

# Small Aircraft Transportation System Concept and Technologies

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**This paper summarizes both the vision and the early public-private collaborative research for the small aircraft transportation system (SATS). The paper outlines an operational definition of SATS, describes how SATS conceptually differs from current air transportation capabilities, introduces four SATS operating capabilities, and explains the relation between the SATS operating capabilities and the potential for expanded air mobility. The SATS technology roadmap encompasses on-demand, widely distributed, point-to-point air mobility, through hired-pilot modes in the nearer term, and through self-operated user modes in the farther term. The nearer-term concept is based on aircraft and airspace technologies being developed to make the use of smaller, more widely distributed community reliever and general aviation airports and their runways more useful in more weather conditions, in commercial hired-pilot service modes. The farther-term vision is based on technical concepts that could be developed to simplify or automate many of the operational functions in the aircraft and the airspace for meeting future public transportation needs in personally operated modes. NASA technology strategies form a roadmap between the nearer-term concept and the farther-term vision. This paper outlines a roadmap for scalable, on-demand, distributed air mobility technologies for vehicle and airspace systems. The audiences for the paper include general aviation manufacturers; small aircraft transportation service providers; the flight training industry; airport and transportation authorities at the federal, state, and local levels; and organizations involved in planning for future national airspace system advancements.**

## Introduction

**T**HIS paper summarizes both the vision and the early public-private collaborative research for the small aircraft transportation system (SATS). The paper outlines an operational definition of SATS, describes how SATS differs from current air transportation capabilities, introduces four SATS operating capabilities, and explains the relation between the SATS operating capabilities and the potential for expanded air mobility. The SATS roadmap encompasses on-demand, widely distributed, point-to-point air mobility, through hired-pilot modes in the nearer-term, and through self-operated user modes in the farther-term. The nearer-term concept is based on aircraft and airspace technologies being developed to make the use of thousands of smaller neighborhood airports and their runways more useful in more weather conditions in commercial hired-pilot service modes. The farther-term vision is based on technologies that could be developed to simplify or automate many of the operational functions in the aircraft and the airspace for meeting future public transportation needs in selfoperated modes. NASA technology strategies establish a roadmap between the nearer-term concept and the farther-term vision.

This paper discusses the heritage of the SATS vision and technology strategy or roadmap, the related push of enabling technologies, the pull of relevant market forces affecting potential demand for such a system of on-demand, point-to-point air mobility. The po-

tential effects of this vision on general aviation aircraft and airports of the 21st century are also presented.

The purpose of vision is to serve as framework for technology strategies, or roadmaps, leading to desirable future states. To be effective in this function, the visioning process must be dynamic and shared among stakeholders. The origins of the SATS vision dates from a 1989 government-industry-university workshop,<sup>1</sup> with recent refinement during the Advanced General Aviation Transport Experiments (AGATE) Alliance research. The current SATS project objectives and plans for a 2005 demonstration are derived from this vision. The vision continues to evolve as it is shared among an increasingly broad spectrum of stakeholders among the public and private sector SATS partners. That evolution has expanded the vision from a largely vehicle-centric technology focus to include airspace systems technologies and operational capabilities in the future National Airspace System. In addition, the earlier focus of the vision on self-operated aircraft has expanded to encompass the operation of aircraft by hired pilots in on-demand, widely distributed, point-to-point air transportation services.

The audiences for the paper include general aviation manufacturers; small aircraft transportation service providers; the flight training industry; airport and transportation authorities at the federal, state, and local levels; and organizations involved in planning for future National Airspace System advancements.

## SATS Technology Strategy

The technology strategy for SATS is designed to support innovation in air mobility. The early form of these innovations will likely be as new air service business models to be deployed in intercity travel markets that are either too small to be served by scheduled air carriers [even under essential air service (EAS) subsidies] or where existing services do not effectively meet consumer needs and expectations. In the longer term, the innovations could take the form of greater use of automation and simplification of aircraft and airspace functions. The technologies are being developed under the SATS Project as part of a NASA Airspace Systems Program investment, established within the mobility element of the NASA strategic plan. The NASA mobility goals support convenient, scalable, on-demand access by air to more locations, more affordable access to air travel

Received 19 June 2003; presented as Paper 2003-2510 at the AIAA-ICAS International Symposium on Air and Space—The Next 100 Years, Dayton, OH, 14 July 2003; revision received 21 October 2003; accepted for publication 23 October 2003. This material is declared a work of the U.S. Government and is not subject to copyright protection in the United States. Copies of this paper may be made for personal or internal use, on condition that the copier pay the \$10.00 per-copy fee to the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923; include the code 0021-8669/04 \$10.00 in correspondence with the CCC.

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## Aviation's Future is Driven By Technology

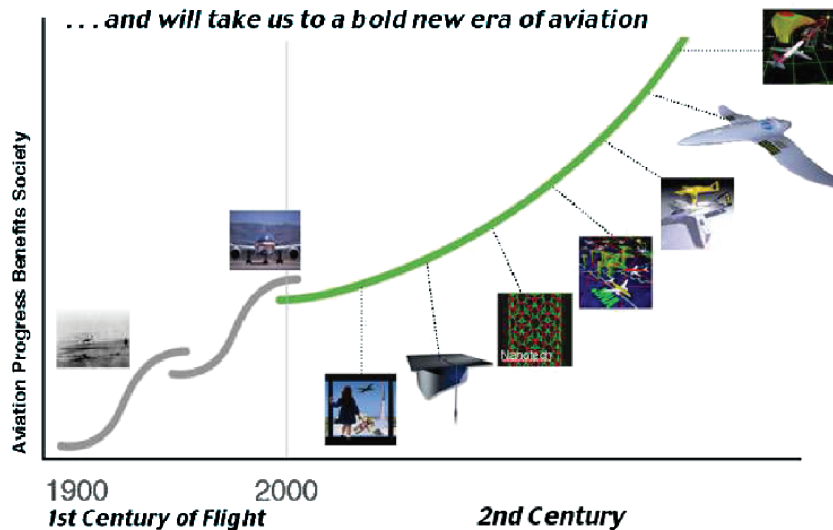


Fig. 1 NASA Blueprint for Aeronautics depicts innovation life cycles, past and future.

for the entire population, and faster travel for expanded radius of day travel.\*

The NASA Aeronautics Blueprint<sup>†</sup> and the Final Report of the Commission on the Future of the U.S. aerospace Industry<sup>‡</sup> provide additional context for SATS. The Blueprint presents the NASA Administrator's vision for aeronautics technology intended to "usher in a bold new era of aviation during the 21st century." The Blueprint concludes: "The cost of inaction [in aviation advancements] is gridlock, constrained mobility, unrealized economic growth, and loss of U.S. aviation leadership."<sup>†</sup> The Blueprint framework for aviation innovation life cycles is illustrated in Fig. 1. The figure depicts the current stage of transition from the first two innovation cycles during the 20th century aeronautics revolution to a 21st century aviation era of innovation. The Blueprint articulates a vision for "ondemand as well as scheduled air mobility, not just to hundreds, but to thousands of communities throughout the Nation and the world,"<sup>†</sup> defines the role of Government, and explores the public good served by such a vision.

In 2001, Congress established the Commission on the Future of the U.S. Aerospace Industry to study and report to the President on the economic- and security-related issues associated with the future of this industrial sector in the U.S. In their Final Report, the Commissioners expound their vision for the future of the U.S. aerospace industry. They articulated a future state in which anywhere, anytime mobility will enable dramatic improvements in the productivity of U.S. companies, in military capabilities, in the lives of our citizens,<sup>†</sup> and when "Fast, safe, and secure point-to-point transportation should be available not just between major hub airports, but also between convenient local airports via low-cost, jet air-taxis."<sup>‡</sup> These strategic documents were both influenced by and provide framework for the SATS technology strategies.

### Technology Push and Market Pull

The motive forces behind SATS respond to both the push of enabling technologies and the pull of emerging market forces. The technological push for SATS in the nearer term includes the emergence of a new generation of affordable small high-performance transportation aircraft currently in development. This new generation of aircraft incorporates advanced avionics, propulsion, manufacturing, and other technologies that set them apart in cost of higher performance (speed) and in operating capabilities in the Na-

tional Airspace System from past generations of aircraft. These new aircraft incorporate software, communications, navigation, and surveillance systems that enable expanded use of the National Airspace System and its airports. These new technologies could enable near-all-weather access to more runway ends and helipads in the nation, with reduced requirements for traditional, expensive ground-centric infrastructure. Near all-weather in the context of the current SATS project implies ceiling minima of about 200 ft and visibility minima of about  $\frac{1}{2}$  mile. The current SATS project does not address technology development affecting operations in crosswinds, reduced braking effectiveness on wet runways, or other severe meteorological considerations; in the future these considerations will play into the definition of near allweather. The new generation of aircraft appear to be capable of providing economical, on-demand, point-to-point transportation service between the thousands of smaller communities with markets too limited in size to be served by scheduled air carriers using existing turboprops or regional jets. Smaller general aviation and regional airports could serve thousands of suburban, rural, and remote communities throughout the nation, through these technological advancements. The safe, efficient utilization of smaller aircraft and smaller airports can make possible new levels of community accessibility and public mobility in the nearer term of 5 to 10 years.

In the longer term, the 15- to 25-year vision for air mobility is framed by both predictable and reasonably probable technological advancements. These advancements will affect propulsion, communications, navigation, surveillance, manufacturing, structures, materials, cockpit display systems, flight controls, acoustics, and aerodynamics. Every aeronautics technology stands to be propelled into the future by the unfolding scientific advances affecting engineering at the micro- and nanometer scale as well as biologically inspired innovations in aircraft and the continuing forces of Moore's Law on computing power and Gilder's law<sup>2</sup> on bandwidth and information technology. The technological push enabled by these forces has the potential to lower many of the barriers to more widespread personal use of self-operated aircraft as contrasted with hired pilot transportation services. Those barriers include cost; safety; the complexity of aircraft flight systems and related operating procedures in the National Airspace System; and derivative issues such as training, insurance, and airport and airspace infrastructure.

The pull from transportation market forces includes both the demographic-driven demand for transportation and the increasing value of time in an information-based, highly networked economy. The demographic effects of both economics and population drive the demand for higher-speed transport. Analyses illustrate that as per capita income rises per capita annual travel rises and that because

\*Data available online at <http://www.plans.nasa.gov>.

<sup>†</sup>Data available online at <http://www.aerospace.nasa.gov/aero/blueprint/>.

<sup>‡</sup>Data available online at <http://www.ita.doc.gov/aerospace/aerospace.commission>.

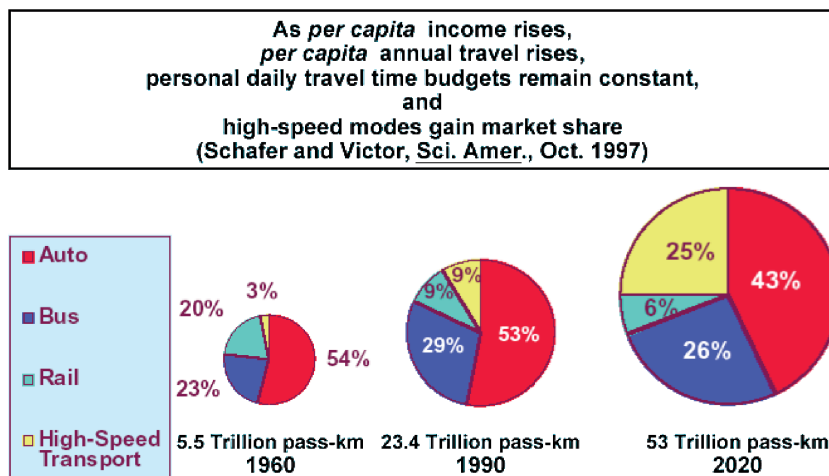


Fig. 2 Demand growth for higher speed travel modes.

personal daily travel time budgets remain constant (at about 1.1 h per person per day, globally) the effect is that higher-speed modes gain market share.<sup>3</sup> Figure 2 illustrates the past and projected effects of the population and economic demographics on higher-speed travel demand. Based on the trend analysis, the data project that demand for higher-speed travel modes (air and high-speed train) by about 2020 will be larger than all automobile travel was in 1990. In addition, the data project that higher-speed mode demand will be about 275% greater in 2020 than in 1990. In absolute value, passenger-kilometers of automobile travel would roughly double in these projections. For both the hub-and-spoke system and the highway system, such growth is beyond the physical limits of planned capacity growth. Although these trends are global and have not been decomposed here into U.S.-specific values, the trends imply that alternatives (such as SATS) to the highways and current hub-and-spoke systems will be important to satisfying expectations of global populations for transportation.

In the era of the horse, the 1.1 h per day travel time budget estimated by Schafer and Victor translated into about a five-mile day-trip radius of action. In the era of the automobile and train, this day-trip radius expanded to about 50 miles. In the SATS vision for a future era of on demand, personal air mobility, this daily radius of action could increase another factor of 10 to about 500 miles, between virtually all origins and destinations.

#### Value of Time (Doorstep to Destination)

In addition to the extrinsic (economic) value of time in an information economy, the intrinsic value of time in terms of quality of life represents a major motivation behind the SATS concept. That is, increased personal command of one's time is one of the principle motivations behind the idea of using smaller airports, closer to origins and destinations, in smaller aircraft that provide more affordable air mobility, for use by more intercity travelers. The outcome derived from improved time-based efficiencies in air mobility would translate into both extrinsic and intrinsic benefits, based on the value of time.<sup>4,5</sup>

Figure 3 illustrates one limited case of the potential for improved time-based efficiencies in air mobility. The figure depicts measured doorstep-to-destination speeds for one person's personal travel in the hub-and-spoke system over a period of a few years. The data illustrated are for over 100 personal and business trips by the first author of the paper, between 1998 and 2003. The travel times account for the author's transit between residential doorstep and ultimate destinations (and the reverse). These data led to insights by NASA and others in the SATS public-private partnership into the potential for more widespread use of smaller airports and smaller aircraft for more time-efficient public transportation. These measured data are predominantly for travel originating in southeastern Virginia from the Newport News-Williamsburg airport (PHF) or the Norfolk airport (ORF). The calculated data use a proprietary aircraft perfor-

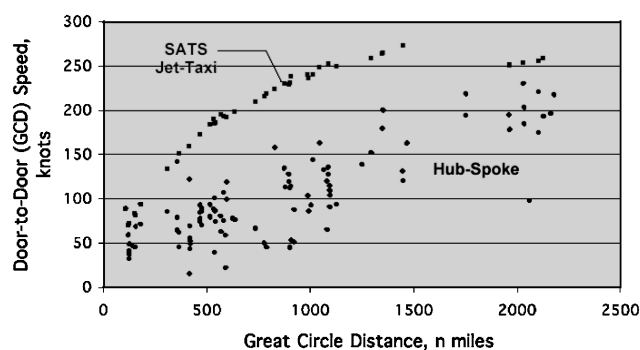


Fig. 3 Comparison of actual and theoretical doorstep-to-destination performance for hub-and-spoke and on-demand jet taxi air mobility.

mance model for one of a new generation of small jets currently in development.

The data in Fig. 3 illustrate a counterintuitive fact that for airline trips of less than 500 n miles, the average doorstep-to destination speeds average around 75 kn. For 500 n mile trips, the distribution in this data set is between the slowest of 15 kn, to the fastest of about 95 kn, in spite of the fact that the aircraft themselves fly at speeds faster than 400 kn. For several hub-and-spoke trips out to about 1000 n miles, trip speeds ranged from the slowest trips of about 50 kn to the fastest trips of about 150 kn. The wide variance is a consequence of the driving time between the trip origins and destinations and the airports used, as well as delays. The figure also depicts the theoretical speed performance from doorstep to destination of each of the same trips, if they were flown in a new generation of light jet. The characteristics of this new class of small jet include twin-engine, pressurized, 350-kn cruise speed, six place, anticipated to be in the marketplace from more than one vendor in about 2006–07. The theoretical speed performance comparison shows that average speeds for the trips could have been more than two times faster than for the hub-and-spoke trips out to trips of about 1500 n miles. For trips longer than about 1500 n miles, the trip speeds for the SATS jet-taxi mode and the hub-and-spoke mode converge.

Additional analysis of the trip data reveals further motivation behind the idea that SATS modes could create efficiencies in travel. For the travel data collected, out of the 100,034 n miles traveled, 13,964 n miles, or about 14% of all miles traveled were a consequence of the hub-spoke routings or of the added ground travel distance to or from the hub-or-spoke airport rather than to the nearest airport. In addition, out of the 850 h of travel, 461 h, or about 54%, were expended that might have been avoided if the SATS jet-taxi mode were taken instead. In summary, the difference in time and distance between the hub-and-spoke actual travel and a theoretical SATS analysis represents a savings of about 14% in total miles traveled and about 54% in time spent.

The SATS technology strategy is based on overcoming the technical inhibitors for making the time-based efficiencies of the SATS mode more available to more travelers in more locations, more affordably. For many rural and remote communities in the nation, SATS has the potential to provide hub-spoke-like accessibility and affordability that currently only exists for the population that lives within reasonable ground travel times from about 500 airports with scheduled air carrier service. Currently about 93% of the U.S. population distribution lies within about 30-min ground travel time to one of the 5400 public-use airports in the country.<sup>6</sup> Only about 22% of the population lives within a 30-min drive of a hub airport. This means that a relatively large percentage of the U.S. population could benefit from the time-based efficiencies of the SATS mode if the barriers to this mode could be reduced. The technical challenge is how to make this mode accessible to the public.

In 2000, NASA requested a review of the SATS strategy by the Transportation Research Board (TRB).<sup>7</sup> The purpose of the review was to gain insights from the perspective of the nation's Transportation Enterprise, as represented by the TRB Committee on SATS into the nature of the transportation systems challenges facing the country, the complexities of the transportation system innovation process, and the role of the NASA aeronautics technology strategies in addressing those challenges. In their findings, the TRB Committee on SATS endorsed the technology strategy, but counseled against the use of the SATS vision because of the inability to quantify market demand created by the SATS mode of travel and other concerns for safety and cost. In response, the public, and private-sector partners in the SATS project have included system analysis focused on assessment of 21st century transportation demand that might be diverted from other transport modes. No effort is planned to assess travel demand induced by the SATS mode.

### Early 21st Century Transportation Challenges and Opportunities

Throughout U.S. history, transportation system innovations have played a leading role in distributing economic opportunity and population across the nation. In notional terms, 400 years ago wealth was created at seaports,<sup>8</sup> 200 years ago at river and canal ports, 100 years ago at railheads, and beginning 50 years ago at the nation's airports and interstate highway on/off ramps. During the 1970s, the introduction of the nation's hub-and-spoke system for air travel continued this economic forcing function.

A few major innovations drove the growth of airline travel over recent decades, including hubbing, as well as the earlier developments of the jet engine and deregulation. These developments carried both desirable and undesirable effects. The emergence of the hub-and-spoke model of scheduled air carrier operations in the 1970s significantly benefited the nation's travelers, air carriers, hub cities, and spoke communities.<sup>9</sup> Those benefits include frequency and cost of service. The less desirable features of the hub-and-spoke system relate to network vulnerability characteristics to the difficulty in such a system to give top priority to passenger convenience and door-to-door time efficiencies and to the consolidation trends that reduce air service for smaller communities as the industry matures. The vulnerability of the hub- and-spoke system to disruptions caused by weather, equipment failures, labor issues, or acts of terrorism are in part a result of the centralized, scheduled, serial dependencies, and related network characteristics. As the hub-and-spoke system has matured, it has become less able as an industrial sector to adopt innovations that could lead to significant decreases in doorstep-to-destination trip times or to much more widely distributed air service for smaller communities.

Over time, each transportation system innovation (canal, rail, highway, hub- and-spoke) progressed through its life cycle characterized by an S-shaped curve of cumulative market performance over time. In the case of competing modes, the life cycles of transportation systems exhibit substitution behaviors, for example, in the simple case of the car substituting for the horse for intercity travel over a period of about 30 years<sup>10</sup> (see Fig. 4).

The dynamic balance between accelerating and retarding forces shapes these S curves of market development. New developments

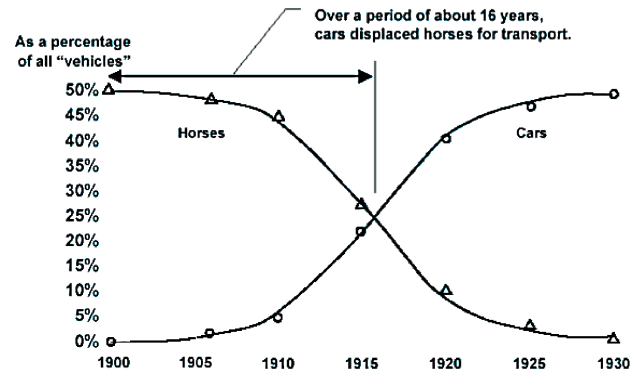


Fig. 4 Substitution of cars for horses.<sup>10</sup>

in the science of networks offer new approaches to thinking about the forces affecting the life cycles of innovations.<sup>11,12</sup> The interactions of technologies that enable new capabilities, in the context of social systems, create the forces that shape the S curves. In transportation systems innovation, these S curves can exhibit substitution behaviors, as one mode grows to first augment, and then supplant an antecedent mode.<sup>13</sup>

Certain conditions must be present for the emergence of an innovation to grow, either into a market vacuum or as a substitution in an existing market. In the lexicon of the science of networks,<sup>11,12</sup> the conditions that govern the rate of diffusion of an innovation in the market include the following: the scale-free nature of the network (or the ability of the network to attract increasing links between increasing numbers of nodes based on preferential attachment or fitness); thresholds of vulnerability (or the degree of market pull or opportunity); existence of a single well-connected percolating cluster (or the presence of an effective host for incubating the innovation); the number of early adopters there are in the population at large (or potential early consumers); and the connectivity between the early adopters and the innovators (or the effectiveness of communications and public outreach from the percolating cluster). If a network contains a percolating vulnerable cluster, then it is possible for global cascades to occur. Global cascades exhibit self-perpetuating growth, altering the state of the entire system.<sup>11,12</sup>

The presence of these conditions explains the substitutions or transitions between S curves exhibited in the transitions in life cycles of innovations from horses to cars, from props to jet airliners, from mainframe to desktop/distributed computing, or from wired to wireless communications. As any system reaches the maturity phase in its life cycle, a period of slowed growth develops during which retarding forces dominate over accelerating forces. It is during this maturity phase that opportunities emerge for the emergence of the next system innovation or the next S curve of market growth. It is not predictable whether these conditions are present in the current development of the SATS-inspired business strategies. However, currently more than six new turbine-powered aircraft are in development, along with several companies intending to deploy on-demand jet-taxi services.

Looking forward into the 21st century, beyond maturity phases of the national highway and hub-and-spoke systems, the nation will face challenges in creating transportation-enabled economic growth, jobs, and wealth. NASA's investments in SATS technologies are designed to incubate 21st-century alternatives in air mobility that continue to support economic growth, as can be driven by transportation advancements.<sup>14</sup>

Transportation in the U.S., long the underpinning of economic strength, is losing speed, accessibility, flexibility, and efficiency.<sup>15</sup> According to Coyle, Bardi, and Novack, it took 12 days to travel by carriage from Philadelphia to Pittsburgh in 1800. By 1840, a canal and rail system reduced the trip to seven days. In the 1850s, a direct rail line reduced to only two days. In 1910, improvements in rail speed reduced the trip to about eight hours, a 97% reduction in travel time in one century. With the advent of air transport in the 1960s, the trip was reduced to only 50 min. However, travel time has

not decreased significantly since then. Airline travel times in 2000 between Philadelphia and Pittsburgh are now longer than it was in the 1960s (Ref. 15).

Our rising costs to reduce highway and hub-and-spoke congestion and delays are reaching the point of diminishing returns, and transportation demand continues to soar.<sup>16</sup> As time becomes the "scarce commodity" of the information age, demand for aviation transportation will outpace the capacity provided by the system of today's 400 hub-and-spoke airports.\* Thus, early in the 21st century, when speed is at a premium, the nation's doorstep-to-destination travel speeds will become slower. In the absence of scalable alternatives to the hub-and-spoke and ageing highway systems, economic expansion in the information age is being limited to fewer well-connected regions and communities.<sup>17</sup>

Community vitality and economic opportunity increasingly depend on access to rapid point-to-point transportation, in particular air transportation. Even small airports have the potential to attract new businesses, new jobs, new community revenues, and higher standards of living. Fortunately, well over 90% of the U.S. population lives within a 30-min drive of over 5000 public-use landing facilities. This infrastructure of airports and the related unmanaged airspace is an untapped national resource for mobility, representing untapped potential for economic opportunity.<sup>18</sup> Airports accessible in near all-weather conditions offer the potential for even greater economic gains for the communities they serve. Of about 5400 public-use airports in the U.S., only about 600 are equipped with instrument landing systems (ILS) for operations during low ceilings and low visibilities (Federal Aviation Administration data).

The NASA-led SATS research project is a proof-of-concept evaluation of specific technologies that can enable the SATS longer-term vision of the practical use of smaller aircraft and more widely distributed community airports for public transportation.

### Limitations on Benefits of New Highway and Airport Infrastructure

Studies of both highway and hub-spoke congestion are confirming the diminishing returns on investments in these systems aimed at managing congestion. One conclusion of such a recent study concluded, for example, "analysis of 15 years of data in 70 metro areas adds to the growing body of evidence that [...] highway construction is an ineffective means of managing congestion. In fact, numerous studies indicate that highway construction often generates more traffic, raising congestion levels. Given the enormous cost of highway construction, our transportation officials need to investigate a broader menu of congestion relief measures that include other transportation modes, new technology, pricing, land use, and other strategies."<sup>19</sup>

Similar conditions are unfolding in the hub-and-spoke system. The expansion potential for both the hub-spoke and highway systems is limited by the physical nature of their system constraints. In the case of the hub-and-spoke system, the system capacity is ultimately limited by runway occupancy time for landing and departing aircraft. However, even before the system capacity limit is reached the queuing effects in the system cause delays to grow exponentially.<sup>20</sup> The system currently operates near 57% capacity<sup>21</sup> and the queuing-induced flow breakdowns regularly experienced before 11 September 2001 can be expected to return. A new runway adds 1% to the system capacity; significant improvements in separation and sequencing technologies can add about 30%. However, the known demand for travel will grow more than 100% in the next 20 years. Furthermore, the latent or pent-up demand for transportation of people, goods, and services appears to be significantly larger, driven by the forces created by the soaring value of time in the information-based/highly-networked economy.

The U.S. currently utilizes about 5% of its landmass for population. If we are to meet the challenge of 21st-century transportation

demand, we will need many options, including perhaps options that consider alternative land use, beyond the confines of the current population distribution. One such option would be to improve land use through transportation capabilities enabled by a SATS.<sup>22</sup>

### Externalities Affecting 21st-Century Mobility

Several forces are shaping transportation demand characteristics as we move into the first decade of the 21st century, including the following: 1) the maturing of the hub-spoke infrastructure into the saturation phase of its natural growth cycle by about 2008–2010<sup>23</sup>; 2) the increasing gridlock on the nation's already mature highway system and even on the rail system<sup>24</sup>; 3) a migration of Americans and their jobs from urban and suburban locations, further from city centers and further from existing hub airports; 4) the growth of the baby-boomer generation into maturity and retirement can increase travel demand in this demographic sector; 5) the transformation of industry from standardized to personalized, customized products and services (transportation is one of the last industrial sectors to see customization of services of the kind occurring in personal computers, cellular services, automobiles, and other products); and 6) the value of human time (and therefore the premium value of doorstep-to-destination speed) related to increased productivity during the information age.<sup>24</sup>

These forces contribute to a chaotic period for the nation's transportation system. The chaotic characteristics during the maturity phase of any life cycle include saturation, dissatisfaction, consolidation, depersonalization, diminishing innovation, and economic risk avoidance. This chaos, in transportation, takes the forms of infrastructure saturation; consumer complaints (even "air rage"); consolidation of manufacturers and service providers to obtain economies of scale; depersonalization of services (including effects of increased security); consolidation of industry; increasing pace of smaller refinements in products and services; fewer (if any) significant innovations; and reduced financial risk tolerance (including the effects of bankruptcies as a means of managing airline debt, fleets, and labor relations). Meanwhile, the growth of service-oriented air transportation in such customized operations as fractional ownership is growing rapidly.

From a natural life-cycle viewpoint, periods of chaos and maturity serve to stimulate ensuing significant advancements. The successive emergence of horse paths, canals, ocean steamers, railways, roadways, and hub-spoke airways for intercity travel illustrate these life cycles. Each new mode emerged during the maturity phase of the preceding mode. In addition, each of these new modes represented a "disruptive" or discontinuous innovation.<sup>25</sup> Each of these innovations created (or induced) new market demand by enabling consumers to take trips not previously imagined or possible in advance of the innovation. The SATS vision allows for the notion of creating new travel consumption, as well as diverting travel from highways or less efficient hub-and-spoke trips.

The structure of sustaining and disruptive innovations provides a useful framework for understanding and positioning the SATS concept. Sustaining innovations are those that continue the improvements in system performance expected by a known consumer base, served by an entrenched industry. Disruptive innovations do not address the needs of known customers, do not have initial markets large enough to satisfy the near-term growth requirements of entrenched industries, and are based on new functionalities. The trigger for the emergence of a disruptive innovation is the point in system performance improvement at which the slopes of the market need and technology improvement intersect, with performance exceeding market needs. The saturation phase of the current hub-spoke airway system, coupled with highway gridlock, creates environment conducive to the potential emergence of a disruptive innovation.

Transportation demand will be driven by the increasing value of time during expansion of an information-based/highly networked economy, when human/intellectual capital replaces physical capital as the basis for creation of wealth. The increase value of time would make doorstep-to-destination speed the premium commodity during this era. In addition, the next-generation consumer will place a higher premium on privacy, security, independence, flexibility, and

\*Data available online at <http://gulliver.trb.org/publications/circulars/ec029.pdf>.



freedom of choice in products and services, including transportation. The spread of highway gridlock along with urban sprawl, along with the expense and limitations of mass transportation solutions will also exacerbate the emerging transportation demand-supply gap. Responsible land-use and energy-use choices could also be enabled by new technologies, while responding to demand for higher-speed transportation (doorstep to destination) early in the 21st century.<sup>26</sup>

Within the context of these externalities, a set of enabling vehicle technologies has emerged from recent national public-private investments, including a new generation of engines, avionics, airframe, navigation, communication, and operator training for a new generation of small transportation aircraft.

### General Aviation and Aeronautics Technology Strategies

The development of general aviation and aeronautics technology strategies over the past two decades has involved the government, industry, and the university community in collaborative roadmapping activities. The major activities supporting these strategies include the following:

1) AIAA Workshop on the Role of Technology in Revitalizing U.S. General Aviation,<sup>\*</sup> 1989: This government-industry-university workshop, organized by the AIAA General Aviation Technical Committee, established an early framework for targeted technologies that would influence future aircraft design concepts potentially affected the growth of the industry in small transportation aircraft.<sup>27</sup>

2) NASA Advisory Council Task Force on General Aviation, 1994: This task force, appointed by the NASA Administrator in 1993, provided definition of technology priorities and a call for the development of a public-private partnership for research program implementation.<sup>28</sup>

3) NASA-industry General Aviation Roadmap: Between 1996 and 1998, NASA chartered public- and private-sector groups with a stakeholder or technology provider perspectives to create programmatic technology strategies building prior, longer-term strategies, technical progress, and market needs. The general aviation roadmap created the foundations for program investments and implementation by government, industry, and universities. These investments included the AGATE program, the General Aviation Propulsion (GAP) program, the SATS project, and other related general aviation technology development investments.<sup>\*</sup>

4) SATS Strategic Council: The Joint Sponsored Research and Development Agreement (JSRDA) between NASA and the National Consortium for Aviation Mobility establishes a collaborative, cost-sharing business instrument for the governance and program management terms and conditions for the SATS Project. The JSRDA established a strategic council composed of individuals representing organizations that have a direct interest in the SATS project outputs and their long-term commercial deployment. The membership includes the major aviation association representatives from this industrial sector, along with the Federal Aviation Administration (FAA), the Pentagon, U.S. Department of Transportation (DOT), the states, and NASA. The council employs a facilitated roadmapping process to develop a shared longer-range (25-year) strategy. This council has produced the following initial vision statement as a guide for the deployment of their longer-term strategy: "enable a safe, secure, affordable, easy-to-use, advanced mode of personal air transportation that expands access to more communities and decreases travel time for a broad segment of the American public."

These strategies established the framework for coordinated public and private sector investments in general aviation during the period from 1993 to the present. From 1993 to the present, the following NASA-led public-private partnerships have been implemented in support of NASA aeronautics goals related to general aviation:

1) NASA AGATE Alliance is a public-private, cost-shared, research program from 1994 to 2001, focused on technologies affecting engine controls, flight systems, icing protection, crashworthiness, composite manufacturing, flight training, and lightning protection for small transportation light planes.<sup>29</sup> In addition to laying the technological foundations for a revitalization of the U.S. general aviation industry, this program pioneered inno-

ventions in public-private collaboration in research and technology development.<sup>30</sup>

2) The NASA General Aviation Propulsion (GAP) Program is another partnership.<sup>\*</sup>

3) The NASA Aviation Safety Program is the third partnership.<sup>†</sup>

4) The final partnership is the NASA Small Aircraft Transportation System Project.<sup>‡</sup>

In 2001, the GAP and AGATE programs completed the development of significant advancements in technologies for engines, avionics, airframes, and pilot training. Over the eight-year period from 1994 to 2001, these programs invested a total about \$300 million of cost-shared government, industry, and university resources toward the revitalization of the capacity of the U.S. general aviation industry to deploy leading-edge technologies in their products and services. This sum represents the largest investment in research and design (R&D) in the history of this sector of the aviation industry. The near-term products of these investments have stimulating the emergence of a new generation of safe, affordable, quiet, turbine-powered advanced small transportation aircraft, summarized Table 1. In addition, the first new propeller-driven general aviation transportation lightplanes in over 15 years have entered the market.

The FAA and NASA, along with industry, universities and the states (in the NCAM partnership), continue to invest to enhance safety and enhanced operating capabilities in the NAS, through the FAA Safe Flight 21 Program and the NASA Airspace Systems Program, Vehicle Systems Program, and Aviation Safety and Security Program.

The specific technologies employed in the cockpit systems architectures of these aircraft offer the computing platform and digital communications capabilities required to support the operating capabilities conceived for development and demonstration in the SATS project (described next). Those technologies appear as illustrated in Fig. 5. In addition, these new aircraft employ numerous other technologies developed over the past decade and earlier, which significantly enhance crashworthiness, cost of design and manufacturing, lightning protection, aerodynamic performance, engine controls and monitoring, and other features.<sup>29</sup>

### Small Aircraft Transportation System Project

The SATS project in the NASA Airspace Systems Program is a proof-of-concept, technology development effort, to evaluate four new operating capabilities in the National Airspace System. The project culminates in a 2005 demonstration.<sup>32</sup> The purpose is to demonstrate to a wide audience the operating capabilities in development by the SATS Program, and explain the implications of those capabilities towards the SATS vision. The outcome of the demonstration is intended to inspire public understanding and confidence in the ability of new aviation technologies to enable the use of smaller aircraft and smaller airports for public transportation.

The requirements for the demonstration flow down from the following three sources: 1) Congressional and state stakeholder expectations, including the conference committee guidance accompanying the FY 2001 appropriation for the SATS budget, specifying development of a demonstration of four operating capabilities; 2) NASA Aerospace Enterprise Mobility goal and Revolutionize Aviation objectives for reduced intercity travel times, and related strategies embodied in the NASA Blueprint for 21st-century aviation; and 3) emerging business plans in the aviation transportation industry include new aviation technologies for equitable, on-demand and scheduled, point-to-point, widely distributed, commercial and self-operated air mobility services.

The SATS 2005 technology demonstration event is planned to encompass conferences, demonstration flights, simulator flights, and video depictions of the results of the five-year SATS program. The demonstration objectives are focused on three topics.

### Technologies

Demonstration activities include the operation of aircraft and simulations equipped with the new technologies, with participation by

<sup>\*</sup>Data available online at <http://sats.nasa.gov>.

<sup>\*</sup>Data available online at <http://www.grc.nasa.gov/WWW/AST/GAP/>.

<sup>†</sup>Data available online at <http://avsp.larc.nasa.gov/>.

<sup>‡</sup>Data available online at <http://sats.nasa.gov/>.

**Table 1** New turboprop lightjets and propeller-driven transportation aircraft (four- to six-place aircraft applying technologies potentially compatible with SATS operating capabilities; approx. \$1.00 per mile total aircraft operating cost)

Aircraft/gross weight (GW)	Price (approximate)	Cruise speed (max)	Balanced field length or takeoff length (sea level)	Range (NBAA IFR) <sup>a</sup>
Adam A-700/GW not available ( <a href="http://adamaircraft.com">http://adamaircraft.com</a> )	\$2 million	340 kn	2950 ft BFL	1100 n miles
Avocet (Israeli Aircraft Industries)/7210 lb ( <a href="http://avocetprojet.com">http://avocetprojet.com</a> )	\$2 million	365 kn	3000 ft BFL (approx.)	1200 n miles (max cruise)
Cessna Mustang/GW not available ( <a href="http://mustang.cessna.com">http://mustang.cessna.com</a> )	\$2.3 million	340 kn	3120 ft takeoff	1300 n miles (45-min IFR reserve)
Cirrus SR-22/ 3400 lb ( <a href="http://www.cirrusdesign.com">http://www.cirrusdesign.com</a> )	\$300,000	165 kn	1020 ft takeoff	1000 n miles
Diamond D-Jet/4750 lb ( <a href="http://diamondair.com">http://diamondair.com</a> )	<\$1 million	315 kn	2400 ft takeoff	1320 n miles (max cruise)
Eclipse 500/5680 lb ( <a href="http://eclipseaviation.com">http://eclipseaviation.com</a> )	\$1 million	375 kn	2900 ft BFL (approx.)	1280 n miles (with four occupants)
Hondajet <sup>31</sup>	R&D aircraft	—	—	—
Lancair Columbia 400/3400 lb ( <a href="http://www.lancair.com">http://www.lancair.com</a> )	\$365,000	200 kn	~1000 ft takeoff	~1000 n miles
Safire S26/6000 lb ( <a href="http://safireaircraft.com">http://safireaircraft.com</a> )	Not available	380 kn	2500 ft takeoff	1170 n miles (45-min IFR reserve)
Toyota	R&D aircraft	—	—	—

<sup>a</sup>National Business Aviation Association—Instrument Flight Rules.



Eclipse 500



Cessna Mustang



Cirrus Design SR-22



Lancair Columbia 350/400

**Fig. 5** Cockpit system architecture for a new generation of light transportation aircraft.

public audiences. The technical products of the SATS project include 1) software and 2) operational procedure definitions in the National Airspace System. Demonstration activities include the operation of aircraft and simulations with participation by public audiences. The aircraft are equipped with the recently developed technologies, including commercial-off-the-shelf computer-based cockpit system architectures, airborne Internet for communication-navigation-surveillance functions, enhanced vision systems, and augmented flight controls.

#### New Transportation Service Models

Demonstration activities include the explanation of new transportation service business models to the public in written, oral, and video presentations, including use of “day in the life” trip scenarios. These new transportation service models include commercial as well as self-operated, on-demand, fractional, charter, air-taxi, and owner-flown transportation. This analysis will assess the ability of the new models to satisfy the program level requirements derived from the NASA goals and objectives for mobility and revolutionize aviation.

#### Value of the Results

Demonstration activities include the interpretation for the public by written, oral, and video presentations of economic value of these new transportation services on local, state, and national scales. The value to the state and local audiences will be depicted in terms of personal, business, public service, and package transportation benefits. The national value will be depicted in terms of the potential for reduced cost of deploying expanded National Airspace System (NAS) capacity through the SATS operating capabilities, the reduced cost of enabling access to runway ends with the potential for reduced land-use requirements, and the potential benefits in terms of safety, environment, and mobility-related quality of life. The benefits of mobility-enabled economic opportunity will be characterized at the local, state, and national levels. This analysis will assess the SATS project results in terms of satisfying the program level requirements posed by the Congressional and state stakeholders and their expectations.

The project has four objectives centered on enabling operational capabilities.<sup>33,34</sup>

1) Higher volume operation at nontowered/nonradar airports enable simultaneous operations by multiple aircraft in nonradar airspace at and around small nontowered airports in near all weather.<sup>35</sup>

2) Lower landing minimums at minimally equipped landing facilities provide precision approach and landing guidance to small airports while avoiding land acquisition and approach lighting costs, as well as ground-based precision guidance systems such as ILS.

3) Increase single-pilot crew safety and mission reliability and increase single-pilot safety, precision, and mission completion.

4) En route procedures and systems for integrated fleet operations provide simulation and analytical assessments of concepts that integrate SATS-equipped aircraft into higher en route air traffic flows and controlled airspace.

The SATS Concept of Operations that supports these four operating capabilities includes the idea of a newly defined area of flight operations called a self-controlled area (SCA) and the use of navigation and display capabilities for instrument approaches without traditional ground-based navaids. In instrument meteorological conditions, an SCA would be established around SATS-designated nontowered, nonradar airports. In the SATS 2010 Concept of Operations, aircraft would arrive at a SATS airport on a standard Instrument Flight Rules (IFR) flight plan under Air Traffic Control (ATC) control. Pilots of compliant-equipped airplanes would approach the SCA, obtain sequencing information from a device at the airport (referred to as an airport management module), request a clearance to enter the SCA, and would be cleared for operations in the SCA. Within the SCA, arriving or departing pilots would take responsibility for separation assurance between their aircraft and other compliant-equipped aircraft, using onboard displays and calculation of separation and sequencing guidance.

Under the concept under development by the SATS project, the sequencing information would be provided to the pilot from a device on the ground at the nontowered airport. This concept would employ a proposed ground-based automation system, called an airport management module (AMM). The AMM provides information about sequencing, airport meteorology, missed approach procedures, and other flight information over data-link communications. The AMM would make sequencing assignments based on calculations involving aircraft performance and position information, winds in the terminal area, missed approach requirements, and a set of predetermined operating rules for the SCA. For this operational concept to be viable, a link between the AMM and ATC is desirable, for controllers to facilitate airspace management based on the same information that pilots were being given.

Equipment required in the aircraft for this capability includes an approach-certified IFR global positioning system receiver, an ADS-B transceiver, a communications data link, a cockpit display of traffic information, plus software and display graphics for self-separation and onboard conflict detection and alerting, and self-spacing. The early airspace simulations of operations with these kinds of aircraft in nonradar airspace indicate that, within the assumptions, the concept could allow for several aircraft operating simultaneously in self-controlled airspace.<sup>36</sup>

The SATS project technology development includes demonstrating the capability to provide access to small airports in low-visibility conditions while avoiding land acquisition and approach lighting costs, as well as avoiding the expense for ground-based precision guidance systems such as ILS and avoiding the expense of additional land-use requirements for runway protection zone gradients for traditional instrument approaches. Current airports without navigation aids and/or instrument approach procedures are limited to Visual Flight Rules (VFR) minimums for ceiling and visibility, which can be as restrictive as 1000 ft and 3 miles, respectively. This objective is focused on developing, evaluating, and demonstrating concepts, technologies, and procedures that enable approaches and departures in lower-visibility conditions than are permitted at airports that currently have high-minimums approaches. This objective includes demonstrating the technologies and procedures that enable environmentally sensitive approaches and departures, for example, keeping traffic up higher longer and routing approaches and departures away from noise sensitive areas. The project will assess whether this ca-

pability can be provided at a cost that is acceptable to users, airports, and the FAA, and if it can be provided at or above current safety levels. The nearer-term goal is to demonstrate the ability for landings and takeoffs with minimum ceiling and visibility requirements of 200 ft and  $\frac{1}{2}$  mile, respectively, at a currently VFR-only airport, with a 3200  $\times$  60 ft runway, with standard 3-deg, straight-in precision (vertical guidance) provided by onboard systems.

The SATS project goals include the development and demonstration of enhanced vision displays, decision aids, and controls automation that enable a single private instrument pilot with a median-level currency of 80 h per year to operate with precision, safety, and mission reliability equal to that of a single crew member with air transport pilot (ATP) level of proficiency. This comparison will be made for an ATP operating a general aviation aircraft with current instrumentation (i.e., steam gauges and basic radio navigation avionics.) The SATS pilot would be flying with two or more simultaneous operations in nontowered, nonradar airspace, with standard 3-deg, straight in precision (vertical guidance) approach, while comfortably flying to personal minimums, with no high-cost approach lighting, in category A aircraft (FAA Aircraft Approach categories base minima on maneuvering speeds. Aircraft in category A are able to maneuver at speeds of less than or equal to 90 kn on approach.).

### SATS Implications in the NAS

The SATS project was conceived to be an incubator for NAS architecture considerations and procedures that would be prohibitively challenging to develop and demonstrate in the hub-and-spoke and scheduled air carrier portions of the system. Targeted as it is at airspace that is currently underutilized (nonradar, nontowered), the nearer-term opportunity exists to establish the viability of the new operating capabilities and technologies in portions of the NAS that are less challenging with respect to adaptation to change.

In the longer term, the SATS technologies could have favorable implications for the operating capabilities at air carrier facilities; SATS-derived equipment could have high levels of affordability in applications in larger aircraft at larger airports. In addition, the potential for SATS-derived market growth appears to be a reasonable expectation, associated with greater accessibility of smaller communities to be connected to the hub-and-spoke system in smaller aircraft from smaller airports. This increased accessibility could logically have the favorable effect of increasing load factors for the existing hub-spoke system, especially for trips of 500 miles and longer.<sup>37</sup> The potential advantage to the airlines include 1) congestion relief at hub facilities, 2) accelerated access to more affordable advanced technologies, and 3) outreach to a fourth tier on demand market in communities too small to be economically served by current scheduled regional aircraft.

Although the SATS-targeted operating environment will be in classes C, D, E, and G airspace and facilities serving suburban, rural, and remote communities, the aircraft will possess the required navigational performance capabilities for operability in classes A and B airspace. Technology development is planned for simultaneous noninterfering (SNI) approaches at hub airports. SNI operations are conceived to enable regional, runway-independent, and general aviation aircraft to operate at class B facilities with no impact on capacity. Through intelligent design of the SATS architecture and operating capabilities, the potential exists to greatly exploit the benefits of a faster, distributed air transportation system for rural communities with minimal impact on the capacity of airspace and airports by large aircraft today.

### State of Affairs in Rural Air Transport: EAS, Small Community Air Service Development Grants, and SATS

The conventional wisdom is that air transport cannot work in rural areas because the population base, hence demand, in rural communities is too small to sustain profitable airline service. Indeed, without subsidy from federal programs like the EAS, and a number of state and locally funded subsidies, small communities that now enjoy even a limited level of airline service would soon lose it. In addition to the lack of demand, because of limited economic development and population in most small rural communities, the airline service that is provided is not sufficient in terms of cost,



**Table 2 Time and distance examples for rural traveler access to departure airports**

Origin–Destination	Distance, miles	Travel time
Norfolk–Omaha	118	Est. 2 h, 51 min
Norfolk–Sioux City	83	Est. 2 h, 5 min

frequency, convenience, and comfort to keep rural travelers out of their automobiles.

The difficulty associated with sustaining airline service in small communities is a self-fulfilling prophecy. Airlines operate the routes only because they are mandated to do so. Unfortunately, the mandated service is a function of a one-size-fits-all airline business model. Instead of rethinking rural air transport and determining what would work to meet the demands and expectations of travelers in these communities, the EAS policy and the airline mindset imposes a highly limited version of airline service (in terms of kind of aircraft and frequency of service). Whereas in most markets the air carriers realize that customers want frequency, efficient connections, and comfort afforded by modern jet aircraft, in small communities the model is limited frequencies, connections that are inefficient, and turboprop aircraft that fail to meet traveler expectations for speed and comfort and traveler perceptions of safety and reliability. The gap between what is expected and what is provided is further exacerbated by the relative cost of traveling on what is otherwise not very desirable service.

Consider the following example. A traveler from Norfolk, Nebraska, a small city located 118 miles northwest of Omaha, is considering a trip to Seattle to visit relatives. She has the choice of three air travel options. She can fly from Norfolk on subsidized EAS service provided by Great Lakes Airlines. She can drive to Sioux City, Iowa, and catch a flight on Northwest Airlines and its regional affiliate. Finally, she can drive to Omaha and choose between a number of carriers, including Southwest Airlines. The choices are illustrated in Table 2.

1) The first choice is as follows: Fly from Norfolk; Great Lakes on Beech 1900 turboprop, one stop to Denver, transfer to United Airlines Airbus A380; depart 5:20 pm, arrive 9:48 pm—air travel time of 5 h 28 min; return UA Boeing 777 to Denver, transfer to Beech 1900, one stop to Norfolk; depart 2:00 pm, arrive 9:58 pm—air travel time of 5 h and 58 min; fare is \$547.50.

2) Choice two is as follows: Drive to Sioux City—2 h 5 min; Northwest AirlinK to MSP, then nonstop to Seattle—air travel time of 6 h 7 min; Northwest from Seattle to MSP, then transfer to AirlinK—5 h and 30 min; fare is \$512.00.

3) The final choice is as follows: Drive to Omaha—2 h and 51 min; SWA to Las Vegas, then to Seattle—air travel time of 6 h 30 min; return from Seattle via Phoenix—air travel time of 9 h; fare is \$312.

The choices just discussed illustrate an interesting mix of fares, connections, aircraft, and travel times. Although the business traveler can choose, in the interest of time savings and convenience, to use the Great Lakes service direct from Norfolk, other travelers can give the other options more consideration. Consider a family of four. Driving to Omaha saves a significant amount of nearly \$900. Driving to Omaha and spending more time in airports during layovers might not be an ideal itinerary, but the cost savings is substantial. If the family of four decides to drive to Omaha, the effect is that the load factor on the Norfolk service declines, and the carrier sees no incentive to provide larger aircraft, more frequencies, or better schedules. In short, the leakage of even a few travelers on any given day from the Norfolk catchment area tends to seal the fate of airline service for that community.

The problem is exacerbated further when considering itineraries that take a traveler to the East. Norfolk's air service takes passengers to Denver, a trip involving 5 h and 30 min of air travel time. If the Norfolk passenger happens to have an ultimate destination on the east coast, he has to spend valuable time back tracking across the country. The automobile trip to Omaha becomes attractive as the passenger compares the increased fares and increased travel times.

The problems facing small community air service stem, at least in part, from inappropriate airline business models and the politically contrived structure imposed by the EAS. The first problem is aircraft

size. Imposing aircraft of 19 or 34 seat sizes on communities with limited demand means that planes fly less than half full in many cases. The second problem is destination. If service is limited to one destination, travelers might find that air travel from their community is not only costly, but also inconvenient. The final problem is fares. Fares, even with subsidy, are not low enough to attract and sustain a steady flow of passengers.

For many years, political leaders at all levels have preached the need to sustain airline service to small communities. In recent legislation, Congress appropriated \$20 million to fund grants as part of a Small Community Air Service Development Grant program. Not surprisingly, the bulk of the money in this program is used to attract, maintain, or enhance scheduled airline service. Unfortunately, grant funding appears to have limited longer-term value in maintaining scheduled service to meet the low levels of demand in small communities. To the extent that subsidies might attract new service or enhance existing service, there is little chance that such improvements can be sustained beyond the subsidy periods.

Taken together, the EAS program and the more recent small community DOT grant program, represent a well-intentioned but somewhat ineffective effort on the part of the aviation community. For a variety of reasons related to the development of the air transport industry in this country, air service is equated with scheduled airline service in the minds of many community leaders, federal policy makers, and industry observers. Scheduled airline service is appropriate for communities that have the necessary population base and supporting airport facilities. For many small communities the airline models that have evolved in recent years are inappropriate. This category of communities will never likely have the population or facilities to support network (full service) or low-fare (no-frills) carriers because the full service carriers rely on premium fares and feeding from large hub operations, and low-fare carriers rely on high load factors and high aircraft utilization. Solving the air service problems for small communities will require that policy makers and small community leaders recognize the validity of the emerging on-demand, point-to-point model as a counterpart to the historical scheduled airline model. The SATS concept, although not expressly designed to substitute for airlines in small community air transport needs, is worth considering as an adjunct to the existing EAS model.

### SATS Transportation System Analysis and Assessment

The development and ultimate deployment of SATS technology requires innovative thinking about public-private partnerships. Based on the premise of SATS as a disruptive or discontinuous innovation (distinct from a direct extension of existing public air transportation business models), a significant challenge exists in amassing the requisite resources from any one existing industry or governmental organization. (At their inception, disruptive innovations do not attract mainstream organizations or resources.) The public-private partnership between NASA and NCAM for the SATS project implementation and for longer-term strategy development was formed with these factors in mind. This partnership has produced several recent studies of the technical and market potential for the SATS concept.

Recent assessments of SATS market characteristics focused on the potential market factors for on-demand, point-to-point, and widely distributed air service include the following:

1) Research Triangle Institute (RTI) (lead for the North Carolina and Upper Great Plains SATSLab) conducted an evaluation in North Carolina of the potential business case for on-demand, rural, business travel originating in the state.<sup>38</sup> This study applied a Monte Carlo simulation of business travel decisions and system performance for a fleet of Lightjets (e.g., the Eclipse or Adam jets) serving about 70 small airports across the state. The results of the study, under the assumptions made, illustrated a business case for about 450 passengers per day, served by about 150 aircraft, with 2% service denial rates and 3-h response times, and a return on investment of about 15–20% with cost to the traveler of about \$1.85 per seat mile. The study also illustrated the strong economic case for the SATS technologies and their effects on yields.

2) A NASA contract study by Dollyhigh<sup>39</sup> evaluated the theoretical diversion of travel mode choice to SATS from competing

modes, based on the value of timesavings. The study used a mode-choice modeling tool that incorporated the American Travel Survey distribution of numbers of trips and modes against trip distances. This analysis revealed the theoretical mode diversion from highways and less time-efficient hub-and-spoke trips. The cost model for the SATS mode was based on the new class of lightjets, operating at about \$2.09 per seat mile, plus \$200 per trip. Based on the assumptions, this analysis estimated that in the year 2022 this cost and time of travel would generate a diversion of about 31 million trips in about 13,500 aircraft of this kind. The study did not address trips that might be induced by a new travel mode choice.

These early market assessments help guide the technology development roadmaps in both the near and farther term.

### Summary

The SATS concept represents a departure from the direct extension of air transportation business and service models of the past in three significant ways. First, the SATS concept is based on an on-demand, point-to-point, and widely distributed network topology. Second, the operating capabilities are conceived to use airspace and runways in instrument meteorological conditions that cannot be used in the current NAS architecture. Third, the concept is based on developing and applying new aviation technologies to make the use of smaller aircraft and more widely distributed community airports practical for public transportation.

The results of early assessments of market adoption appear to support the viability of economically attractive business models for on-demand air service in business travel markets that are not well served by the scheduled hub-and-spoke system. The early technical assessments appear to support the viability of the high-volume operating capability in nonradar airspace as a means of making access more reliable to more airspace and more runways possible in near-all-weather conditions.

The small aircraft transportation system concept has potential to respond to certain externalities affecting the needs for mobility in the 21st century. In the near term, the SATS project is developing technologies that would enable reliable, safe, scalable, affordable, on-demand air access to small communities that cannot attract scheduled air service today. In the longer term, the SATS vision provokes advances in mobility in the form of greatly increased radius of action of daily life.

### Acknowledgments

The excellent contributions of Bassel El-Kasaby, University of Nebraska at Omaha student in the Aviation Institute, in citation research, editing, and formatting are gratefully acknowledged.

The use of trademarks or names of manufacturers in this report is for accurate reporting and does not constitute an official endorsement, either expressed or implied, of such products or manufacturers by NASA.

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