrifield, Assistant Secretary of Commerce, as one solution to the nation’s need for accelerating both technology transfer and financing of commercial adoption.

The recommendation eventually found a champion at the NASA Ames Research Center and went through the Agency’s internal review process before being approved by Richard Truly as a technology transfer program for cost-shared, multi-party R&D. The Agency’s Technology Utilization (TU) directorate institutionalized the program for five years (1990-1995) as the Joint Sponsored Research Program (JSRP). During that brief period, the JSRP was used to design and implement industry-wide aeronautics partnerships in rotorcraft (RITA/VLC), unmanned vehicles (ERAST) and General Aviation aircraft (AGATE).

29 Paul Masson, Senior Management Consultant for Corporate Finance participated for two days
31 Ibid., Page 3
NASA Strategic Framework for On-Demand Air Mobility

1. Introduction and Background

The basic question posed to the federal managers, Beggs, Truly and Middlefield was the following: “For projects and programs that require commercial adoptions and investment incentive, what are the collaboration options and decision criteria?” Other questions that evolved out of this one are the following:

   1. How to satisfy policy objectives requiring commercial adoption?
   2. How to accelerate technology development and transfer?
   3. How to incentivize commercialization?
   4. How to influence supply chain development?
   5. How to attract investment capital to support commercialization?
   6. How to accomplish these goals while staying within the limits of Federal management authorities and practices?

2. Collaboration Options Analysis

This section provides the analysis and rationale for four collaboration options based on the preliminary ODM planning decisions to date. Collaboration types are chosen based on the objectives to be achieved and the performance requirements or constraints. The section identifies six option selection criteria and then identifies and defines the four options. The analysis of the options in terms of the criteria begins with a discussion of policy objectives, followed by a section for each of the criteria, and finally a discussion of patterns of politics that have generated policy.

Terminology

The analysis in this chapter uses the term “collaboration” to mean any form of public/private coordination to pool research and development resources to achieve a given public good objective while concurrently generating collective private sector benefits. The terms strategic partnership, alliance and consortium will be used to describe forms of public/private collaboration. Furthermore, the term “innovation public/private partnership” (I-PPP) is used to describe the ODM collaboration. (See 5.1.3 Audience below.) The term “project/program” will be used to define the ODM planning to date.

To be clear, there is a distinction between "partners" as "technology sources" versus as full commercialization partners. "ODM commercialization partners" would including organizations that satisfy the following intersecting requirements: 1) technology sources; 2) strategically aligned; 3) capable of spending their own/internal resources on R&D; 4) are cultural compatibility; 5) have the legal capacity to enter R&D cost/rights sharing agreements; and 6) are operationally compatible.

Audience Analysis—PPP Political/Policy Acceptance, Distinguishing Innovation

The options analysis and conclusions are drawn from continued or future political support for the following: a) public/private partnerships; b) innovation public/private partnership for NASA Commercial Space initiatives; c) R&D investment for competitiveness; and d) R&D investment for advanced manufacturing. 33

33 Donald Trump’s Contract With the American Voter, 100 Day Action Plan to Make America Great Again, DonaldJTrump website, Positions, Accessed November 10, 2016
A recommendation is made to adopt the term “Innovation Public/Private Partnership” (I-PPP). This identification provides NASA managers a short phrase that legitimately aligns with the projected political positions for policy, while distinguishing the collaboration as bounded by NASA ARMD’s advanced technology charter.

**Six Decision Criteria from Federal Technology Partnering Best Practices and Objectives**

The narrowing and choice of a collaboration option is based on decisions that address both objectives and design requirements. The decisions come from the collective best practices for both large and small-scale federal technology partnership programs implemented by 11 different departments and agencies. Political and policy objectives are based upon what the program is intended to achieve. Performance requirements and restraints are shaped by six considerations, as follows:

1. **Stakeholder organizations** – What organizations must be engaged as direct versus indirect stakeholders in generating and using the project/program outputs?
2. **Strategic level commitment** – What commitments must be secured from stakeholder senior managers to achieve the project/program outputs?
3. **Technology alignment** – What existing technology development programs must be aligned with the project/program plan?
4. **Resource commitments** – What external resources (funding, personnel, facilities) must be committed to achieve the project/program objectives?
5. **Cultural compatibility** – What degree of cultural compatibility among stakeholders is necessary to achieve the project/program objectives?
6. **Legal & operational requirements** – What legal authorities are required to incent stakeholder commitment to achieve the project/program objectives? What operational procedures are necessary to implement the legal authority?

**3. Four Collaboration Options**

The ODM planning, to date, has not generated sufficient project/program content or stakeholder information to select a specific collaboration approach that would specifically match industrial commercialization objectives. The currently available information supports narrowing the collaboration decision to four options. The recommended range of options below is based on achieving the policy objective of commercial adoption of certified technology to support improved transportation systems solutions, e.g., intra and inter-urban aircraft:

- **Government directed, industry advised** – Government directed, and majority funded programs and projects through one or more organizations chosen by government managers with industry input.
  - Federal managers facilitate project/program planning workshops with academic and industry advice. The federal managers decide on the R&D plan to be implemented through contracts, grants and cooperative agreements, some of which may include a requirement for cost sharing to incentivize commercial adoption.

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federal government launches and operates a project/program office that includes representatives from regulatory agencies or parallel funding Departments. The federal government is responsible for the project/program operational implementation and output distribution. Intellectual property rights are allocated according to respective statutory authority of each award mechanism.

- **Joint strategic partnership** – Government/industry/academia coordination through a joint task force or executive group to decide on different levels of co-funding for projects/programs through multiple organizations.

- **Joint alliances or consortiums** – Government/industry/academia membership in a single alliance or consortium organization that decides on different levels of co-funding for project/programs to achieve agreed upon goals.

- **Industry-led, government participant** – Industry-led coordination of government-industry-academia through a single alliance or consortium to decide on different levels of co-funding for project/programs to achieve industry-defined goals.

### 4. Criteria for Selecting an Option

This section provides analysis and conclusions regarding current ODM planning relative to the decision criteria, and how to move from the technology roadmapping phase to the commitments by commercial stakeholders.

**Analysis**

The ODM plan proposes to directly satisfy three policy objectives, as follows:

1. Technology development,
2. Certification,
3. Commercial adoption.

“Directly satisfy” means that the project/program outputs will achieve specific goals defined to satisfy the above three policy objectives.

The ODM plan proposes to indirectly satisfy two policy objectives, as follows:

4. Scale up and down of commercial adoption into other aviation markets
5. Improved intra-urban and short-haul transportation solutions.

“Indirectly satisfy” means the project/program outputs will disseminate through social, economic (company or trade association), governmental and regulatory channels for use to satisfy the above two policy objectives.

The ODM planning presentation\(^{35}\) and the NASA statement of work for this project state the following policy level objectives:

ODM provides an early entry point for certification of human rated aviation technology, including the following:

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\(^{35}\) 2nd NASA-FAA On-Demand Mobility and Emerging Aviation Technologies Workshop, Slide 2, George Finelli, NASA LaRC, Aeronautics Research Directorate, Presentation dated March 8 and 9, 2016
NASA Strategic Framework for On-Demand Air Mobility

- Higher risk tolerance, operational and safety benefits with smaller aircraft
- Technology developed at lower costs and faster lifecycles with early certification and adoption to prove statistical safety
- Scaling up and down to other aviation markets for larger and smaller aircraft

The program would need to identify the following:

- Forms of collaboration most likely to result in commercial adoption
- Potential alignment in and leveraging of investment contributions supporting the ODM vision (i.e. intra-urban and short-haul transportation)

There are currently no policy statements proposing ODM to satisfy international competitiveness needs. If such a policy objective were invoked, then future analyses would include (as examples) evaluation of the Z-Park Sky Innovation General Aviation Alliance licensed by the Chinese Civil Aviation Authority in April 2016 and the Airbus E-Fan program. The need for national policy on ODM is more broadly addressed in Chapter 6.

Criteria for the four options used by prior administrations that can meet the ODM needs are defined as follows:

1. **Government directed, industry advised** – Federal managers facilitate project/program planning workshops with academic and industry advice. The federal managers decide on the R&D plan to be implemented through contracts, grants and cooperative agreements, some of which may include a requirement for cost sharing to incentivize commercial adoption. The federal government launches and operates a project/program office that includes representatives from regulatory agencies or parallel funding departments. The federal government is responsible for the project/program operational implementation and output distribution. Intellectual property rights are allocated according to respective statutory authority of each award mechanism.

2. **Joint strategic partnership** – Federal managers organize a Task Force with senior level representatives of industry and academia. The Task Force is chartered to jointly design an R&D program/project to achieve a given objective by coordinating expenditures at organizations in all three sectors. The Task Force is organized per a governing board model with Co-Chairs guiding an Executive Committee that meets regularly to coordinate implementation. A project/program office chosen by the Co-Chairmen supports the Task Force. The individual tasks are funded per a best efforts agreement using a mix of federal, state and commercial funding. Intellectual property rights are allocated per the intellectual property laws regarding source of work, funding and personnel employment.

3. **Joint alliances or consortiums** – Federal managers sponsor the formation of a multi-party agreement (alliance) or non-profit consortium to undertake an R&D program/project to achieve a federally defined objective. The alliance/consortium is organized as either a fixed term or ongoing entity, with a charter and bylaws that establish a Board, management office and membership rights and responsibilities. The agreement specifies the adoption of an existing R&D project/program plan or creation of such a plan, with fixed requirements for resource contributions and intellectual property rights and protections. The alliance/consortium Board is composed of elected commercial and academic sector
members, with seats allocated per resource contribution levels. The Board minority representation consists government observers who exercise the federal interest by their financial commitment to the R&D plan. The alliance/consortium retains independent business administration, legal counsel, and auditors. The legal counsel files a notification of the alliance/consortium formation with the Department of Justice as required under the National Research and Production Act of 1993 (NCRPA) as amended, to qualify for anti-trust exemption from treble damages.

4. **Industry-led, government participant** – Federal managers identify an existing industry group that has the charter to operate as an alliance/consortium to undertake an R&D project/program to achieve a given objective. The alliance/consortium operates per membership categories (including government membership), governance, management, administration and project/program support functions permitting it to collaborate with the federal government as a “single interface” with the commercial and academic sector. The alliance/consortium has the legal charter to receive federal, state and commercial sector funds to be pooled for joint research and development and has filed notice of its intentions to the DOJ under the NCRPA. The alliance/consortium forms a separate “program” for accounting and management purposes, thereby permitting the creation of a separate program Executive Body, composed of industry, academia and government representatives. The Executive Body adopts or creates an R&D project/program plan that is funded by member contributions or government grants and cooperative agreements. The Executive Body establishes intellectual property protections and rights within the program plan and per the Bylaws of the existing organization.

Two of the collaboration options provide joint planning, governance, management and funding with independent (third party) administration are the closest fits to the ODM project/program as currently defined. The basic tradeoffs are as follows:

1. **Joint Strategic Partnership** – This starts with federal leadership and launch, leading to a shared vision, around which a shared culture is built, transitioning to industry leadership. Operations and management can be from a federal, state of third-party source, with required project team reporting. Performance to tasks is generally on a best efforts basis. Cost sharing is standard.

2. **Joint Consortium** – This can start either with a Federal request with a third-party response to add a program to an existing organization or launch a fixed-life non-profit entity with a written organizational strategy and technology development plan. The organization has a Board and management structure with associated operating support systems. Project work is funded as sub-contracts with required performance targets to secure funding and intellectual property rights. Cost sharing is standard.

**Stakeholders**

To be comprehensively effective, the ODM project/program collaboration requires engaging a broader set of stakeholders than those reported in the public and private meetings. The stakeholder engagement must distinguish between those with a direct interest in the technology certification and commercial adoption versus those with a derivative interest in scaling up/down and developing transportation solutions.

The ODM policy objectives lead to the following stakeholder engagement:
## NASA Strategic Framework for On-Demand Air Mobility

<table>
<thead>
<tr>
<th>ODM Workshop Statements</th>
<th>Stakeholder Scope</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODM provides an early entry point for certification of human-rated aviation technology</td>
<td>• FAA Tech Center, Small Aircraft Directorate, NextGen (HQ)</td>
</tr>
<tr>
<td></td>
<td>• R&amp;D organizations w/certification track records</td>
</tr>
<tr>
<td>Higher risk tolerance, operational &amp; safety benefits with smaller aircraft</td>
<td>• Legacy GA airframers</td>
</tr>
<tr>
<td></td>
<td>• Tier 1 GA airframe suppliers (avionics, manufacturing, materials)</td>
</tr>
<tr>
<td>Technology developed at lower costs and faster lifecycles with early certification and adoption to prove statistical safety</td>
<td>• New aviation industry entrants</td>
</tr>
<tr>
<td></td>
<td>• New entrant Tier 1, 2 &amp; 3 suppliers from other transportation sectors (autos, rotorcraft, UAV)</td>
</tr>
<tr>
<td></td>
<td>• NASA Glenn (propulsion) &amp; ARC Securities Evaluation Office (SVO)</td>
</tr>
<tr>
<td></td>
<td>• Regional Economic Development Administration (EDA) aerospace clusters</td>
</tr>
<tr>
<td>Scaling up and down to other aviation markets</td>
<td>• Existing large aircraft &amp; rotorcraft</td>
</tr>
<tr>
<td></td>
<td>• Existing and new entrant UAV vehicle</td>
</tr>
<tr>
<td></td>
<td>• Fleet operators: Airlines, GA, UAV</td>
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</tbody>
</table>

The NASA statement of work requests the identification of collaboration options that lead to the following stakeholder engagements:

<table>
<thead>
<tr>
<th>Task Order Guidelines36</th>
<th>Stakeholder Scope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forms of collaboration most likely to result in commercial adoption of the outcomes of NASA-sponsored, FAA-supported ODM research portfolios</td>
<td>• Existing commercial adoption R&amp;D consortia for aviation and advanced manufacturing</td>
</tr>
<tr>
<td></td>
<td>• Trade associations committees working with standards setting organizations</td>
</tr>
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<td></td>
<td>• Regional, multi-modal transportation authorities</td>
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<tr>
<td>Potential for alignments in and leveraging of investment contributions…supporting the ODM vision</td>
<td>• Federal SBIR/STTR</td>
</tr>
<tr>
<td></td>
<td>• DOD AFRL and ManTech</td>
</tr>
<tr>
<td></td>
<td>• DOC National Network for Manufacturing Initiatives (NMMI)- Note: Name to be changed</td>
</tr>
<tr>
<td></td>
<td>• State EDA’s funding aerospace clusters</td>
</tr>
<tr>
<td></td>
<td>• Stock analysts for market traded firms (SIA)</td>
</tr>
<tr>
<td></td>
<td>• Venture and equity fund managers for privately held firms (NAVF)</td>
</tr>
<tr>
<td></td>
<td>• Angel capital groups with a declared aerospace interest with the Angel Capital Association (ACA)</td>
</tr>
<tr>
<td></td>
<td>• Champion capitalists (Larry Page, Jeff Bezos)</td>
</tr>
</tbody>
</table>

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Issued to National Institute of Aerospace
Executive-Level Strategic Commitment

The ODM project/program collaboration requires strategic commitments from senior technology development, certification and funding program managers of federal and state organizations. The collaboration will also require strategic commitments from private sector business unit managers, CEO’s of early-stage companies, and financing influencers. A limited number of technology development managers, startup CEO’s and financing influencers have been engaged to date based on the reported public and private meetings.

This analysis distinguishes between technology certification versus commercial adoption, which drives the scope of stakeholder engagement and the level of required strategic commitment to the ODM project/program.

“Technology certification” is defined as the collective of FAA approved type designs (type certificate or supplemental type certificate) and associated production certificate issued to manufacture the product under the type certificate. Operational certification is also a significant factor in ODM implementation, requiring collaboration that can mostly be accomplished through existing public standards bodies such as RTCA and ASTM.

“Commercial adoption” is defined as the completion of a business case that incorporates the certified product as an upgrade, replacement or new element within a business unit plan that provides a technology migration map (requirements, technical work statement, application potential), and secures personnel and financial commitments leading to a production plan. The business case becomes a product plan within the business unit plan, which is approved by an owner or manager with sufficient authority to assure implementation over given period, e.g. 1 to 3 years.

To achieve early technology certification requires engaging mid and upper-mid level managers of legacy and new entrant firms as ODM participating stakeholders. The participant lists of ODM roadmap meetings indicate that these managers have been engaged. The meetings also attracted a small number of retired Federal and commercial aviation managers who influence their former organizations.

To achieve commercial adoption requires outreach to the C-Level managers of General Aviation legacy organizations and the Board and C-Level manages of new entrant organizations. This engagement is necessary due to the resource requirements required to achieve commercial adoption and to share a combination of certification and commercial expertise between existing legacy organizations and new entrants. Previous NASA aeronautics technology alliances in Rotorcraft (RITA) and General Aviation (AGATE) started with senior federal managers meeting with the C-Level managers of existing legacy firms, while often meeting with the founders.

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37 Aircraft Certification, Licenses and Certificates, FAA Website, accessed October 9, 2016.
and Board member investors of the new entrants. In some cases, both the legacy and new entrant firms participated in regional economic development aerospace clusters, requiring outreach and engagement with the Economic Development Agencies (EDA) boards and their respective presidents.

Achieving transportation system adoption requires engaging senior level managers of federal government, regional Economic Development Administration, and commercial firms as indirect ODM stakeholders. Achieving transportation system adoption, especially for new intra-urban vehicles, requires engaging senior political and policy leaders at regional councils of governments with formal regional transportation plans, e.g., the Southern California Association of Governments (SCAG) 2012-2035 regional transportation plan.41

5. Technology Alignment

The ODM planning events have identified a core of aligned technology programs in both legacy and “startup companies” based on workshop reports of attendees’ commercial interest in electric aircraft, hybrid propulsion, simplified vehicle operations and advanced manufacturing. There are additional technology programs of large corporations, state economic development authorities and existing aviation consortia that may align with the program, but have not been engaged in ODM workshops or meetings. A systematic mapping of core stakeholders to their suppliers and partners is a necessary step in selecting the collaboration option and completing the partnership design.

Technology alignment means mapping stakeholder innovation supply chains and networks to identify current or planned technology development projects or programs that can add to or draw from the proposed NASA initiative. These core stakeholders recruit and engage their respective suppliers and innovation support organizations.

Stakeholder innovation networks are best understood by mapping the related programs of large corporations, single-product startups (e.g. Zee Aero, Kitty Hawk), existing consortiums (Vertical List) or innovation public/private partnerships. For example, ITS America is the ground transportation communications and information systems I-PPP that creates shared architectures for ground-based transportation. ITS America includes corporate membership that matches the avionics firms targeted for ODM. Additional examples of possible technology programs for alignment include the following:

- **Connecticut ACM.** The Connecticut Aerospace Components Manufacturers (ACM) coordinates research and development, manufacturing and workforce development in the only U.S. cluster that combines propulsion, rotorcraft and aviation vehicle development.

- **BREG Aerospace & Advanced Manufacturing/Materials Clusters.** GA and Large Aircraft-A southern Kansas economic development partnership has re-organized their aerospace initiatives a single cluster organization that is planning workshops for GA and aircraft technology development in advanced manufacturing/materials and software to support simplified vehicle operations.42

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41 Regional Aviation Demand, Airport Infrastructure and Airport Ground Access, Regional Transportation Plan, 2012-2035, Southern California Association of Governments, Sustainable Communities Strategy, Page 62
42 Aerospace Cluster Strategy Elements, Blueprint for Regional Economic Growth: South Central Kansas, July 2015
• **Electric Vehicle Supply Chain and Workforce Development Group.** Tesla is anchoring the formation of a working group that will combine electric vehicle design and battery application along with required supply chain and workforce development. The objective is to accelerate commercial adoption by integrating the technology development with supply chain and workforces.43

• **Airbus U.S. Engineering Center.** Airbus E-Fan 4.0. Airbus has launched VoltAir SAS to build a family of electric powered aircraft. The publicly announced business plan calls for VoltAir to produce a vehicle designated 2.0 as a trainer, and a vehicle designated 4.0 as a four-seater targeted at the U.S. market. Airbus USA has recently consolidated all their North America Engineering in Wichita, close to the U.S. general aviation industry concentration.

6. **Resource Alignment**

The ODM collaboration requires cost sharing from private firms to incent commercial adoption along with resource commitments from the FAA and selected aerospace clusters or existing partnerships to provide the expertise and test facilities necessary to achieve the program/project goals. The resource alignment requires distinguishing between direct versus derivative stakeholders to distinguish priority of risk taking and decision making in the collaboration. To date, the NASA ODM plans have not prepared a forecast of resources necessary by level or mix.

The resource alignment identifies the specific technology (background intellectual property), personnel, facilities, test equipment and funding necessary to achieve the project/program objectives.

The ODM technology roadmaps imply collaboration with personnel at facilities outside of NASA’s immediate R&D network of contractors and university organizations. The certification requires multiple groups within the FAA and commercial firms with certification track records. The high-risk technology development requires accessing background knowledge from the new entrants, which in turn requires alignment with their respective funding sources. The following is the full range of potential resource alignment based on a project/program that seeks to achieve commercial adoption.

The federal departments and agencies listed below have programs that relate to the three ODM planning roadmaps:

- Multiple Agencies – SBIR and STTR programs
- DOT/FAA R&D – Centers of Excellence (COE) for General Aviation e.g. PEGASUS at Purdue, Joint Center for Advanced Materials, Aircraft Noise and Aviation Emissions, Intermodal Transport Environment
- DOT/FAA – Small Aircraft Directorate- Vehicles & personnel for flight testing
- DOD/Mantech w/AFRL – Aviation vehicle advanced manufacturing
- DOD – Manufacturing- National Network for Manufacturing Innovation (NMMI)

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The states listed below (alphabetically) fund both aviation research and commercial adoption primarily through cluster organizations but also through focused programs.

- Alabama – Huntsville Region
- California – Southern Region (8 counties), e.g. AMP SoCal
- Connecticut – South Central Region, e.g. ACM
- Florida – South Coast and at South Carolina border
- Iowa – Iowa City Region
- Kansas – South Kansas Region (10 counties), e.g. Blueprint for Regional Economic Growth (BREG) Aerospace Cluster
- Missouri – St. Louis Region
- Ohio – Cincinnati Region
- Oklahoma – Tulsa and OK City Regions
- Texas – Dallas Region
- Utah – Salt Lake City Region
- Virginia – Richmond (Virginia Small Aircraft Transportation System – SATS – Lab)

The major universities listed below (as examples) have commercial aviation research and technology development programs relevant to the ODM vision.

- Embry-Riddle Aeronautical University
- Massachusetts Institute of Technology
- North Dakota State University
- Purdue University
- Stanford University
- University of Kansas
- Washington University
- Wichita State University

**Private Sector Participants**

Soliciting stakeholders to commit resources supported by private sector capital and loan markets requires classifying stakeholders according to their financial structure. The draft ODM plan implies partnering with private sector firms that are stock traded, private-equity owned, and startups. The financing sources of the startups include minority investments for future acquisition, venture capital, angel capital and champion capitalists. The categories below of private sector resource matching would be applied against specific company structures:
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- Tax Credits – The eligibility for R&D tax credits, regional development zone credits, workforce development credits and equipment acquisition for accelerated depreciation.

- State and Local Incentives- State and local investment incentives programs that provide funds to match specific investments in facilities, equipment and personnel.

- Private Sector Institutional – Equity and long-term debt funding by category of technology and “lifecycle” stage of for-profit business development.
  - Institutional markets – Stock traded firms are evaluated by analysts on their investments. There has historically been an aerospace working group within the Securities Industry and Financial Markets Association (SIFMA).
  - Hedge Funds – Stock and privately held firms are evaluated by networks of hedge fund analysts that focus on the speed of return from a given investment.
  - Private Equity Funds – Private Equity Funds Privately held firms are strategically directed and funded by managers of private equity funds looking for long-term trends.
  - Venture Capital – Late stage startup firms that have established markets and products receive multiple rounds of funding to capitalize on closely held IP to further penetrate markets.

- Private Sector Networked
  - Angel Capital – These networks of wealthy individuals are the seed and early stage funding sources for startups. The Association of Angel Capitalists (ACA) provides a list that categorizes each network’s interest.
  - Champion Capitalist – This term describes the collection of wealthy individuals who choose to fund one or more startups solely to advance a given technology or capability. The alignment of personal funds from Larry Page, Elon Musk or Jeff Bezos is a function of both their vision and the detailed information provided to their advisory staff.

7. Assessing Partnership Options Against Criteria

Cultural compatibility exists among the comprehensive ODM stakeholders necessary to achieve technology development but not yet that required to achieve commercial adoption. The stakeholders necessary to achieve commercial production of aircraft applying Simplified Vehicle Operations (SVO), advanced manufacturing, alternative propulsion and other technologies are emerging from a new cultural domain (e.g., Silicon Valley). These new entrants bring financing needed and would benefit from collaborations with elements of the aviation industry that are vastly experienced with aviation safety standards, risk mitigation criteria, and processes for certification. To their credit, many of the new entrants are participating in aviation public standards activities, such as the ASTM committees.

The choice of an ODM collaboration option must consider whether the shared vision or threat is strong enough to motivate a shared culture. If so, collaborations based on the shared culture increases the range of partnering options. If not, then compatibility can be built over time through NASA leadership (for example) and organizational processes to minimize conflicts and maximize solutions related to the inevitable conflicts that arise during collaborations.
The identification of anchor stakeholders for strategic, technical, and financial alignment provides the basis to judge the level of cultural compatibility required to achieve ODM objectives. The outcome of this judgment is used to choose a collaboration model that supports the type of education, socialization and cross-education necessary to build compatibility.

“Compatibility” is defined as the degree of shared “corporate culture” across five different disciplines: senior management, senior technologists, finance, product and production regulation, contract law (federal and commercial) and intellectual property law (federal and commercial). The factors that go into the compatibility decision include the following:

- Industry mix by scale and type – What mix of representatives will be participating from new entrants versus established firms? For example, how should a team composed of Silicon Valley technologists with limited experience in high risk, high certification industries be organized?
- Mix of government experience – What is the mix of experienced entities working with government? For example, how should a team composed of commercial sector and academic personnel working with federal test facility managers accustomed to dealing with internal customers be organized?
- Roadmap workshop experience – Did the workshops build a common vision, mission and set of shared language? For example, do the workshop participants regularly communicate to cross-educate each other for better collaboration?
- Recent NASA aeronautics collaboration precedents – What was the experience of NASA aeronautics collaborations for the Advanced Composite Consortia (ACC), Vehicle Systems Program, SATS, AGATE and RITA? Was a shared vision and set of technology roadmaps sufficient to create compatibility? Were the legal, operational and intellectual property representatives capable of easily communicating and implementing joint actions?

**Legal Authority and Operational Requirements**

The ODM collaboration legal authority will require some form of shared decision-making, resources and intellectual property rights to achieve the certification and commercial adoption objectives. The operational capabilities will need to support multiple work teams for technology development, systems integration and assurance, configuration management and partnership management (technical, financial and intellectual property performance). The operational capability will also need to provide management information systems reports applicable to all stakeholders’ financial, technical and IP managers.

The NASA precedent is for the lead NASA center partnership counsel and project/programs controls managers to make the decision on authorities and operational capabilities. There are precedents, across all NASA centers, where the legal authority and operational systems chosen for the collaboration are based on standardized policy and procedure to simplify implementation and not account for customized collaboration designs.

The legal authority and operational requirements decisions, therefore, must either match the practices, policy and institutional procedures of the lead center or specify the customization necessary to achieve the project or program objectives. The choice of legal authority and
operations support is a function of the objectives for commercial adoption that drives intellectual property allocation, the mix of required matching resources and necessary cultural compatibility.

Current ODM plans calls for collaboration across multiple economic sectors in working teams that result in commercial adoption of certified technology. The planning assumptions include resource-sharing commitments from partners to fund the ODM initiative and to improve technology commercialization. The objective and resource-sharing approach requires an authority that permits task-by-task resource sharing, intellectual property allocation and five-year Freedom of Information Act (FOIA) exemption as a commercial adoption incentive.

The collaboration options differ in their precedent legal authorities and operational procedures both within NASA and across federal organizations. Strategic partnerships are organized to provide an executive body that coordinates projects using multiple legal authorities and operational systems. This increases the strategic management cost, but better aligns with existing authorities and business practices. Consortia are organized as entities that receive funds and manage projects based on a strategic plan determined by a member-designed Executive Board. This structure simplifies the strategic management but requires a legal authority and federal operational interface customized to meet the consortium agreement. Government launched consortia can incorporate federal legal and operational requirements, but commonly result in reduced decision-making by the consortium’s private sector counterparts with whom government participants often are culturally incompatible.

There is no NASA-wide preferred legal authority nor operational procedure for large scale, multi-party collaborations. There are distinct differences between the respective centers relative to their legal offices and experience in large-scale, multi-party collaborations. This pattern is the same as in the DOD, with different commands and units utilizing different authorities and procedures. The DOD shared avionics environment initiative (Future Airborne Capability Environment (FACE) Consortium), for example, is an outgrowth of a NAVAIR initiative that was converted to a project consortium managed by the Open Group, a non-profit organization chartered to operate shared software development consortia.

The types of factors that go into decisions about legal authorities and operational requirements include the following:

- **Lead Center** – What NASA center will lead a given project/program, and therefore what legal authorities and associated operational procedures are common at that center?
- **Resource Combinations** – What legal authority permits the flexibility to move resources across work teams?
- **Intellectual Property Incentives** – What legal authority permits the allocation of intellectual property to incentivize resource contributions and commercial adoption?
- **Management System** – Can the collaboration use existing public or private operational systems, or will it require a customized system?

**Collaboration Options are Function of Policy Evolution and Economic Scale**

While there are no federal or industry-standardized definitions for public/private innovation collaborations, there are well-documented patterns of politics that have generated policy providing government managers with a limited range of collaboration options and a core set of decision criteria.
The fundamental U.S. policy pattern for science and technology collaboration has been to expand the federal role whenever there is an inability for the nation’s collective interests to be met by state government or private sector investment to meet public needs. The pattern of collaborations, therefore, has grown from supporting peer-to-peer exchanges to one of investing in the riskiest science and technology and facilitating investments on a scale that matches the scale of national and global economic growth. The decision to launch R&D collaborations has also grown from a reactive decision to a pro-active decision given the timing necessary to both organize the R&D by scale and manage the programs to meet future, projected needs. The policy pattern summarized includes the following:

- **Peer-to-Peer Knowledge Exchange – Agriculture** – Early nineteenth-century farmer-to-farmer exchanges through agriculture clubs that were expanded by federal funding for land grant colleges that grew into the Cooperative Extension Service.\(^{44}\)
- **Technology Demonstration Funding – Machinery** – Mid nineteenth-century federally funded demonstration projects for the telegraph.\(^{45}\)
- **Applied Research in Critical Industries – Agriculture and Aviation** – Early twentieth-century creation of NACA and Agricultural Research Service (ARS) to undertake applied research in critical industries.
- **Standards Creation – All Industries** – Early twentieth-century, expansion of the former Bureau of Weights and Measures into the National Institute of Standards, and later standards providing uniform technology application practices.
- **Open Dissemination of Science – All Industries** – Mid-twentieth-century federal policy decision to fund basic and selected applied research via universities for broad public benefit through creation of NSF.\(^{46}\)
- **Prime Contractor Coordination – All Industries** – Mid-twentieth-century adoption of teaming through a prime commercial or non-profit contractor to coordinate science, technology and deployment of large-scale projects.
- **Government-Industry Coordination – All Industries** – Mid-to-Late twentieth-century creation of industry advisory committees (FACA) and task forces that coordinate strategic level partnerships between federal, state, academic and commercial organizations.\(^{47}\)
- **University Technology Commercialization – All Industries** – Early 1980’s incentives for university based technology transfer and commercialization.\(^{48}\)

\(^{47}\) The Federal Advisory Committee Act, 1972, website: gsa.gov/portal/content/100916, Policy & Regulations, Federal Advisory Committee Management, accessed October 21, 2016
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- Federal Tech Transfer Partnering, Alliances & Consortia – All Industries. Late 1980’s through early 2000’s expansion of federal technology transfer mandate and authorities. 49
- Regional Innovation Partnerships – All industries – 2008 to present, investment in regional innovation clusters aligned with most competitive industries, e.g. National Network for Manufacturing Innovation (NMMI) and Investing in Manufacturing Community Partnerships (IMCP). 50

“Innovation Public/Private Partnership: (I-PPP)

This terminology combines the “PPP” phrase that means cost-shared public/private collaboration with the word “innovation”, which runs the scope from technology development through commercial adoption to business model innovation. The term “I-PPP” acknowledges the Administration’s policy declaration to expand the use of PPP’s for infrastructure, while concurrently distinguishing ODM program as scoped to innovation. The I-PPP term is defined by the OECD and EU but not in the United States 51.

The decision on policy objectives to be achieved creates a distinction between direct versus derivative partners, from which the correct collaboration option and design can be chosen, especially if derivative partners will be the rationale for achieving national level policy objectives. Generally, both options can accommodate direct versus indirect partners, but the membership categories, rights and obligations vary per the two models.

The choice of a collaboration option is primarily a function of the policy objectives to be achieved. The decision must distinguish between technology outcomes, certification, commercial adoption, industry impact (e.g. incentivizing new companies) and end user benefit (e.g. transportation). The policy objectives to be directly achieved require partnership commitments. The policy objectives to be indirectly achieved require a design decision on where and how to engage “derivative” partners.

There are precedents of federal and state program managers asserting that they will achieve national level policy objectives by investing resources with partner organizations. A common assertion is that investments with partners will generate new jobs, launch new industries, or create tangible public benefit, such as safer food or better transportation. The precedents also demonstrate that workshop participants will support this argument, but often are effective because they motivate mid- or intermediate-level personnel with an interest in securing project funding.

Program planners should define “Commercial Adoption” with sufficient detail to map level of Management connection at direct vs. derivative stakeholders. The definition of “commercialization” is used to identify the degree to which the partners must commit to technology outputs, matching resources and commercialization investments. Generally, the more flexible the commitments, the more one chooses a strategic partnership, whereas the more fixed the commitment, the more one chooses a consortium.

The ODM planning statement for “…early certification and adoption” means a program with the objective to develop and certify technology that also is commercially funded for production. This adoption requires distinguishing between those organizations directly involved in certification for adoption, such as certifying additive manufacturing materials, and those indirectly involved in the adoption, such as the angel capitalists funding the materials formulation companies.

The scope and mix of required matching resources, which should be defined by Direct Planning Managers, is necessary to identify specific partners, the approach to their recruitment and the business mechanism (legal authority and operations support) necessary to pool resources. Generally, strategic partnership is used for more flexible resource commitments, whereas the consortium is used to contractually fix resource commitments, particularly of limited test facilities and equipment.

The definition of scope and mix must be specific regarding test facilities, equipment, key personnel and background intellectual property. This profile is necessary because the ODM planning assumption to incorporate new technologies requires mapping the full range of technology sources that may be relevant and the collaborators’ associated ability to provide matching resources. The rotorcraft industry’s Vertical Lift Consortium (VLC) may be a valuable technology partner, but the VLC operates as a non-profit research coordinating organization between the DOD and the Department’s primary helicopter suppliers. The VLC reported $255,000 of unrestricted net assets as of year-end 2014, leading to the conclusion that it has no independent ability to cost-share in technology development. However, the VLC could join as a “non-profit” member within selected collaboration design options on the condition that it receives matching funding from commercial firms for any work performed. The VLC used to operate a specialized test facility that may, for example, be needed for the ODM project/program.

Program planners should identify examples of target topics for discovery and learning that will require adjustments. The examples of topical areas for possible new “discoveries” is used to decide on the degree of anticipated change in the strategy associated with the project/program plan. (Generally, strategic partnerships are used when more discovery and adjustment is anticipated, whereas joint consortia are used when the range of discovery is limited, and there is a greater emphasis on development, testing and evaluation.)

Technology projects/programs always adjust to discovery and implementation learning. However, the degree to which a collaboration can adjust is a function of the cultural compatibility among leaders and the underlying legal and operational structure. A collaboration with high expectations of discovery often engages new industry entrants and participation by derivative stakeholders, which requires a governing and management system designed for shifting leadership. A collaboration based on a legal authority and operational structure derived from fixed formats and federal-only operational procedures will not be capable of generating the new tasks nor providing implementation support when new teams are formed to pursue new discoveries.

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8. Findings and Recommendations

Finding 5.1 – Four collaboration options relevant to ODM include those that engage multiple economic sectors in working teams across several technology areas to generate certified technology that is commercially adopted, resulting in advances supporting transportation systems solutions, e.g. intra and inter-urban aircraft.

Finding 5.2 – Based on our options analysis, we have identified two of the four as the most suitable for and ODM (I-PPP). These recommendations include a) a Joint Strategic Partnership; and b) a Joint Consortium.

Recommendation 5.1 – NASA should organize a formal assessment of the two recommended alternatives for an I-PPP: either a Joint Strategic Partnership, or a Joint Consortium.
Chapter 6 – National Policy and Regulatory Considerations for Enabling ODM

Prelude

Leaders within government and industry agree that focusing the capabilities of a large organization to achieve a specific result requires that all participants are working to achieve the same goal. In the words of Jack Welch, former Chairman of General Electric, “In order to lead a country or a company, you’ve got to get everyone on the same page…”

He went on to say “…you’ve got to be able to have a vision of where you’re going. America…can’t have a bunch of piece meal activities. It’s got to have a vision.”

For moving the many wheels of government in the same direction, vision must be articulated in policy. Lacking a statement of official policy that keeps relevant parties “on the same page”, resources are likely to be scattered and progress toward achieving needed benefits will be hampered.

Launching a program to achieve On-Demand Mobility requires a shared vision of benefits that our nation will derive from innovative applications of technology to the movement of people and goods. Policy based upon the ODM vision will provide the governing principles for implementation, including ODM architecture, regulatory boundaries, resource allocation and incentives for cooperation between contributing and competing factions.

With vision expressed as policy, progress is possible. By briefly reviewing aviation’s progress and discussing coordination between the various elements that are needed to expand mobility, this Chapter is an argument for establishing ODM Policy.

1. Introduction

A brief review of our nation’s aviation development is presented below to illustrate the rate of progress in the absence of specific policy. It is implied, if not actually asserted, that results our nation derived from aviation during the 113 years since the first controlled flight of a manned heavier-than-air vehicle might have been achieved faster, been less fraught with missteps, and delivered earlier and greater benefits had there been a clear, longer term vision expressed in national aviation policy. To further make the case, this chapter outlines how ODM Policy would focus the efforts of stakeholders.

Throughout history around the globe, transportation has been and continues to be an enabling technology for expanding economic development and improving quality of life. Current U.S. Department of Transportation policy reflects general agreement that our nation needs a highly capable means for the transport of people and goods. Missing from DOT policy, however, is specific attention to the role that aviation plays in stimulating the economy and improving peoples’ lives.

Advances in air transportation, particularly since the advent of jet-powered airliners in the 1950s and 1960s, have significantly facilitated commerce both domestically and internationally.
Consequently, demand for movement by air has increased dramatically. Progress in satisfying passenger demand, however, has been impeded by a lack of planning, efficient implementation of emerging technology, and needed infrastructure.

A comprehensive domestic policy to advance air transportation capabilities and efficiency has not been apparent in the history of U.S. aviation, and does not exist today. Rather, artificially constrained market forces and response to accidents have been the driving factors in the development and governance of air transportation. In some respects, such governance has slowed introduction of technologies or procedures that might have been beneficial for travel and distribution efficiencies.

Perhaps the benefits derived from air transportation are so obvious that government assumes all parties are on the same page and that an overarching policy on air transportation is not necessary. The slow pace of aviation advancements in recent years suggests otherwise.

2. Growth Despite the Absence of Policy

Since the Wright Brothers’ first flight over a century ago, aviation in the U.S.A., initially grew as entrepreneurs and adventurers embraced the opportunity to launch a new and exciting form of transportation. Development, however, was haphazard, leaving many potential benefits aside. Although the Wrights and other Americans, such as Glenn Curtiss, were leaders in the emerging technology of flight, nearly all the aircraft that participated in World War I were European designs.

Fledgling attempts to move mail by air were initiated as early at 1911, led by a local businessman who flew post cards, letters and circulars between a Long Island flying field and the U.S. Post Office in Mineola, New York. No federal funds were involved—the endeavor being formulated and implemented without government direction. In 1912 the United States Postal Service (USPS) recommended that Congress appropriate $50,000 to explore the delivery of mail, but the request was denied. Nevertheless, during that year the Postal Service pursued the concept of air mail and issued permits for private carriers to deliver mail on an experimental basis between nearby locations, incurring no expense to the federal government. In 1916, using appropriations for “Steamship or other Power Boat Service,” the U.S. Congress allocated funds for air mail service in Massachusetts and Alaska, but no bids were received because potential participants were unable to obtain suitable aircraft for the task. (A year earlier, as part of the FY1916 Naval Service Appropriations Act, Congress created the National Advisory Committee for Aeronautics, forerunner of today’s National Aeronautics and Space Administration.) By mid-June, 1918 Congress appropriated $100,000 to establish an experimental air mail route between New York City and Washington, DC, with a stop in Philadelphia. The U.S. War Department furnished aircraft and pilots until the USPS undertook all aspects of the program in August of that year. By September 1920, transcontinental mail service began between New York City and San Francisco. Congress specifically appropriate funds for that route, but other city pairs such as New York/Washington, DC were discontinued.

In the absence of national policy, the sporadic efforts at air mail service took almost 10 years to reach an organized, if minimal, state of development.

The vastness of the continental U.S.A. demanded the capabilities of flight, yet development of a U.S. industrial capacity to deliver aircraft lagged the output of European manufacturers. When the USPS inaugurated service in 1918, the aircraft selected where Curtiss JN4H models powered by engines imported from Hispano-Suiza, a French company. In 1921 the Postal Service selected the
de Havilland DH-4, an aircraft designed in England by Geoffrey de Havilland but manufactured in the USA and powered by the American designed and built Liberty V-12 engine. The beginnings of a U.S. industry were finally taking shape, but slowly.

More than 20 years after the Wrights first flew, Congress passed the Air Commerce Act of 1926 and created the Aeronautics Branch of the U.S. Department of Commerce to oversee the testing and licensing of pilots, certificating aircraft and investigating accidents. Reflecting the expanding importance of commercial aviation, the Aeronautics Branch was renamed the Bureau of Air Commerce in 1934. Soon thereafter, it divided into the Civil Aeronautics Administration (CAA) with particular focus on Air Traffic Control and the Civil Aeronautics Board with oversight of safety regulation and accident investigation.

Although the CAA was tasked to deal with air traffic control, early efforts were largely shaped by the scheduled airlines out of concern that the public’s demand for more flights would result in aircraft colliding. Earl Ward, an employee of American Airlines, is credited with creating the first Control Center; Glen Gilbert, Ward’s assistant, developed the first rules for separating air traffic. A patchwork of national airspace air traffic and safety management systems was forming, largely at the hands of the early airlines.

Although turmoil in Europe began in the mid-1930s and led to the outbreak of World War II in September 1939, the U.S. Government appeared reluctant to embrace aviation as a significant asset of national defense. For example, the importance of NACA research was discounted until literature searches of European documents, including those of countries hostile to the U.S.A., revealed the value that foreign governments placed in NACA efforts. Despite Japanese Army actions in Asia, the Civil War in Spain and the military incursions of Germany in Western Europe, the U.S. lacked a full complement of aircraft when our nation entered WWII in the last month of 1941. The war’s impetus, however, inspired U.S. manufacturers to produce an inventory of fighters, bombers and training aircraft that by the War’s end in 1945 was unrivaled by either our allies or our advisories. This progress in the U.S.A. continued to be led by industry efforts largely in a vacuum of government policy.

In the early 1950s, framed by government policies and investment, European designs paced advances in civil aircraft. Developed in the United Kingdom by de Havilland, the four-engine DH 106 Comet became the first jet-powered airliner when it was introduced to paying passengers in 1952. The four-engine Vickers-Armstrong Viscount, also designed and manufactured in the UK, became the first turboprop-powered aircraft in scheduled service when it began commercial operations in 1953. Unlike the Comet, which experienced three structural failures in flight due to pressurization and fatigue issues that necessitated major redesign, the Viscount was successfully deployed and remained in service for many decades. Both the Comet and the Viscount were programs that resulted from national policy set by the Brabazon Committee, formed by the U.K. government in 1942 to investigate the future needs of the British Empire for scheduled airlines.

Several years later than British efforts to develop advanced civil aircraft, Boeing Commercial Airplane Company’s 707 airliner became the first U.S.-designed and manufactured jet to enter commercial service in October 1958 with Pan American World Airways. Although driven by demand from scheduled airlines for a fast, long-range jet airliner, the design of the Boeing 707 benefited from the U.S. Air Force’s need for a more capable aerial refueling aircraft, to be known as the KC-135 Stratotanker. Hence the prototype Boeing Model 367-80 served as the proof-of-concept prototype for both the civilian transport and the military tanker, and the U.S Military was
Boeing’s first customer for what became the 707. Unlike the Comet and Viscount designs, U.S. air transportation policy did not play a role in development of the Boeing 707 or its competitors, the Douglas DC-8 and the Convair 880/990 series (though clearly U.S. military policy was instrumental in creating the highly successful Boeing 707 airliner).

The same year that U.S. airlines began scheduled operations with jet transports, Senator Mike Monroney (D-OK) introduced a Bill “…to create an independent Federal Aviation Agency, to provide for the safe and efficient use of the airspace by both civil and military operations, and to provide for the regulation and promotion of civil aviation in such a manner as to best foster its development and safety, and air traffic control”. Within nine years the new Agency lost its independent status and became an Administration within the newly formed Department of Transportation (DOT). Responding to President Johnson’s concerns that the U.S. lacked a coordinated transportation system, legislators adopted the position that aviation would be assumed by DOT and governed as one of several modes of transportation used by U.S. citizens. Concurrently, analyses of aviation accidents were transferred to another new federal entity, the National Transportation Safety Board (NTSB).

Had coordination initiated by Sen. Monroney resulted in a national policy for civil aviation, directed from the DOT in the interest of accelerating advancements in technologies and mobility, the legislators’ action might have created the foundation for more widespread industrial, federal, state and local shared vision for air transportation’s future writ large. The continuing shortfalls, both in infrastructure and innovative support for aviation and in intermodal connectivity, are evidence to the contrary.

As Senator Monroney’s vision of an independent agency dedicated to aviation was unfolding, hijacking of airliners became the newest means for expressing political and social discontent. Aligned with passenger safety, hijacking was quick to be addressed by Congress. Within months of the first of several commandeered flights in 1961, President Kennedy signed an amendment to the Federal Aviation Act of 1958 that made hijacking a federal crime and empowered special FAA personnel to carry weapons onboard airlines. Those laws were strengthened significantly following the terrorist attacks on September 11, 2001. Whether dealing with hijacking, terrorism, accidents, or environmental considerations, issues related to public safety rather than civil aviation per se drove legislation as the public’s need for air transportation grew. Regardless of how aviation is governed, safety has always had and continues to have a profound impact.

Under DOT, aviation continued to grow in the absence of national policy that might have shaped and accelerated its progress. Labor issues consumed considerable time of the Federal Aviation Administration’s senior management following the FAA’s formation and were not resolved before several significant work actions disrupted the efficient flow of air traffic.

Market forces also impact government’s approach to aviation. Possibly the most significant Congressional action was the Airline Deregulation Act, signed into law on October 24, 1978. Although numerous companies applied to the DOT and FAA for authorization to be scheduled airlines and many began operations in the years following Deregulation, most new entrants failed. Also during the years following Deregulation, many traditional carriers either closed down or merged with larger airlines. Today, four air carriers (American, Southwest, Delta and United), transport over 75% of all passengers using scheduled service. Furthermore, air carriers in the U.S.A. informally follow a practice commonly called “Capacity Discipline”, which reduces the availability of seats by limiting flights from specific airports and results in more of the available
seats being occupied (i.e., increases load factor). Departures from major hub airports have been reduced by nearly nine percent since Capacity Discipline was introduced; at secondary and tertiary airports departures are fewer by about 2%. Whereas seasonally adjusted load factor for scheduled air carriers was 69.5% in 2000, by mid-year 2016 seasonally adjusted load factor had risen to 83.4%.

Throughout the past decade, under the overall mantel of “NextGen,” Congress and the Federal Aviation Administration have focused on defining and implementing an air traffic control infrastructure that applies advanced avionics technology to improve the efficiency of air traffic movements while maintaining or improving the excellent safety record of air transportation. Progress has been slow, however, and advances are as likely to come from foreign governments and companies as they are from domestic sources. FAA reorganization and changes in managerial processes have not been particularly productive.

Even a brief history of U.S. aviation reveals that governance has been reactionary and ad hoc.

In the absence of overarching national policy, technology and innovative management of the U.S. air transportation system have progressed inefficiently. The U.S government has failed to appropriately acknowledge air transportation as integral to mobility as well as an enabling technology for economic development and improved quality of life.

3. Tragedy Preempts Policy

Safety plays a dominant role in government and public acceptance of aviation as a transportation system. Thus, it is understandable that accidents have been drivers for significant legislation dealing with aviation as well as private sector response.

For example, loss of a Fokker F-10 Trimotor flown by Trans World Airlines on March 31, 1931 resulted in the deaths of all occupants, including the well-known Notre Dame football coach Knute Rockne. Public outcry in response to that accident lead to sweeping changes in many aspects of aviation, ranging from aircraft design (e.g., abandonment of wooden wing spars for air transports) to government oversights of air carriers. The catastrophic midair collision between a TWA Lockheed L-1049 Super Constellation and a United Airlines Douglas DC-7 over the Grand Canyon in June 1956 resulted in significant changes in air traffic management, including mandatory use of instrument flight plans for scheduled air carriers and greater application of radar within ATC. Regulations affecting on-demand carriers were profoundly altered by the loss of a chartered Martin 4-0-4 airliner carrying members of the Wichita State University football team in early October 1970. Often accident-generated changes were subject-specific and not all-encompassing. Case-in-point: FAA rules impacting operational control of air charter companies were found in need of major revision following the NTSB’s investigation of a Challenger CL600 that aborted its takeoff and crashed at Teterboro Airport on February 2, 2005, 35 years after the regulatory reform for on-demand operators resulting from the Wichita State accident.

Truly profound changes in air transportation resulted from the terrorist attacks of September 11, 2001 when four airliners were hijacked. Three of those aircraft were flown into prominent buildings. The fourth, United Flight 93, was commandeered by hijackers apparently intent on crashing the aircraft, a Boeing 757, into either the U.S. Capitol Building or the White House. United Flight 93’s passengers stormed the cockpit and sufficiently disrupted the flight. As a result of their actions, the hijackers apparently lost control of the aircraft, which crashed in a remote
section of Pennsylvania. Congress reacted swiftly, with the most obvious change being the formation of the Transportation Security Administration (TSA).

4. Additional Thoughts

Impressive attempts to achieve a national aviation policy, such as those of the Joint Planning and Development Office (JPDO) during its existence from 2003 to 2014 as well as the efforts of the Aeronautic Science and Technology Subcommittee, et al in 2010, have not borne fruit. The U.S. approach to aviation development and governance continues to be reactionary, not visionary.

With deference to former GE Chairman Welsh’s comments in the Prelude to this chapter, aviation’s leaders are not reading from the same page.

The twin drivers of constrained market forces and safety have shaped governance of air transportation in the USA. While the safety results have been impressive, opportunities for advances in air transportation may have been missed and progress has been far too slow—technology opportunities have moved much faster. An overarching policy that clearly articulates what tomorrow’s transportation/distribution system could be and the role that aviation should play, is needed.

Furthermore, a lack of national policy inhibits achieving a leadership position in the development of a global system for managing air traffic. Since it can be argued that those who define the architecture for a market have a distinct advantage in selling their wares in that market (e.g., think of Microsoft), lack of a focused and nationally accepted policy for air transportation places U.S. manufacturers and service providers at a disadvantage.

The lack of comprehensive policy on aviation has impacted implementation of advanced processes for transportation management and impeded optimum mobility. Vehicle design, regulatory environment, operational efficiencies, and applications of advanced technology have also lagged. There is no doubt that air transportation is essential. The correlation between mobility and benefits has long been established, and policy should draw reference to those relationships to solidify the case for unified national support for investment in transportation technologies and creation of a National and global system for tomorrow. The absence of a clear vision articulated in National policy stands in the way of U.S. global leadership and continued economic and regulatory influence.

5. Policy is Needed Now

Efforts to transform air transportation can easily lose priority in the continuous U.S. debate regarding public investments in infrastructure and social programs. A new dialog, inspired by emerging technologies and lead by a clear vision of comprehensive approaches to transportation and distribution innovation, is required. The concept of On-Demand Mobility provides the theme around which, with NASA leadership, a National program for innovation, investment and implementation can be provoked. Without a clear and compelling policy that focuses the talents and contributions of relevant constituents, the Nation’s transportation system will continue to lose ground to foreign interests, and U.S. regulatory leadership will gradually be assumed by other Nations whose vision and willingness to “leap frog” legacy approaches take better advantage of investments in technology. At a minimum, there should be a compelling, shared vision for ODM and clear policy for implementing that vision.
6. Vision Aligns Constituencies

To coalesce the disperse constituencies that are needed to achieve fruition of bold ideas, leaders state their vision and anchor their concept with a key phase that is easily recalled.

For example, his inaugural address President John F. Kennedy clearly articulated the vision that his administration ushered in a new era “…signifying renewal as well as change…” and “…that the torch has been passed to a new generation of Americans…” His call: “Ask not what your country can do for you; ask what you can do for your country” emphasized the Kennedy vision and became the rallying cry for many bold initiatives of significant value during his brief years in office. In the late 1960s, European aerospace leaders from several countries created Airbus Industries to compete against Boeing, McDonnell, and Lockheed, three independent U.S. manufacturers that collectively made nearly all the airliners sold outside the U.S.S.R. With its vision of unity and rallying cry, “Beat Boeing”, Airbus now splits the market for airliners of 150 or more seats with Boeing Aircraft Company, while McDonnell Douglas and Lockheed as they existed then, eventually vacated the air carrier manufacturing scene.

Vision and words that easily become “top-of-mind” among important constituents are powerful tools for coalescing stakeholders that are essential for success. To be effective, especially within government, vision must be codified in official policy.

7. ODM Involves Many Constituents

Technologies in several disciplines will pace the development of On-Demand Mobility as a transformational form of transportation. Stakeholders influencing the functionality and benefits of ODM are indeed many, including the following:

- Legislators
- Regulators
- Manufacturers
- Shareholders of service providers
- Operators
- Passengers
- Media and Opinion Leaders

Within each category of stakeholders there exist areas of concentration including regulations, airspace management, air traffic control, flight operations and personnel licensing, to name a few, thereby illustrating the multi-dimensional character of ODM implementation.

Furthermore, implementation of advanced transportation technology and architectures, particularly within aviation infrastructure is influenced by several government bodies, such as the Federal Aviation Administration, the Department of Transportation, the Environmental Protection Agency and the Transportation Security Administration. Achieving consensus will indeed be a challenge. The absence of national policy will exacerbate that challenge while clear policy articulation will facilitate a more timely and efficient introduction.

The fundamental challenge of ODM is achieving safe, efficient and easily implemented movement of vehicles optimizing carriage of people and/or goods on the surface and/or through the air between vastly more locations than are presently served by aviation, e.g., “Flying from here to there, anytime, anywhere” (i.e., point-to-point, on-demand mobility). Research is required to
generate non-interfering, minimum-time paths between departure point and ultimate destination, so called Door-to-Door routing. Work in trajectory management and vehicle control, therefore, is required before the architecture of optimal flight paths can be implemented.

Flight path management has traditionally been the role of the FAA. NASA research related to vehicle propulsion systems, flight controls and configuration require alignment with FAA certification. Effective coordination and agreement between NASA and FAA research and governing bodies will be essential, thus emphasizing the need for policy that aligns the efforts of agencies.

Additionally, consumer considerations must be addressed. To implement emerging ODM technologies and to encourage operators to offer ODM services, regulatory compliance must be more easily negotiated, cost of entry (i.e., vehicle acquisition and operating economics) must be affordable, and operations must be safe and efficient. NASA/FAA, the public, as well as service providers must see the same vision and work together to achieve a national policy on ODM.

To be implemented, ODM services will require new DOT and FAA regulations as well as a fresh look at existing regulations currently designed for existing and legacy transportation providers. For example, Part 380 of the U.S. Department of Transportation regulation requires interested operators that wish to arrange public charter flights first to submit a charter prospectus to the Special Authorities Division of DOT with information required by the DOT regulation about the proposed transportation services. Federal Aviation Regulations have established FAR’s barriers or gates that differentiate classic charter from scheduled service. (e.g., Commuter operators are defined as providers of at least five scheduled round trips per week, while on-demand operators provide scheduled flights for paying passengers with five or less round trips per week. Neither definition facilitates ODM.) Broadly, the entry requirements to engage in public transportation are extensive and convoluted. Timely introduction of ODM will be constrained if the regulatory environment discourages new entrants and impedes the application of essential technology leading to new flexibility, greater efficiency in scheduling, increased frequency of travel, and lower costs.

It seems highly unlikely that legislators will initially permit a laissez-faire approach to On-Demand Air Transportation that mirrors the transformational impact of Uber and Lift on the surface taxi cab market. There may be a need, however, for integrating the “Uber-like” process, thinking and technology that has connected market demand with customer need, resulting in significant traction within ground travel. Today, much air transportation capacity is unused because Federal Aviation Regulations are not aligned with technology that is capable of matching potential air vehicle seats with passengers in need of travel.

Implementation of ODM will be complex, and many of the issues involve interfaces between technology, acceptability, modes, demand and other non-technical considerations. For ODM’s introduction to succeed, and for the realization of substantial National benefits achievable with greater mobility, NASA’s leadership and research must be coordinated with other government agencies, with industry and with the will of legislators.

The absence of unifying National policy regarding ODM condemns synergy between relevant departments and agencies to unacceptable delay and possible failure.
8. Operator and Stakeholder Interviews and Regulatory Considerations

Policy presents a focal point for viewing relevant information, processing input, developing solutions and implementing innovative concepts. As part of the process of gathering information, operators currently engaged in Air Charter or Business Aviation (presumably among first adopters of a future ODM system) were asked to respond to the following questions:

- **Do you face challenges with government oversight from FAA or DOT that would be more easily and productively resolved if a national policy supporting air transportation existed?**
- **Would a national policy on air transportation be helpful to your business?**
- **Are there technologies that NASA can and should pursue that will improve mobility using on-demand air transportation, thereby facilitating economic development and improved quality of life; and if so, would a NASA position on such technology be significant in developing an overall national policy on air transportation?** For example:
  - What technologies would be needed to enable more travel by air on-demand
  - What technologies would assist current providers, such as your company, and future providers of On-Demand Mobility?
  - Would improving the ease or efficiency of flying the aircraft you operate provide a transformational new dimension of On-Demand Mobility?
    - An ATC system (possibly 4D) that enabled more flexible routing
    - Improvements in ATC, such that flights could be flown more efficiently
    - Applications of technology that would make aircraft easier to fly (e.g., linking the autopilot directly to ATC, possibly using CPDLC or drone-like systems)
- **What benefits (either economic, quality of life or both) do you feel would result if there were greater use of On-Demand Transportation?**
- **What technologies would be needed to ease the regulatory burden of achieving FAA and/or DOT approval to provide On-Demand Transportation?**
  - What FAA and DOT regulations would you recommend be changed to facilitate On-Demand Transportation such as your company provides?

**Response**

A common theme emerged from the selected set of operators who responded to the questionnaire. To fully realize the benefits that air transportation could provide, a more capable air traffic management and control system is required. Operators want the ability to fly great circle routes in a wider range of reduced visibility and weather conditions, on demand. Interviewees suggested that today’s ATC system is inefficient, difficult to utilize without sophisticated training, and requires high levels of recent experience by operators. Whether utilized by commercial or private operators, ODM will demand a more capable air traffic management system. The also expressed the need to apply technology to reduce the cost of manufacturing and certification of future aircraft.

The objective of an advanced ATM system would be as follows:
Accommodate greater traffic density while reducing the labor needed to achieve separation
  - Significantly lower or eliminate pilot workload
  - Significantly reduce dependency on human monitoring of traffic
- Direct, most efficient or operator-desired routing must be provided to all current airports in the U.S.A., and ultimately to landing facilities as yet undefined.
- Air traffic services from the ground to the flight levels everywhere, beyond the current architecture serving a relatively small total volume of the nation’s airspace at a relatively small fraction of the total landing facilities in operation today and in airspaces that will become valuable for operations in the future (by UAS as well as ODM aircraft for example).

Another common theme is the need to apply technology to reduce the cost of manufacturing and certification. Respondents expressed their conviction that air transportation was an enabling capability for advancing economic and life quality benefits. All parties interviewed felt that policy formulation would be beneficial in focusing the nation’s resources on expanding the use of air transportation to markets not presently served.

9. Regulatory Restraints vs. Regulatory Enablers

Aviation safety derives benefit from regulations that identify risk, restrain dangerous practices, and assure protection of life and property. For On-Demand Mobility to be accepted as a viable means of transportation by the public as well as by government, it must be safe—not only in fact but in perception. Thus, appropriate regulatory oversight of ODM is essential.

An ODM system, however, will incorporate new technology. Existing regulations are based upon legacy and current technology. New regulations applicable to ODM will be needed, and those new regulations must at least reflect the application of current advances as well as anticipate emerging technology to serve the safety and efficiency of On-Demand Mobility.

Operators interviewed for this study emphasized that regulations should reflect how technology can shape governance of ODM operations. For example, technology that simplifies flight should be a factor in specifying the minimum qualifications for pilots in commercial operations as well as licensing for non-commercial operators. All aspects of the aviation infrastructure—aircraft design, certification, operation, personnel qualifications (air and ground-based), inspection, airport certification, airport operations and security, must be considered. An unambiguous ODM policy generated with stakeholder input and resulting in consensus is essential. Policy aligns objectives of diverse stakeholders and beneficiaries. Failure to establish a policy that considers and incorporates the widest range of relevant inputs would be unwise.

Each element of ODM architecture invites alternatives or a new approach. For example, the current regulatory requirement for 1,500 hours of experience for Charter Captains discounts added safety that advanced technology such as automation offers. Advanced ODM vehicles would challenge such arbitrary prescriptions, and ODM implementation might be delayed if review and revision is not undertaken. Aircraft certification is fraught with similar pitfalls. Future regulations must consider capabilities inherent in the enabling technologies of ODM.

Again, a clear ODM Policy will facilitate and encourage development of appropriate regulations requisite to safety while encouraging development of On-Demand Mobility. Policy will enable
NASA Strategic Framework for On-Demand Air Mobility

NASA to work effectively with traditional and non-traditional users, service providers and investors to counter inappropriate regulatory barriers and to create a positive regulatory structure necessary to the expeditious introduction of On-Demand Mobility.

10. Policy Must Reflect Vision and Facilitate Progress

Chapter 6, sections 6.1 and 6.1a presents the case for creating a national transportation policy incorporating On-Demand Mobility. Reflecting the need for coordination between stakeholders, section 6.2 summarizes interviews with current operators. Other chapters within this document—The NASA Strategic Frameworks for On-Demand Mobility—define the characteristics and benefits of ODM and make the case that NASA should research and develop the enabling technologies for a successful ODM system. Section 6.3 summarises key regulatory issues that must be addressed nationally and locally for ODM to become a reality. Furthermore, Section 6.3 continues the assertion that an unambiguous policy embracing ODM is required to focus efforts and resources of enabling constituents.

While the novelty and excitement of aviation’s early era might have obscured the need for national policy in the past, there is no chance this will be the case for On-Demand Mobility. Enablers of ODM, particularly Members of Congress who will need to authorize funding, the media covering government programs, and the leaders of public opinion, must embrace the ODM vision as an application of advanced technology to transform the movement of people and material. Architects of ODM must avoid pitfalls of ad hoc planning by ensuring the articulation, adoption, and publication of a clear National Transportation Policy in which ODM is unambiguously incorporated.

11. Establishing New Processes

On-Demand Mobility envisions a new mode of travel using technology-enabled vehicles that can provide air transportation to virtually any location at any time, at lower cost and with fewer negative externalities than those associated with aviation today. On-Demand Transportation incorporates:

- Utilization rates that are significantly higher than today’s general aviation and charter aircraft.
- Lower costs that result from increased manufacturing volume and higher user demand
- Optimized trajectories that are dynamically determined.
- Operations that employ greater use of automation (probably verging on fully autonomous flight management).
- Activity levels that will inadvertently, but systematically increase public acceptance in areas of noise, pollution and safety.

Existing regulations may be unable to facilitate ODM and may actually impede the introduction of ODM. Furthermore, local, regional and state authorities may wish to impose other considerations on a system as potentially ubiquitous as ODM, thereby adding levels of government oversight.

Relevant Regulations Needed

Recognizing that Federal Aviation Regulations reflect an earlier era in aviation’s development, the FAA recently revised FAR Part 23 to transition from detailed prescriptive standards for aircraft
manufacture to a performance-based approach under which the agency establishes the performance objectives for new products and gives manufacturers flexibility on how regulations will be met. While the revisions were helpful for today, Part 23 will still be inadequate for reducing the manufacturing cost and certification time for systems that have no precedent in today’s general aviation and/or commuter operations.

Manufacturers of general aviation and commuter aircraft have no experience with Performance-Based Certification (PBC), particularly as it will be applied to ODM. Research is needed to reduce the risk that the Original Equipment Manufacturer (OEM) will assume in implementing new ODM technologies in accordance with the agency’s revised FAR Part 23. For example, what should be the performance standards for passenger-carrying aerial vehicles, battery-powered and capable for vertical takeoff and landings, operating many cycles per day and incorporating a high degree of automation? Neither designers, manufacturers nor the FAA have experience certifying such systems.

Historically, FAR Part 23 reflects the traditional use of small aircraft that operate on average less than 200 hours annually. Data collected from the FAA’s General Aviation and Part 135 Activity Survey for CY 2015 show that multi-engine piston-power GA aircraft fly on average 121 hours annually and single-engine piston-power aircraft 91 hours. Turboprop GA aircraft during CY 2015 flew 261 hours. Activity levels for Part 23 aircraft used for air taxi and commuter operations flew about 400 hours annually. The application of a revised yet untried FAR Part 23 to a radically new vehicle such as envisioned for ODM faces several issues, not the least of which is a utilization rate greater than the typical aircraft certified under FAR Part 23.

Furthermore, a transportation system centered on ODM concepts touches more Federal Aviation Regulations than simply the airworthiness standards of Part 23. On-Demand Mobility will challenge many of the norms that are codified in such regulations such as FAR Part 61 (Certification of Pilots, Flight Instructors and Ground Instructors), FAR Part 119 (Certification: Air Carriers and Commercial Operators), FAR Part 135 (Operating Requirements: On-Demand Operations and Rules Governing Persons on Board Such Aircraft), FAR Part 139 (Certification of Airports), FAR Part 141 and 142 (Flight Schools and Training Centers, respectively), as well as other aspects of federal oversight of aviation.

For example, FAR Part 135.4—Applicability of rules for eligible on-demand operation—specifies that aircraft must be flown by a two-person crew; the captain must have a minimum of 1,500 flight hours, the second in command must have a minimum of 500 flight hours; and if the aircraft is powered by more than a single powerplant, the captain must hold an Airline Transport Pilot rating, among other requirements. Since vehicles envisioned for ODM may employ electrical propulsion systems, vertical takeoff and landing capabilities, advanced autopilots, and are envisioned to be autonomous (or at a minimum be highly automated), the requirements of FAR Part 135.4 are not aligned with the level of knowledge and skill a pilot-in-command would need to operate an ODM vehicle.

On-Demand Mobility, the capability to fly from here to there, anytime, anywhere, also requires a fresh look at airspace management and control. Air vehicles will be operated with a high degree of automation verging on being autonomous. Flight paths will be defined by 4-D coordinates where the fourth dimension is time. NASA’s ability to simulate such a concept of air traffic management and control should be used to provide supporting data and recommendations to the FAA for appropriate ATM and ATC for ODM operations.
Clearly, existing Federal Aviation Regulations must be reviewed and most likely revised to provide efficient and effective oversight of On-Demand Mobility and to facilitate implementation of such a transformational form of air transportation. Research that defines what is required will be needed.

12. Seeking Consensus

On-Demand Mobility involves radically new vehicles and concepts of operation, as well as an expanded community of interested parties. Technical stakeholders include government regulators, research organizations, academia, existing operators of transportation systems, and entrepreneurs exploring new business opportunities. Consumer stakeholders that move people and goods are also key elements in the success or failure of ODM. Indirect stakeholders include local governments that regulate land use.

For ODM to be implemented, all stakeholders must agree that ODM offers significant value and be willing to establish a suitable regulatory structure for its implementation. Achieving consensus among all stakeholders is a necessary first step in establishing a regulatory process for vehicle manufacturer and operation.

Precedents exist that illustrate how consensus can be achieved. The aviation community’s approach to Fractional Ownership, a novel interpretation of FAR Part 91 that became very popular in the latter years of the 1990s, provides a reference for how NASA and FAA might collaborate in developing regulatory oversight of ODM. The FAA created an Aviation Rulemaking Committee (on which NASA participated) consisting of constituents from relevant elements of the aviation community to propose appropriate FARs for Fractional Ownership operations. The result was FAR Part 91K, a new regulation accommodating fractional ownership that was approved by the federal government and accepted by the aviation community.

Formulation of FAA requirements for crash resistant seats and the use of shoulder harnesses in Part 23 aircraft also offers an example of how NASA might assist the Federal Aviation Administration oversee ODM. Research on crash characteristics of GA aircraft was conducted at the NASA Langley Research Center between the late 1960s and early 1980s. Findings from that research program were used to revise FAR Part 23 to require higher g-loads for testing seats on GA and commuter aircraft (see FAR Part 23.561).

NASA’s role in supporting the work of the Joint Planning and Development Office (JPDO) on formulation of the Next Generation Air Transportation System also presents a useful example of how consensus can be developed.

Clearly, formulating regulatory and operational structures that enable On-Demand Mobility to serve the nation’s needs economically and socially will require agreement by many diverse constituencies. Unless those diverse participants share NASA’s vision of ODM—unless everyone is reading from the same page, so to speak—and are directed by a unifying ODM policy, progress will be highly inefficient and might not be possible.

13. Essential Areas for ODM Development and Operation

NASA is positioned and has the opportunity to lead research related to many technical areas, including:

- Vehicle design
NASA Strategic Framework for On-Demand Air Mobility

- Propulsion system
- Control system
- Lightweight materials
- Configuration optimization
- High-volume/low-cost manufacturing
- Effect of high utilization rate on maintenance, dispatch availability and useful life
- Vehicle certification

- Vehicle operation
  - Characteristics of various operating modes
    - Semi-autonomous
    - Autonomous
  - Failure modes and effects analysis
  - Flight crew training
  - Maintenance crew training

- Air Traffic Management & Control
  - Integration with existing users of the legacy ATC/ATM system
  - Optimum implementation of 4-D airspace management

- Airport design and site planning
  - Ground-handling reliability and safety for OEM operations
  - Vehicle noise
  - Vehicle emissions
  - Public perception of ODM benefits and negative externalities

- Vehicle economics
  - Cost analysis of manufacturing
  - Costs analysis of operating modes
  - Cost analysis of ODM as a transportation system

- Technical expertise and research to provide an objective assessment of ODM

NASA research is essential to identify, to quantify and were possible, to reduce the development and implementation risks that champions of On-Demand Mobility will confront as early adopters of such a transportation system.

14. Summary

The strategic challenge for aviation lies in how best to support concurrent progress in safety while integrating technology and business-driven innovations into a national system for On-Demand Mobility. Policy, in this regard, provides a framework for shaping investment portfolios for relevant federal departments and agencies as well as for private industry.

Based upon the findings presented in this report, the authors envision a transformational transportation system involving air vehicles to safely and affordably move people and goods, on demand, between vastly more locations than currently possible, and to do so potentially faster and more efficiently than with currently available systems. Articulating the collective vision of ODM and its contributions to society, NASA should exert leadership in formulating national policy for On-Demand Mobility and conduct unique research relevant to ODM.
Once formulated, a national ODM policy will enable legislators, regulators and the public to read from the same page. Objectives will be clearly identified, priorities established, and progress achieved.

15. Findings and Recommendations

Finding 6.1—Aviation development in the U.S.A. was shaped primarily by market forces and response to accidents.

Finding 6.2—The U.S.A. does not have a definitive policy on air transportation.

Finding 6.3—Entities likely to develop or operate advanced vehicles for On-Demand Mobility believe that existing regulations will impede and potentially prevent the implementation of On-Demand Mobility.

Finding 6.4—A clear vision that is easily imagined, reinforced by a memorable message and memorialized in policy, is a powerful force for coalescing constituents to advance new ideas.

Recommendation 6.1—NASA should propose an overarching policy for implementing the vision of On-Demand Mobility that provides air transportation from here to there, anytime, anywhere.

Recommendation 6.2 — NASA, together with a body of stakeholders should identify a comprehensive set of ODM policy issues and sponsor a policy research effort to determine the impact of alternative policy options. In this way, informed policy decisions can be made

Recommendation 6.2—NASA should convene representatives from the broad spectrum of stakeholders that would benefit from On-Demand Mobility, with the goal of supporting the development of an appropriate regulatory framework for ODM vehicle manufacture, certification and operation.

Recommendation 6.2.1 – The Fractional Ownership Aviation Rulemaking Committee that developed FAR Part 91k, and the General Aviation Safety Committee that provided leadership for enhanced survivability of Part 23 aircraft, are examples of committee formulation and action that NASA should facilitate.

Recommendation 6.2.2 – NASA should include diverse representation from traditional and non-traditional stakeholders that would participate in and benefit from On-Demand Mobility.

Recommendation 6.3 – NASA should support the following Policy Statement:

Whereas existing technology is capable of significantly expanding the use of airspace for the safe, productive and efficient use of aerial vehicles, whether piloted, semi-autonomous or fully autonomous, either scheduled or on-demand, it is the policy of the U.S. government to support innovation, development, and implementation of aircraft and Air Traffic Management systems that facilitate On-Demand Mobility.
Chapter 7 – Stakeholder Outreach Planning

1. Introduction

As discussed in Chapter 4 (Organizational Contributions and Roles), achieving the vision for on-demand air mobility requires a systemic and interdependent set of advancements by a range of participants across several domains, including stakeholders, collaborators and contributors with both complementary and sometimes competing interests in an advancement like ODM. We propose that each of these domains must be engaged, through organized outreach, to garner support for the ODM concept and benefits.

2. Stakeholder and Participant Outreach Workshops Plan

This chapter suggests candidate outreach planning, including workshops to engage the broader community of stakeholders, beneficiaries, and participants in promoting and contributing to the ODM vision. The national experience during the early 2000s in rallying a diverse community of stakeholders around the U.S. NextGen vision and ultimately the program, can serve as a model for this approach. The success in that endeavor can be attributed in part to the inclusion of broad audiences of stakeholders in promoting the NextGen vision and benefits.

The target domains include at least the following:

- Economic development organizations
- State and local aviation officials
- Airport authorities
- Land-Use authorities
- Travel and entertainment industry
- Transportation security community
- Aviation services and suppliers

A candidate agenda for a prototypical outreach workshop process is as follows:

I. ODM Vision
II. ODM Public Value Proposition
III. ODM Safety and Environmental Considerations
IV. Stakeholder Domain-specific Implications for ODM operations and services
V. Breakout Discussion Groups on Strategic Implications
   a. Political
   b. Legal
   c. Environmental
   d. Operational
   e. Economic
   f. Societal
VI. Plenary Reporting by Discussion Groups
VII. Action Planning
3. Outreach Planning Schedule and Resource Requirements

This section was intended in the original project technical plan to document a draft schedule and resource requirements for executing an outreach initiative. Following the advice of the project clients at NASA HQ/ARMD, we are developing an outreach plan with limited fidelity. The reason for this approach is that NASA program portfolio decisions are yet to be made regarding investments in a focused activity on ODM. Therefore, the need for a detailed outreach workshop schedule is premature.

When the time comes, NASA should organize a national Outreach Workshop Planning Committee, perhaps initially comprised from the following organizations:

- A4A (Airlines for America), [http://airlines.org](http://airlines.org)
- NASA HQ ARMD
- Department of Commerce
- Department of Defense
- DOT
  - Volpe National Transportation Systems Center [https://www.volpe.dot.gov](https://www.volpe.dot.gov)
  - Office of the Assistant Secretary for Transportation Policy [https://transportation.gov](https://transportation.gov)
- Leading ODM industry executives and trade associations
- National Business Aviation Association (NBAA), [https://www.nbaa.org](https://www.nbaa.org)
- National Air Transportation Association (NATA), [http://nata.aero](http://nata.aero)
- General Aviation Manufacturers Association (GAMA) [http://www.gama.aero](http://www.gama.aero)
- U.S. Chamber of Commerce, [https://www.uschamber.com](https://www.uschamber.com)
- U.S. Economic Development Administration (EDA), [https://www.eda.gov](https://www.eda.gov)
- National Rural Economic Development Institute (NREDA), [http://www.nreda.org](http://www.nreda.org)

This committee would be responsible for finalizing a schedule of workshops, providing resources, hosting workshops, and assigning participants from their organizations in the workshops.

4. Venues

The candidate venues for the proposed Stakeholder Outreach Workshops should be organized where appropriate to leverage annual or regional conference and symposia hosted by the domain-specific groups. Examples include the following:

- National and Selected State/Regional Economic Development Conferences
- American Association of State Highway Transportation Officials Conferences (AASHTO)
5. **Summary**

The proposed categories of stakeholder outreach workshops should engage some organizations with which NASA does not customarily have relationships and interactions. This aspect of the outreach workshop concept argues for the development of an assignment by NASA of a facilitator for such planning such interactions. Candidates for this facilitator role could include, for example, the Volpe NTSC in Cambridge Massachusetts, the National Institute of Aerospace in Hampton, Virginia (which conducted such workshops earlier for ODM), the U.S. Chamber of Commerce, or other candidates. The outcomes of these outreach workshops would include strategic input from the communities at large for the ODM technical, policy, and regulatory community’s strategy execution; facilitation of ownership and buy-in within communities at large for the ODM vision and public value proposition; and the establishment and education of the broader public about the ODM potential for economic and quality of life contributions.

6. **Findings and Recommendations**

**Finding 7.1** – Workshops and other gatherings of stakeholders have been successful in addressing programs affecting a broad community of implementers and beneficiaries.

**Finding 7.2** – NASA has a history of organizing and facilitating large-scale programs requiring input from a diverse community of stakeholders

**Recommendation 7.1** – NASA should assign a facilitator for planning workshops and similar interactions with a broad community of obvious and latent stakeholders that would be engaged in On-Demand Mobility.

**Recommendation 7.2** – NASA should assume a leadership position in the overall ODM outreach program and facilitate participation by other government agencies as well a private industry.
Appendix 1: Literature Review Annotated Bibliography

Dr. Roger A. Parker, AirMarkets Corporation
Dr. Laurie Garrow, Georgia Tech and Atlanta Analytics


Appendix 2: The Models Used by the AirMarkets Simulation

Dr. Roger A. Parker, AirMarkets Corporation

The Trip Generation Model (TGM):

Assume $P_i$ is the population of city $i$ in time period $t$, and let $T_i$ represent the total trips taken by passengers originating in that city during that time. Thus $C_i = T_i / P_i$ is the period $t$ per capita trips from city $i$. The dependent variable is the logit transformation of per capita trips. The logit transformation is a common method used to stabilize variance in a bounded variable, such as a proportion as used here. The specific model form is

$$y_{i,t} = \ln \left( \frac{C_i}{1 - C_i} \right) = \alpha + \beta g_{i,t} + \lambda u_{i,t} + \phi_1 c_{i,t} + \phi_2 c_{i,t}^2 + \varphi J_{i,t} + \delta A_{i,t} + \sum_{v=1}^{V} \theta_v I_v + \eta y_{i,t-1} + \epsilon_{i,t}$$

In this formulation, the Greek letters represent empirical coefficients estimated from available data. The independent variables are as follows (in all cases $i$ denotes the city and $t$ the time period):

- $g_{i,t} = \text{the population growth rate for the city},$
- $u_{i,t} = \text{a measurement of labor activity for the city, such as the unemployment rate produced by the Bureau of Labor Statistics of the U.S. Government},$
- $c_{i,t} = \text{a measure of general economic activity for the city, such as gross domestic product or the Coincident Index of Economic Activity produced by the U.S. Federal Reserve Bank},$
- $J_{i,t} = \text{the average jet fuel price for the time period},$
- $\Delta f_t = \text{the change from the prior month of the 3rd nearby NYMEX oil futures price},$
- $I_v = 1 \text{ if the time period equals } v, 0 \text{ otherwise, normalized to period } V, \text{ where } V \text{ is the number of time periods in a year},$
- $y_{i,t-1} = \text{the value of the dependent variable lagged one time period}.$

The population, economic indices and jet fuel price are straightforward. For U.S. cities, the government produces appropriate data, which is also readily available in Europe and other developed parts of the world. For less developed areas, the World Bank produces the best data available for economic measures. The oil futures price change accounts for the future price of oil, which is highly correlated with airline ticket prices. Oil price and futures price information can be collected from petroleum industry sources. The summation term accommodates adjustment parameters for seasonal effects, where the empirical coefficients estimate the time effect and the indicator functions ($I$’s) designate the appropriate coefficient to use for the period that is represented by $t$. The lag term reflects the autocorrelation between trip production in one period and trip production in the previous period. The term $\epsilon_{i,t}$ represents the usual stochastic error term associated with regression analysis.

With the logit of the per capita trips known, the total number of generated trips is readily computed using the inverse of the logit transformation. That is,
The empirical coefficients found in the basic per-capita model are calculated by using weighted least-squares regression of the independent variables for a given city against the air trips observed to originate in that city, as described in Parker (2011). Statistically, as econometric models go, these are reasonably good. Within the United States, for example, $R^2$ vary from 0.969 (for Oakland, California) to 0.309 for Grand Forks, Iowa. The average is 0.788, with 81% of the models having values over 0.7. Indeed, the median $R^2$ value is 0.804.

**Trip Distribution Model (TDM):**

While a separate trip generation model exists for each city, only one trip distribution model is required for the estimation of the travel in an origin-destination city pair. Let $p_{ijt}$ be the fraction of the passengers who originate in city $i$ and fly to city $j$ in period $t$. As is the case with the TGM, the dependent variable is the log odds of this probability. (This stabilizes the variance of the bounded variable $p_{ijt}$.) The model form is

$$z_{ijt} = \ln \left( \frac{p_{ijt}}{1 - p_{ijt}} \right) = \mu f^*_{ijt} + \lambda d_{ij} + \lambda^2 d_{ij}^2 + \lambda^3 d_{ij}^3 + \lambda^4 d_{ij}^4 + \pi v_{ijt-1} + \tau \sum_{q \in Q} w_q A_q + \xi_{ijt},$$

In this formulation, as before, the Greek letters represent empirical coefficients estimated from available data, while the Roman letters signify independent variables. The independent variables in this equation are as follows:

- $f^*_{ijt}$ = the fare proxy (instrumental variable) for flights between city $i$ and $j$ for time interval $t$.
- $d_{ij}$ = the great circle distance between city $i$ and $j$.
- $v_{ijt-1}$ = a measure of the travel resistance caused by the air travel network, called the network impedance, connecting origin $i$ with destination $j$, as calculated for period $t-1$.
- $w_q$ = the so-called Destination Fixed Effects (DFE) of destination $q$ from the set of destinations which are connected to the origin $i$. $A_q = 1$ if $q = j$, 0 otherwise.

The term $\xi_{ijt}$ represents the error term associated with linear regression analysis.

When compared to many regression-type equations, these independent variables are rather complex, and warrant a separate discussion to make their derivations clear. That discussion is presented below.

Again, once the log odds a computed, a simple transformation returns $p_{ijt}$ from $z_{ijt}$. Quite simply

$$p_{ijt} = \frac{e^{z_{ijt}}}{1 + e^{z_{ijt}}}.$$  

As with the TGM models, coefficients were estimated using weighted least-squares regression analysis on the available data. The $R^2$ value for the model is 0.8364, quite respectable for an econometric model such as this. All the coefficients are significant at the 0.05 level except the second and third powers of distance, but since there is no computational or data cost in leaving them in the equation, the slight increase in fit is essentially free.
The original analysis was performed using 2008 and 2009 data. It has been updated with 2015 values of the independent variables.

There are four independent variables in this TDM model – Fare Proxy, Distance, Network Impedance and Destination Fixed Effect. Three of these (all but distance) are significantly more complex than the variables found in the TGM. Because of their relative complexity, each is discussed in this Section in substantial detail.

The first is the simplest – distance. This is the great circle distance, \( d \), between the city pair. Clearly, if A and B are two cities, the distance from A to B is the same as from B to A. Notice that there are four terms in the TDM estimation equation involving \( d \), being \( d \) to the first to fourth power. There are four distance terms to capture anomalies associated with distance (if any), and because they cost next to nothing to add to the model while improving the fit to a minor degree.

In a model such as this, fare is endogenous. That is, demand depends on fare so the fares are not independent of demand, and cannot thus be a proper independent variable in the model. To address this problem, a so-called instrumental variable is used. The effect of an instrumental variable is to create a proxy for fare that is independent of the demand. Several authors discuss instrumental variables and their appropriate use in econometric modeling, including Jung and Fuji (1976), Evans et al (1993), Morrison and Winston (1990), Angrist and Krueger (2001), Katz (2001), Espasa et al (2002), Greene (2003), Hahn and Hausman (2003), Gillen et al (2004), and Morrison et al (2005).

The fare proxy instrumental variable used in this model is given by

\[
 f_{ijt}^* = \alpha + \beta t + \sum_{j=1}^{K} \gamma_j I_j + \delta f_{ijt-1}.
\]

In this equation, as usual, the Greek letters are empirical parameters. \( f_{ijt}^* \) is the fare proxy value for fares from \( i \) to \( j \) at period \( t \). The \( f_{ijt-1} \) is the actual observed average fare in the \( ij \) market lagged one period, to \( t-1 \). The summation expression represents a constant which reflects the unique time period effect on fare. The parameters include empirical coefficients that result from the time series regression of fare described below, and the \( I_j \)'s are indicator variables for the respective periods; that is, equal to 1 if \( t \) is that period and 0 otherwise.

An analysis of 10,000 fares supplied by the U.S.BSP was used to estimate the parameters of the fare proxy. The adjusted \( R^2 \) value for the model is 0.93, quite remarkable for an econometric analysis such as this.

The third independent variable in the TDM addresses the network of services supplying the travel options available to the air passengers. The network itself has an effect on demand beyond just the fare of an itinerary connecting origin \( i \) with destination \( j \). This is called the network impedance. For example, nonstop air routes are preferred to one-stop itineraries, as they are more convenient and generally faster. Thus, the allocation of travel is to some extent affected by the network configuration. Measuring the network configuration has been an issue in all air travel demand modeling (see, for some perspectives, Jung and Fuji (1976), Borenstein and Rose (1994), Saab and Zouein (2001), Brons et al (2002), Brueckner (2004), Berry et al (2006), and
Parker (2010)). It is also true that the travel network always impedes, rather than enhances, the ability of a passenger to move from an origin or destination (unless one is flying purely for the joy of riding on an airplane).


Inclusive value is a term that refers to the expected maximum utility for a finite set of choices. That is, if we have a discrete choice model, the concept of the probability of each available choice is well-defined, and thus we can compute the mathematical expectation of functions of that choice structure, the expected maximum utility. See Ben-Akiva and Lerman (1985) and McFadden (1999) for more in-depth discussions. As the network connecting an origin city with a destination city changes, with improvements in the service (such as the addition of an ODM service) or reductions in service (such as the elimination of routes), the air passenger’s expected maximum utility as defined by the discrete choice model representing the passenger’s selection decision will also change. Thus, the expected maximum utility measures how “good,” (or more accurately, how “less bad”) a particular network configuration is – a direct measure of impedance.

Let $V_{ij}(m)$ represent the utility of alternative service option $m$ connecting the origin $i$ to the destination $j$. Let $M$ be the set of all such options. Then, under conditions which are discussed below, the probability of a passenger choosing option $m$ is

$$\Pr[m] = \frac{e^{V_{ij}(m)}}{\sum_{n \in M} e^{V_{ij}(n)}}.$$  

This is the classic multinomial logit model of choice. The expected maximum utility for the set of alternatives $M$ is given by (McFadden, 1999, p 259)

$$E\left(\max_{m \in M} (V_{ij}(m))\right) = \ln \left[ \sum_{n \in M} e^{V_{ij}(n)} \right].$$

Notice that the expression in the square brackets is exactly that in the denominator of the logit model above. For obvious reasons, this quantity is referred to as the log sum.

The log sum for a given OD market can be readily computed from the AirMarkets Simulator. The simulator is used to define the itinerary set for a specified market, and then the maximum
utility is calculated for a random sample of passenger agents. The impedance measure is the average of these computed maximum utilities. The averaging is required because each passenger agent uses a somewhat different utility function, and expected (average) maximum utility is the desired measure. The results of the calculation are then stored in a matrix for use in the TDM. When the model is applied, the appropriate value required for the calculation of the distribution proportion is extracted from the table as variable $v_{ijt}$. Also, note that the impedance measure contained in the equation is lagged one period, to avoid the endogeneity that would arise from using a contemporaneous value.

The final independent variable in the TDM is the Destination Fixed Effects (DFE) term. To a certain degree, every city has a unique “attractiveness.” Orlando attracts many people because of the theme parks located there: Cleveland, not so much. To measure the attractiveness, ticketing data from various sources – e.g., DB1A and DB1B in the United States, IATA data elsewhere in the world – is used to estimate the constant value which best fits the observed ticket level, given the distance, fare, and impedance values independently estimated. The value is denoted $A_q$ in the TDM equation. The DFE is a constant for each origin city. In the expression

$$
\sum_{q \in Q} w_q A_q
$$

$Q$ represents the set of cities in the model, $w_q$ is an indicator function that has the value 0 if $j \neq q$, and 1 otherwise, and $A_q$ is the DFE for city $q$. Thus this expression has the effect of providing the correct DFE for the destination city $j$ being considered. The coefficient $\mathbb{1}$ in the distribution model equation modifies the DFE values for data sets that are subsequent to those used in the original function parameter estimation.

In the estimation and calibration of the TDM model parameters used in the AirMarkets Simulator, the proxy fare was calculated from the fare data, and the distance and DFE drawn from tables that were built from calculations based on ticket sale data by market and survey data collected by the Boeing Company in the first half of the first decade of this century. The impedance was calculated from executions of the code in the AirMarkets Simulator that represents the choice function for air passengers. See Carson et al (2007) for details on how these calculations were carried out.

The Discrete Choice Model of Travel Options.

Let $K$ be the set of options that traveler $i$ has available to him for travel from $i$ to $j$. Then, let $U_i(X)$ be the utility of option $j$ for traveler $i$, which is a function of one or more independent variables, like purpose of the trip (business or leisure), or the cost (fare) and trip duration associated with option $j$ represented by the symbol $X$. It must be assumed (both philosophically and practically) that $U$ is itself a random variable, since it is impossible to know all the features of $i$’s choice selection process. Thus, in the literature, we see the utility written as $U_i(X) = V_i(X) + \epsilon$, where $\epsilon$ represents a random term.\(^53\)

\(^{53}\) This is like classical regression analysis, where there is an added random term to represent the unknown aspects of the modelling effort.
Then, under reasonable assumptions about the nature of the decision process being modeled, and appropriate assumptions about the probability distribution associated with the random term $\epsilon$, the probability that traveler $i$ selects option $j$ is given by this equation:

$$
Pr[i, j] = \frac{e^{V_{ij}(X)}}{\sum_{k \in J} e^{V_{ik}(X)}}.
$$

The utility function $V_{ij}(X)$ is the key component of this formulation. The symbol $X$ refers to a collection of option attributes and associated passenger characteristics that are important to how the choice is made. How it is derived is beyond the scope of this discussion, but details can be found in many texts, including Ben Akiva and Lerman (1985), Louviere, Hensher and Swait (2000), Train (2003), and for the specific case of this problem, Garrow and Parker (2007), Parker (2010) and Garrow (2012).

The specific equation form of $V_{ij}(X)$ used by the AirMarkets Simulator is given by the following expression.

$$
V_{ij}(X) = \beta_f(i) \ln(f(j)) + d(j)[\beta_d(i) + \beta_{bd}(i) \ln(d_{base})] \\
+ \beta_{dc}(i) N_{dc}(j) + \beta_{ic}(i) N_{ic}(j) \\
+ \beta_{1st}(i) X_{1st}(j) + \beta_{ec}(i) X_{ec}(j) \\
+ G(r(i), t(j)).
$$

The independent variables of this equation are defined as follows.

- $\beta_f(i)$ is an empirically-estimated coefficient giving the relative importance to passenger $i$ of cost (fare) of the $j$-th choice, $f(j)$. Note that cost is not used directly, but rather log of cost. This reflects the reality that a unit increase in cost has less effect as the total cost rises.

- $\beta_d(i)$ is the empirical coefficient giving the weight of itinerary duration in the utility function for $i$, where $d(j)$ is the duration choice $j$.

- $\beta_{bd}(i)$ is the weight of the base (shortest) duration of all the $K$ available options, denoted $d_{base}$. This accommodates the fact that comparisons are made between available options, rather than hypothetical ones, and that the effect of the comparisons are based in part on their specific context.

- $N_{dc}(j)$ is the number of direct connections in the choice $j$, which is important if the option is a scheduled commercial flight. $\beta_{dc}(i)$ is the coefficient measuring the penalty of such a direct connection, while $N_{ic}(j)$ is the number of interline connections in such an itinerary, and $\beta_{ic}(i)$ is the coefficient giving the penalty of indirect connections.

- $X_{1st}(j)$ is a dummy variable equal to one if the option is equivalent to a first-class cabin on the aircraft, with coefficient $\beta_{1st}(i)$, and $X_{ec}(j)$ is a dummy variable equal to one if choice uses the main cabin $X_{ec}(j)$ on the aircraft.

For any trip, a traveler can be either departure or arrival time sensitive. $G(\square(i), t(j))$ defines the time-of-day utility structure for this time sensitivity. It is more complex than the linear function described so far, and is intimately connected to the definition of thin-haul and ODM service that is considered below. Specifically, there is a relationship between the utility of a travel choice and the desired ideal travel times available from all available choices. For example, suppose the choice being considered is a scheduled commercial airplane departing $R$ at 10:00 AM and
arriving at S at 12:30 PM. If the traveling passenger \( i \) wants to get to S around 12:30, this might be a good choice. But if it wants to get to S at 5:00 PM, there may be a later scheduled flight that would be preferable because the arrival time is more suited to the desires of the traveler.

Empirical evidence has validated the following equation form for \( G \):

\[
G(t_j : \tau(i), \beta_E(i), \beta_L(i), \lambda_E(i), \lambda_L(i), a(i), b(i)) = \begin{cases} 
\frac{\beta_E(i) \left( (t_j - \tau(i) - a(i) + 1)\lambda_E(i) - 1 \right)}{\lambda_E(i)}, & t_j < \tau(i) - a(i) \\
0, & a(i) < t_j < b(i) \\
\frac{\beta_L(i) \left( (\tau(i) - t_j - b(i) + 1)\lambda_L(i) - 1 \right)}{\lambda_L(i)}, & t_j > \tau(i) + b(i)
\end{cases}
\]

Figure A1: Ideal Schedule Delay Time Utility Curve

In this equation, the \( \beta_E(i) \) and \( \beta_L(i) \) coefficients are the empirical weights travel group \( i \) puts on a departure time earlier (\( E \)) than the desired departure time or later (\( L \)) than the departure time, \( \beta_E(i) \) and \( \beta_L(i) \) are empirical values which determine the rate at which the utility declines as a departure time \( t_j \) moves away from the ideal time \( \tau(i) \), and the two number \( a(i) \) and \( b(i) \) define an interval \( (a(i) < b(i)) \) around \( \tau(i) \) for which the traveler is indifferent to the option departure time (utility loss is 0).

Figure A1 shows the general graph of this function, and we can see that the further away an option departure time is from the ideal departure time, the more the utility of the option is degraded. (In the diagram, the rather complicated description of \( G \) shows only the dependence on \( t \), since the other parameters are fixed for a given traveler and travel option.) For a deeper discussion, refer to Parker and Walker (2007).
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Empirically, it is the case that the closer to the traveler’s ideal time a travel choice is, the more utility that choice has, and thus the higher the probability of the traveler selecting that choice becomes. In all, there are 19 parameters empirically estimated for the application of the utility function of the choice model. Details of how they are estimated and the sources of data used to derive the estimates are given in Parker (2010).

The Probability of Demand in a Given Time Period

Now, let $f_{RS}(t)$ represent the empirical data shown in Figure 2.4 of the main discussion of this chapter, expressed as a probability density function. That is, each point on the graph represents the likelihood that an individual traveler will want to go from origin city $R$ to destination city $S$ at that time during the week. With this specification, the probability that a passenger will want to travel from $R$ to $S$ in the time frame $[t_1, t_2]$ during the week is simply

$$Pr[\text{individual wants to travel from } R \text{ to } S \text{ in the time frame } [t_1, t_2]] = \int_{t_1}^{t_2} f_{RS}(t) \, dt.$$  

Thus, the optimum time for a scheduled service to operate in a directional market can be determined by finding the values of $t_1$ and $t_2$ where the integral defined above for that market is maximized. (In fact, a scheduled air service needs to determine three instances in time; the two for the range and a third, $t_0$, where $t_1 < t_0 < t_2$, which would be precisely when the scheduled service departs.) Most importantly, however, is the fact that if $D_{RS}$ is the total demand between an origin $R$ and destination $S$ for the week, then the number of passengers who want to travel between time $t_1$ and $t_2$ is

$$\text{Number of individuals wanting to travel in } [t_1, t_2] = D_{RS} \int_{t_1}^{t_2} f_{RS}(t) \, dt.$$  

However, not everyone travels alone. The behavior of a passenger in its choice of travel departure time and itinerary evaluation in fact often reflects the behavior of more than one individual person. Thus, if we are interested in the number of persons flying as a function of time (e.g., ideal departure time), then we need to accommodate the reality that more than one individual may wish to depart at the same time. The travel group size is the appropriate unit of demand measurement for all travel, but especially air travel, where vehicle capacity is a vital parameter in the definition of scheduled service vs. on-demand service. In the AirMarket Simulator, the agents that represent the passengers are called pags. This is short for passenger agents, and it signifies that it is not individual passengers that are being emulated, but groups of passengers traveling together. Research into actual group sizes as demonstrated by the number of tickets sold as a unit for a trip yields a reasonable representation of the probability distribution of the number of individuals in a group travelling together. The best fit we have found is a Poisson distribution truncated at zero, and has the following equation form:

$$Pr[n \text{ individuals are travelling together}] = Pr[Y = n] = \frac{\lambda^n e^{-\lambda}}{n!(1-e^{-\lambda})},$$  

For this distribution, the expected value of $n$ (expected group size) is given by
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\[ E[n] = \frac{\lambda}{1 - e^{-\lambda}}. \]

The parameter \( \lambda \) can be estimated from a sample mean \( \bar{Y} \) using the expectation equation above, except that the equation cannot be solved explicitly for \( \lambda \). It should also be noted that the parameter \( \lambda \) is assumed to be constant for all \( \bar{Y} \). Empirically this is a valid assumption, although there is reason to believe some differences in markets do exist. A full discussion can be found in Parker (2010).

In most markets, there are other options for travel besides airplanes, including private automobiles, for-hire cars, trains, buses and boats, not to mention a collection of airlines that provide scheduled service. In other words, the passenger has a choice of one of many options, and this fact is an important consideration when scheduling of an air travel option is being considered. The choices for a travel party that wants to go from an origin \( R \) to a destination \( S \) can be reasonably represented by a discrete choice model, as discussed above. Such a model provides an estimate of the likelihood that an individual traveler going from \( R \) to \( S \) will select option \( j \) of the possible available choices to make the trip, given attributes of the travel option and characteristics of the traveler.55

The exponential term for an option with the better departure time is bigger than the same term for a choice with departure time farther away from the ideal time, and thus the quotient in the equation is larger.

\[ \text{Pr}[\text{pag } i \text{ chooses option } j \in K] = \frac{1}{1 + \sum_{k \in K, k \neq j} e^{V_{ik} - V_{ik}}} \]

As the departure time of option \( j \) moves away from the ideal departure time for pag \( i \), the denominator in this equation gets larger and larger, since the values of \( Q_{ij} \) and \( Q_{ik} \) remain the same, while \( G(\tau(j), t(k)) \) becomes more and more negative, and thus the probability that \( j \) is chosen gets smaller and smaller.

Given these stochastic conditions, what is the maximum expected demand for any specific departure time for a scheduled flight? If that demand is sufficiently large, then a scheduled service can be provided with a reasonable chance of sufficient revenue to support the cost of the service. But if that maximum is not large enough to support any scheduled time, then the market cannot be served by a scheduled air carrier at all.

Consider the expected number of passengers from a single pag \( j \), as a function of the departure time \( t \). Let \( t \) range from 0001 AM on Monday to 2400 on the following Sunday, equivalent to minute 1 to minute 10,080 of the standard week. Further, assume all travel alternatives for the

54 However, Haight (1967) cites the following Lagrange series solution: \( \lambda = \bar{Y} - \sum_{j=1}^{n} j^{-1} [\bar{Y}e^{-\gamma}]^j \).

55 We assume the values of travel attributes held by the individuals in the same traveling group are all the same.
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pag are known, so the function \( H(i, j, t) \) is well defined. Then the expected number of individuals at the departure time \( t_0 \) for \( i \) is

\[
E(i, t_0) = \mathbb{E}(n_i)H(i, j, t_0) = \frac{\hat{\lambda}H(i, j, t_0)}{1 - e^{-\hat{\lambda}}}
\]

where \( \mathbb{E}(n_i) \) is the expected number of individual travelers in pag \( i \), (recall it is assumed to be constant for all \( i \)). Finally, suppose the standard week demand for air travel in the market \( R \) to \( S \) is \( D_{RS} \), which consists of \( D^*_{RS} \) pags of average size \( \mathbb{E}(n) \). Note that

\[
D^*_{RS} = \frac{D_{RS}}{\mathbb{E}(n)} = \frac{(1 - e^{-\hat{\lambda}})D_{RS}}{\hat{\lambda}}.
\]

Thus, the total number of expected passengers with ideal departure time \( t_0 \) in market \( R \) to \( S \) is simply,

\[
T_M(t_0) = \sum_{i \in M} E(i, t_0) = \frac{\hat{\lambda}}{1 - e^{-\hat{\lambda}}} \sum_{i \in M} H(i, j, t_0)
\]

where \( M \) is the set of pags in the market \( R \) to \( S \).

Assume we have an aircraft with known attributes of operating cost, fare, range and speed, and we can compute that it requires a minimum of \( C \) passengers in the market in question to purchase enough tickets to support scheduled operation. Then scheduled service can be provided in that market with that aircraft if it is the case that there is a value of \( t \) such that

\[
\max_{1 \leq c \leq 10,080} T_M(t) = \frac{\hat{\lambda}}{1 - e^{-\hat{\lambda}}} \left[ \max_{1 \leq c \leq 10,080} \sum_{i \in M} H(i, j, t) \right] \geq C
\]

That is, the expected demand for a scheduled flight is greater than or equal to the required aircraft minimum load for at least one scheduled departure time. Furthermore, since the values of \( H(i, j, t) \) are known for all pags in the market, it is also possible to determine the minimum value of \( D_{RS} \) to support scheduled service for any aircraft in any particular market.

It should now be clear how to design the air service to meet the needs of any city-pair market, at least from the perspective of the passengers buying tickets. Operational constraints, such as maintenance time and cost or pilot and crew considerations, often dictate when air service will be available. But if the availability does not meet the needs of the air travel customer, then the service cannot be sustained, and any attempt at providing scheduled air service will fail.
Appendix 3: The AirMarkets Simulator

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The AirMarkets Simulator is a high-resolution computer simulation of the entire global air passenger market. It represents every passenger on every flight and every mode associated with air travel everywhere in the world, simultaneously. It distributes air travel demand among all available modes and types of air service across the globe, resulting in 1) estimates of loads and revenues for all services provided in all markets in the worlds, and 2) descriptions of the reliability (probability distributions) associated with those estimates. The financial impact on the service provision elements are estimated by AirMarket, and since they drive all other aspects of the air travel system, estimates of the financial impact on those aspects are also imputed. Any feature of the system can be modified to study the possible impact of hypothetical changes on any other aspect of the system, in as much detail as is needed to make an informed decision with known reliability.

AirMarkets applies the modelling technique of agent-based computer simulation, called Agent-Based Modelling, reproducing the behaviour and the dynamics of individual passengers and air travel providers as flight ticketing evolves over time. The simulation portrays the results of about 30 million passenger agents buying tickets associated with a week’s travel for every market everywhere in the world. The simulation generates load and revenue estimates, by fare class, for every scheduled airline and flight, any on-demand services that might be available, and utilization of competing modes (e. g. rail) in markets where it exists, while capturing the full heterogeneity and dynamics inherent in air travel behavior. This creates a sophisticated “What if?” capability that enables the effects of adding or removing service, changing equipment, changing pricing, etc. to be fully and accurately explored. In addition, the relationships between travel demand and the underlying socioeconomic factors that motivate that demand are explicitly portrayed in AirMarkets. For example, the value of time is a key parameter in the estimation of OD demand in a city pair, and the value of time is largely determined by cultural experience and tradition. In the United States and in European countries, the value of time is very similar, with an hour being worth about US$150. But in India, it is far less than that, rarely reaching US$45. The AirMarkets Simulator accounts for essential differences like these explicitly.

Agent-based models describe a system from the various and distinct perspectives of the individual entities that make up the system – that is, from the bottom up – rather than trying to describe the average or aggregate behavior of individuals in the system – from the top down. An agent-based model separately describes the dynamics of each system component – the agents – which yields significant benefits over other methods. For example, agents can be given individual, flexible, heterogeneous behavior rather than relying on statistical averages to describe decision-making and purchasing. This flexibility creates a natural description of a system, and results in the ability to identify emergent phenomena. Emergent phenomena are system-wide characteristics that result from the interactions among agents, and are often obscurely related to the properties of the individual agents themselves, leading to "a whole is more than the sum of parts" way of thinking. Each agent can be configured with differing complexity, behavior, degree of rationality, evolutionary ability, learning ability and rules of how it interacts with other agents. Agents can be collected into groups that can become subgroups of larger groups, and so on. In other words, an agent-based model allows for adjustment, tweaking and adapting as new things are discovered or as more data allow more complexity in the description of the behavior of and
interaction between agents. The major applications for agent-based modeling currently include understanding such systems as ground traffic flows, market behavior, organizational behavior, diffusion of innovation and adoption dynamics, the spread of epidemics, and phenomena found in evolutionary biology and computational economics. Gilbert and Troitzsch (1999), Epstein (2006), Bratman (2007), Wooldridge (2002), Tesfatsion and Judd (2006), and Parker (2010) are all excellent references on agent-based modelling.

As an agent-based model, AirMarkets emulates the fundamental dynamics of the world’s airline network. As passengers book tickets and cabins fill up, available itineraries for later-ticketing passengers change. Moreover, revenue management systems alter essential properties of the available passenger choices as departure approaches, often based on observed demand to-date. And what happens in a given market can have a substantial effect on the observed characteristics of other markets, since a specific flight can support itineraries serving a number of markets, which cannot be known in advance. While other analytic approaches have difficulty accurately portray this dynamic structure, resulting in significant errors in their network analysis, agent-based models are particularly well suited to the task.

In a sense, AirMarket provides a “sandbox” where the air travel analyst can play with different ideas and concepts before suggesting their implementation in a real air travel service networks. It is like a wind tunnel for air travel analysis. It can be used to explore various configurations and evaluate alternatives with such measures as consumer surplus changes or operational efficiency improvements. And those measurements can be coupled with valid estimates of their accuracy.

In AirMarkets, the primary agent is the passenger. Passenger agents, or pags, are software objects that emulate the behavior of real passengers when it comes to selecting what specific travel mode or itinerary the passenger will use to make a trip. The choice is governed by a mathematical description of the relationship between the passenger’s values of time, money and comfort applied to the attributes regarding those features of the specific itinerary. Then a random number is generated to select the itinerary, which means that different runs of the Simulator can yield different results. However, multiple runs produce a much more important piece of information – the probability distribution of the inherently stochastic properties observed in air travel. Confidence intervals, for example, can thus be accurately estimated.

Demand is determined from the AirMarkets OD Demand Model. From this demand, a synthetic population of pags is created. Each pag is assigned a trip purpose, an origin, a destination, a desired departure or arrival time, a group size, and is given a unique flight itinerary choice random utility model, which is used to select the itinerary from those available at the time of flight ticketing. The empirical ticketing curve for each OD market is used to assign a ticketing instant (time before departure) to each pag.

One simulation run represents travel in the world’s network over a week of time. Typically, it uses roughly 27,000,000 pags (about 46,000,000 passengers) to emulate the air travel in and out of some 4000 cities for which air travel is available, using one of the 987,100 unique flight legs (making up several thousand-trillion possible itineraries) serving over nine million OD markets. Every passenger in every OD and every flight in the world is considered in each run, thus capturing the full dynamics of the system.
NASA Strategic Framework for On-Demand Air Mobility

The major output of AirMarkets is the loading of all the passengers in the world on all the flights in the world’s network. The loading, available for each flight, shows how many tickets were sold in each fare class on the flight leg and hence what the total revenue was. Results can be displayed as comparisons to the base network from which changes were made, so the impacts of the changes are immediately available. Available displays show the market mix on a given flight, flight market shares of load and revenue, comparisons with other network scenarios, traffic patterns though airports and a variety of other data. If cost data is provided, displays of cost/benefit and profitability analyses are also available.

The AirMarkets Simulator also allows for the introduction of flight modes beyond scheduled air service, known as On-Demand Mobility, or ODM. ODM service can consist of aircraft with any configuration of capacity, range, speed, and fare. They can be available in all or any subset of the world’s markets. In addition, the level of awareness and acceptance of ODM service are parameters that can be set to reflect both the marketing capability of the ODM service provider or the public acceptance of a given aircraft.

AirMarkets is a process application, as opposed to a document-based application like Word or Excel. The control panel is how the user manipulates the simulation – defining the scenario, focus and population of passengers, changing system attributes, modifying model parameters, executing simulations, and studying the results. The population of passengers a simulation uses is a collection of passenger agents or pags called a synthetic population, or synpop, and different synpops can be applied to the same network.

Two kinds of simulations can be executed. A “Full Simulation” keeps all the data for the entire world as output, and is useful for exploring impacts across the full spectrum of the network. Monte Carlo simulations, on the other hand, execute a simulation on the same network configuration repeatedly while varying randomly (according to the associated probability distribution) such basic variables as competitive pricing or OD demand. The output of a Monte Carlo simulation is set of probability distributions for important variables as load, revenue, market share and profitability. These are used to establish the accuracy of the data output by the simulation, and estimate the probability distributions of complex configurations of, say, ODM service.
Appendix 4: The Price Curve for Air Travel

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Consider the pricing of air travel as found in the commercial, scheduled air industry. There is a typical curve shape to the pricing structure for tickets offered by the air travel industry. Based on research on the number of tickets sold in relation to the pricing of tickets in over 18,000 individual air travel markets around the world, the curve shown in Figure 2.8 is typical. Across the x-axis of the graph is the range in price for tickets in a specified market. It always starts at 0, and goes to the highest price observed. There is no theoretical upper price limit, so conceptually the horizontal axis goes off to infinity to the right. In practice, there is always a maximum observed ticket price, but there is no ticket value that is an absolute maximum.

The curve describes the fraction of tickets sold at or below the price shown on the horizontal axis where the curve intersects the vertical axis. The shape of this curve is interesting. It does not start at $0, but rather somewhere just above it. This represents the quite inexpensive tickets sometimes sold for emergency travel, such as bereavement fares. Then the number of tickets rises very quickly around the average price for an economy class seat. At around 75%, however, the prices start to climb as more expensive economy seats are sold – usually because of late booking or other revenue management policy – which then merges with first or business class seating. Eventually, at around the 85% level, the price of a seat increases dramatically. There is little movement of the fraction of tickets sold after the curve reaches about 90%. This means that the price can climb very high without much effect on the number of tickets sold. It is here that the market for ODM service is generally found, since the least expensive seats on an ODM aircraft are almost always more expensive than any seat on a scheduled, commercial airplane.

In Figure 2.10 of the main body of this chapter, about 85% of tickets being sold at or below about 29% of the maximum fare. It also suggests that about 2% of the tickets would sell for more than six times the price reflective of the average economy fare. This curve has been found empirically in over 90% of the more than 18,000 markets for which ticket price data has been collected. It is reasonably well represented by a generalized Frechet probability distribution, with the functional form

\[
F(x : \sigma, s, \beta) = \beta \exp \left( - \left( \frac{s}{x} \right)^\sigma \right)
\]

where Greek symbols represent empirically-derived parameters. The relationship between the parameter of this distribution and the attributes of the market, such as distance, demand, etc. is currently under study.