Distributed On-demand Air Transportation Using Small Airplanes and Small and Underutilized Community Airports

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Abstract

The current air transportation system in the United States is being stressed by growing demand and it is not prepared to meet the future needs of the 21st Century economy. A transformation of the National Airspace in how it operates and is managed is necessary. One opportunity for helping meet the growth demands of the 21st Century and that depends heavily on this transformed airspace is a point-to-point, on-demand small aircraft transportation system (SATS) using very light jets and advanced single engine piston aircraft operating from the many small and under-utilized airports existing throughout the United States. This paper discusses the vision for SATS, its current status, and the research and development strategy to achieve the SATS vision.

1 Introduction

1.1 Air Transportation Today

During the last century, the advent of trains, diesel powered ships, automobiles, and aircraft resulted in the development of an effective transportation system that facilitated tremendous economic growth for the United States and the World. Today, this transportation system is being stressed by growing demand and it is not prepared to meet the future needs of the 21st Century economy. The ability of the National Airspace System (NAS) to meet this demand is constrained by the limited capacity inherent in the manner in which the current NAS and hub-and-spoke system operates. Airport delays are again looming as a critical limiting factor to hub-and-spoke-based capacity growth in the foreseeable future. Airline scheduling schemes, inclement weather conditions, and individual air traffic service provider (ATSP) workload and productivity limits are also factors that contribute to the delay at the airport. The nation's primary hub airports have been approaching a gridlock situation during primary operating hours, and building more runways at these locations to absorb the projected growth in air transportation is politically and economically very difficult. Terminal area congestion is also an increasingly important issue.

The growth in air travel demand may even be greater than projected since it is estimated that there is an even greater latent demand for air transportation that simply isn't met by today's air transportation system. There is a need for faster, more convenient, short-range air transportation with a broader reach. Airline door-to-door speeds are not much better than automobile travel when layovers and all the extra time spent in the terminal are included for trips of 200-800 miles. Hub delays are providing the impetus for business passengers to seek transportation other than airlines, especially for trips using short-haul domestic flights. Today, in the absence of any viable service, trips are either not taken, or ground transportation is used despite its high time cost. For short-haul domestic flights the traveler has options other than an airplane, such as the using a car or canceling their trips and using teleconferencing. This stifles economic growth and especially hurts rural and other outlying communities that continue to suffer economically due to the lack of a viable transportation system.

It is obvious that a transformation in the air transportation system is necessary to meet the future needs of the United States and the World. The Vision 100 - Century of Aviation Reauthorization Act in December 2003 directed the United States Federal Government to establish a coordinated effort through a Joint Planning and Development Office (JPDO) to create the Next Generation Air Transportation System (NGATS). NGATS was constituted as a blue print for technology development and portfolio management activities to develop the future aviation system that meets the growing needs of the United States. The JPDO was established within the FAA as a multi-agency office coordinating the efforts of all agencies in the federal government with a stake in aviation. These agencies and departments include the FAA, the NASA, the Department of Transportation, the Department of Commerce, the Department of Defense, the Department of Homeland Security, and the White House Office of Science and Technology Policy. NGATS provides an opportunity to coordinate the development of the future air transportation system that responds to the needs of the flying public.

1.2 The Vision of the Small Aircraft Transportation System

One important aspect of NGATS could be an air transportation system using small aircraft operating from the many under-utilized and small airports existing throughout the United States. Such a small aircraft transportation system (SATS) could enable travel at least three times faster than a car and use the already existing public facilities. Travel could originate from a nearby community airport and conclude at another community airport that is within 30 minutes of your final destination. The travel could be scheduled when needed. This new comfortable, quiet, and convenient air transportation option could also operate reliably in near all-weather conditions, provide the safety and security of the current airline system, and offer this service to you at affordable ticket prices. This is the vision for a future SATS that uses a new generation of comfortable, reliable, and safe small, piston-engine and very light jet aircraft operating from thousands of the small and under utilized community airports that currently exist throughout the United States. Since approximately 98 percent of the American people live within a 30-minute drive of one of these airports, this SATS system would have a profound impact on the quality of life and economy in the United States[1].

A small aircraft transportation system, such as an on-demand, point-to-point air taxi or regional airline, offers an economically attractive complement to automobiles and scheduled legacy commercial airline service for passengers and cargo with roughly 200 to 800 mile destinations. It also represents a viable transportation mode for citizens located in rural sections of the country that are remote from any available commercial air service and provides essential transportation for disaster relief efforts, as was demonstrated following the recent hurricanes: Katrina and Rita. The economic benefits are five-fold:

1. A SATS service into an existing public use airport, currently without commercial air service, could stimulate an economic boom to the local region in terms of attracting new service and manufacturing industries, jobs created in derivative markets such as car rental agencies, hotels, restaurants, etc. to accommodate the business and leisure air travelers, and by the tax revenue generated. Note that scheduled commercial air service into smaller towns and communities has been shrinking in the past decade because of unfavorable economics.

2. There are over 3400 public use airports already in existence that can accommodate

SATS-like air service for negligible additional costs.

3. SATS technologies, such as synthetic vision avionics, and automatic surveillance instrumentation, coupled with 4-6 seat very light jet and small piston airplanes, allow an air taxi service to provide passengers and cargo with reliable, safe, comfortable, and cost-effective air transportation options at a profit [2,3,4]. Thus, a new industry of profitable on-demand air service providers stimulates the national economy, as well as provides a positive economic impact because of the value of the time saved by travelers avoiding long drives to hub airports, long waits in security lines, flying at inopportune scheduled times, and multi-leg flights through interconnecting hub airports.

4. SATS technologies allow for high-volume operations into and out of non-towered, non-radar airports by applying a self-separation capability, which makes no additional demands on air traffic control [5]. Sales of SATS airframe and equipment are expected to grow as a result of the emergence of on-demand air-taxi service, further stimulating the national economy. Local communities also benefit by avoiding the cost of manned towers, and the acquisition plus maintenance costs associated with instrument based landing systems.

5. SATS technologies allow for non-traditional curved/segmented overhead approach and landings into non-towered airports [6]. This results in lower noise footprints and the ability to avoid mountainous terrain and restricted air space, and also reduces the amount of land that is required to be owned, maintained, and cleared by the airport authorities.

2 Status of Vision

The initial technology foundation for the SATS vision has already been built -- through the collaborative research and development (R&D) efforts of the Federal Government, universities, and private industry. Research conducted in the 1990's under NASA's Advanced General Aviation Transport Experiment (AGATE) and General Aviation Propulsion (GAP) projects provided the aerodynamics, propulsion, structures, and avionics technology that have been applied by industry to create improved aircraft, engines, and guidance systems.

Recently, another NASA R&D project called SATS, funded and conducted in partnership by the National Aeronautics and Space Administration, the Federal Aviation Administration, and the National Consortium for Aviation Mobility, developed and demonstrated several key technologies [5-26] that provide enhanced operating capabilities including:

(1) Increased traffic capacity for small airports; without the need for expensive radar, control towers, or ground navigation systems,

(2) Guidance systems for safe, reliability aircraft operation to/from small airports in low visibility conditions,

(3) Flight control and guidance displays for safe, easy-to-fly, single-pilot aircraft operation with enhanced situation awareness.

The SATS project concluded in June 5-7, 2005 with a highly successful public exhibition at the Danville, Virginia airport. The exhibition included live flight demonstrations, technical exhibits, and analytical presentations. Although the SATS project demonstrated the initial feasibility of the enabling technologies to achieve the desired operational capability, additional technical issues and barrier still must be overcome to develop a fully capable, safe, secure, efficient, and affordable air transportation element operating effectively in the NAS to-and-from small airports throughout America.

At the request of NASA, the National Institute of Aerospace (NIA) was tasked to develop a comprehensive, independent assessment and guidance (developed by industry, university, and state, without the influence of any federal government agency representatives) that can be used to maximize the public benefit to be derived from future Federal R&D investments in aeronautics. The resulting report, "Responding to the Call: Aviation Plan for American Leadership," was published in April of 2005. In September of 2005, NIA undertook a supplement effort to develop a national strategy to achieve implementation of the SATS vision.

To this end, non-Federal Government executives and senior researchers and technologists from industry, university, state government, and other aviation organization were invited to define the high priority goals for achieving the SATS vision and to develop and document technology roadmaps projecting the technologies, time, and investments needed to fully realize the SATS vision. The product from this activity was a report entitled, "Research and Development for Safe, Secure, and Affordable Air Transportation for Every Community in America." and this report was published by the National Institute of Aerospace in January 2006. The NIA report describes the strategy, objectives, and benefits of an R&D plan to achieve the SATS vision and provides recommended technology R&D roadmaps that offer information on the important goals, product development milestones, and the estimated resource requirements for each technology area. This current paper highlights the recommendations of that NIA report.

3 Required Research and Development

The strategic goals defined in January 2006 NIA Report were prioritized to reflect their importance in achieving the vision to provide safe, secure, and affordable air transportation for every community in America. The recommended technology targets were grouped in four high-priority areas:

- Service Reliability
- Weather Safety
- Ease of Operation
- Community Compatibility

Within each target area, technology development roadmaps were defined and prioritized. The current report will summarize the work needed in these areas.

3.1 Service Reliability

The number-one research priority area was determined to be Service Reliability. In this area, there are three major goals. These include:

- Integration of small aircraft into the air traffic management system
- Self-controlled airspace for small, remote community airports
- Performance based operational capability

3.1.1 Integration of Small Aircraft into the Air Traffic Management (ATM) System

This goal was believed to have the highest priority and aims at the effective integration of advanced SATS technologies involving avionics and airport technologies for small aircraft into the NAS and ATM system. Objectives for this research are:

- Development and validation of procedures/technologies to effectively integrate the SATS vision into the NAS; and,

- Evaluation of the safety and effectiveness of the procedures developed above, consistent with the Next Generation Air Transportation System (NGATS) integrated plan.

The SATS concept will use under-utilized general aviation airports to provide more direct transportation for the 98% of the population that lives within 30 minutes of a general aviation airport. Consequently, the neighboring hub airports and sectors may not be as greatly impacted by SATS traffic growth because of the redistribution of service to/from smaller community airports. With greater accessibility to community airports, it is conceivable that the population demographics may shift and coalesce around these airports, further relieving the prospect of hub-and-spoke gridlock.

Integration of SATS technologies with the Air Traffic Management system will require research into airspace management, automation tools, sector loading, Air Traffic Control (ATC) procedures, ATC workload, and optimization of the airspace around small airports to maximize safe and efficient operations during instrument meteorological conditions. This leads to research on using self-controlled airspace for community airports.

3.1.2 Self-Controlled Airspace for Small, Remote, Community Airports

The goal for self-controlled airspace is to develop automation suitable for seamless sequencing and self-controlled area flight operations that can produce a four- to eight-fold increase in single-pilot IMC operations at under utilized, non-towered, and non-radar covered airports anywhere in the NAS. It is proposed to conduct research, analysis, modeling, and development to determine the optimum method for automation of sequencing and self-controlled area operations using VFR-like free flight procedures during IMC.

As an extension of "free flight," the self-controlled area (SCA) concept of operation demonstrated the potential for increased arrivals and departures from under utilized rural and suburban airports outside of radar coverage and without towers during instrument meteorological conditions, and without an additional burden to air traffic control. Although significant work was completed for demonstrating the feasibility of high-volume operations (HVO) at SCA airports, new research in this area could substantially expand the number and safety of single-pilot HVO operations during IMC. The ultimate goal would allow VFR-like free flight operations in IMC within any airport terminal area. Systems, procedures, and automation (ground and cockpit) are needed to permit a seamless transition to and from general aviation airport airspace and the National Airspace System en route environment.

Data link communications with ATC should be the considered to facilitate automation functions and backup systems. Cockpit automation in conjunction with data link communications with ATC and other aircraft could provide for enhanced safety of operations and reduced workload. Significant research issues remain in regard to certification of ground-based SCA automation to maintain and assure traffic separation for non-normal and emergency operations. Research should also consider airborne-based automation for SCA operations using air-to-air collaborative negotiation for separation and sequencing that actively involves each pilot, but allows for more flexibility than procedural separation.

3.1.3 Performance Based Operational Capability

The goal of performance-based operational capability is the integration of SATS operations into the ATM system. Research is proposed to address the communication, navigation, and surveillance aspects of this capability.

3.1.3.1 Communication

The Information Age has come to the NAS. The Air Traffic Management system is on the verge of adopting a net centric operations perspective. The NGATS Integrated plan describes net centric as "…architectures that distribute intelligence and functions to smarter and smaller nodes in the system…" Information is shared and intelligent functions are distributed throughout the system. The current NAS is not net centric because information is kept centrally; decisions made using the SATS technology areas would focus on getting shared information to "nodes" (small aircraft and airports) and enabling intelligent processing.

Data link communications will be an enabling technology for the future air traffic management system. The net centric operation between ATM and the aircraft are predicated on high speed, reliable data link communications. Research issues in data links will focus on architectures, data security, data integrity, application segregation, and bandwidth maximization. The data link architecture will need to be designed to provide the necessary Required Communications Performance. To maximize the bandwidth, spectrum allocation for specific aeronautical domains such as communications or navigation will need to be removed. Data link communications will be able to select the technology and spectrum domain as needed to provide the necessary efficiency, minimal latency, and minimal cost. Similar to the Internet, the sender and receiver will not care which channel was used as long as the information is received in a timely fashion. Priority schemes will be needed for time-critical and emergency messages.

There are two topics (among many others) running through aviation today that are tagged as “data link” discussions. One topic is “data link” in the context of controller–pilot interactions. The goal in this topic is to relieve the congestion on the VHF voice frequencies by encapsulating common and inefficient voice transactions with digital data streams. Examples are routine clearances, frequency handoffs, and acknowledgements. The technology is fairly mature in the definitions and standards, referred to as Controller-Pilot Data link Communication (CPDLC). Adoption and widespread use has not yet occurred, and is farther along in Europe than in the U.S. due to their worsening voice congestion problem.

The other “data link” topic is of a larger scope and is also less mature. It is the realization that it is not just the “voice communication” part of the ATM system that has data link requirements, but all aspects of air traffic management will benefit from automation of routine actions which in turn creates the need for data exchange from aircraft-to-aircraft and aircraft-to-ground. Automated Dependent Surveillance-Broadcast (ADS-B) is a data link for surveillance. New ideas for added information (weather observations on the aircraft and 4D trajectory exchanges are two examples) are constantly arising. The aviation community is realizing that to avoid overburdening the aircraft with data link transceivers, some consolidation will be necessary.

For the small airport and aircraft users, the data link requirements revolve around automation of unattended airports or airports without surveillance. These include automated sequencing instructions (used in conjunction with ADS-B and/or Cockpit Display of Traffic Information (CDTI)), requests for runway lighting and automated condition reports, and the reports of conditions, active runway, etc. These items are not all currently defined on any data link, but are most closely associated with the CPDLC meaning of the term “data link”. The job in front of a small airport research team is to define the unattended or non-surveillance airport procedures that will require data link messages. These procedures will have to be refined and their adoption will have to be encouraged and promoted. It will then have to investigate current message set definitions and define new messages as necessary. Research will also involve investigation of the currently available product sets for the aircraft and the ground. Where there are gaps in equipment availability, the economics will have to be investigated and investments may have to be made to stimulate product availability.

All aspects of air traffic management will benefit from sharing of information and from automation of routine actions. This creates the need for data exchange from aircraft-to-aircraft and aircraft-to-ground, both for display to pilots and controllers, and for input to automated processes. Examples of the information to be exchanged are shown in the table. Since the data has multiple sources and multiple users, a network approach to the data communication is indicated. This gives rise to a net-centric model of how future operations will exchange information.

3.1.3.2 Navigation

An expansion of the FAA’s Required Navigation Performance (RNP) and Actual Navigation Performance (ANP) procedures should be evaluated that would provide credit for the evolving advanced technology systems that have been shown to provide greatly increased flight path accuracy with equivalent or improved safety and user efficiency. The RNP/ANP Terminal Instrument Procedures (TERPS) and en route standards need to include not only navigation systems but also consider synthetic vision systems with highway-in-the-sky (SV/HITS) that can provide extremely accurate flight path guidance. Enhanced Flight Vision Systems (EFVS) can also allow the pilot to "see" the runway environment in adverse visibility conditions. The ability to highlight obstacles (deer, aircraft, ground vehicles, etc.) in the runway environment, even in IMC, will provide an improvement in flight safety. The RNP/ANP improvement will be a great aid for small airports, especially those that do not have a precision approach now. The infrastructure improvements will be minimized because the safety areas could possibly get smaller. The determination of RNP and ANP for any particular aircraft should be a calculation that a flight crew can perform. Based on the current working equipment on an aircraft, the flight crew should be able to determine the RNP/ANP values that are available to them.

3.1.3.3 Surveillance

There will also be an improvement in flight safety with the implementation of ADS-B to provide real-time traffic information and alerting on advanced synthetic vision displays. This capability is important not only in the terminal and approach phases of flight, but en route as well. Traffic separation is always a concern in aircraft operation. Just as the new display technology benefits the aircraft in terms RNP, the display technology can enhance the flight crew's "see-and-avoid" capability. Three-dimensional and four-dimensional analysis will be displayed to the flight crew so that they not only know where the traffic is, but where it will be in relation to their flight plan path (conflict probing and de-confliction).

The combined display of traffic plus the Conflict Detection and Alerting (CD&A) technology will assist the flight crew in "see-and-avoid". There are issues with this technology that must be addressed. Hazardously misleading information cannot be given to the flight crew that would indicate that traffic is not a factor or that separation standards would not be broken. There must be redundancy to ensure that a system failure does not cause an issue. ADS-B relies on GPS technology for its position reports. Backup position/navigation sources are also important to traffic display as well as CD&A. Consequently, sensor fusion is also a necessary research area. If CD&A algorithms are driven by traffic information obtained from ADS-B, as well as a secondary device such as TCAS, they must provide the same answer or at the least, non-conflicting information. The CD&A must also be designed such that it does not contradict an ATC call out of traffic.

3.1.3.4 Combined Vision

Another promising technology area that has been briefly investigated thus far is a Combined Vision System, which combines synthetic vision (which uses an on-board terrain/obstacle database) with information derived from other sensors on the aircraft. One such sensor, forward looking infrared (FLIR), is already certified by the FAA for use in Enhanced Flight Vision Systems (EFVS). This EFVS technology has been certified to provide the pilot with the ability to use a Head-Up Display (HUD), showing Primary Flight Display (PFD) type flight information and a FLIR sensor image, to go down to 100 feet above the runway -- if the FLIR shows the runway and indicates that the aircraft is in a position to make a safe landing. Research needs to be conducted to evaluate additional sensors (millimeter wave Radar, Lidar, and others) and to pursue fusion of the sensor image with synthetic vision displays. In a recent simulation experiment, a fused FLIR/SV display was shown to provide pilots with outstanding situation awareness, even while conducting instrument approaches in difficult IMC.

3.2 Weather Safety

In the second targeted area, Weather Safety, research is recommended to develop systems that will protect the aircraft when operating in adverse weather conditions. Important goals include:

- Real-time Cockpit Weather Intelligence
- Enhanced Weather Forecasting
- Airport Weather Sensors
- Enhanced Icing Safety

3.2.1 Real-Time Cockpit Weather Intelligence

Real-time weather provided to the cockpit is necessary to achieve improved safety for near all-weather operation. General aviation flights, at least for piston driven aircraft, operate at the lower altitudes where the weather patterns have the most effect. Real time knowledge of icing, convective activity, and turbulence is invaluable to the pilot. Tremendous strides have been made in providing NEXRAD (Next Generation Radar) weather information to the cockpit for display on the aircraft Multi-Function Display (MFD). The ability to provide weather information via data link to the cockpit is currently being embraced by the pilot population.

However, accessing the data needs to be made more intuitive. The pilot workload in poor weather is much heavier, so the ability to find, access, and interpret real-time weather must require minimal pilot action. Research areas should examine resources and techniques for fusion of weather information involving the integration of data from ground systems, aircraft sensors, and forecasts. Research should involve cockpit automation for assessment of significant weather data relative to the aircraft's flight plan and alternate airports, with assisted interpretation and intuitive interpretation and display of weather information.

3.2.2 Enhanced Weather Forecasting

Work in Enhanced Weather Forecasting to improve the forecast accuracy and capability, particularly recognizing that imprecise current weather information is usually all that is currently available. The development of enhanced weather forecasting for the lower altitudes and the remote areas that small aircraft often operate will have a major effect on the safety and productivity of small aircraft. Currently, low-altitude weather forecasting lacks fine-grid data to make the adequately refined forecasts that are needed along a specific flight path. As a result, when severe weather is forecast in a region, small aircraft currently avoid that region resulting in inefficiency and in many cases a loss of air service.

Aircraft icing for a GA aircraft is a particularly serious issue. Some general aviation airplanes have equipment that permits flight into regions of known or predicted icing. However, detailed information for any specific location is usually not available, even in real time.

The historical emphasis of weather prediction and reporting is on the movement of large air masses and their interactions. Very little has been done in the area of aviation microclimate prediction. Primary reasons have been the magnitude and cost of data collection for localized weather phenomena. With the cost of sensing and computing capabilities continually declining, these constraints should eventually end.

Obtaining truly useful aviation weather information will require coordinated efforts in the following areas:

- Analytical tools that enable the creation of predictive dynamic models of microclimates
- More detailed information about regional weather patterns and movements that affect microclimates
- Develop and implement higher resolution weather satellite composite data
- Develop and install ground-based and on-board storm and icing sensors
- Availability of user-specific predictions

- Real-time dissemination of information and updates to all users

There are three solutions currently being worked to improve weather data collection:

- MDCRS – Meteorological Data Collection and Reporting System – participating transport airplanes collect temperature, wind, and position data on selected airline routes and transmit data over ACARS or other data link services.
- TAMDAR - Tropospheric Airborne Meteorological Data Reporting system received FAA Supplemental Type Certification 6/17/04 for installation on Mesaba Air Lines Saab 340 aircraft.
- More automated ground stations with improved sensor capabilities, located at small airports.

The first need in this area is for a system-level overview of the current weather-related infrastructure, and also of the research, development, and upgrades now in work. Importantly, no document currently provides this overview considering all the many government, university, and industry organizations involved. This overview would serve as the first step in creating a proper systems-engineering approach to both the development and implementation of an optimum weather information and avoidance system. This is a necessary step to give needed form and context to ongoing efforts that are already bearing useful fruit along a broad range of meteorological R&D projects.

3.2.3 Airport Weather Sensors

The goal for airport weather sensors is to develop sensors for general aviation airports that are affordable, enhance safety of flight, and meet FAA requirements for commercial service operations.

Of over 3,300 airports, less than 1,000 have a Federal AWOS or ASOS station. That means some 2,000 airports have none or limited automated weather sensor services and no means for automatic dissemination of this data to the public. While many of these airports would like to have scheduled service operations, the greatest constraint preventing broader implementation of AWOS stations that would qualify airports for such services is basically affordability. Acquisition cost is over $100,000, and the cost of dedicated lease line connectivity for reporting non-Federal AWOS station data to the FAA averages over $1,000 per month per site. Re-engineering of sensors, use of microelectronics, advanced algorithms, and network centric communication could reduce the cost of acquisition and operation by over fifty percent.

Improved weather information along the approach path (not just vertically above the airport), including slant range ceiling height and visibility, is particularly important. Runway condition sensor technology should also be developed to more accurately predict the occurrence of runway ice, allowing for a 30% to 75% reduction in treatment with chemicals [27]. Factors affecting runway icing conditions include runway surface color and composition, wind velocity and direction, surface moisture, atmospheric moisture content, traffic volume, amount and angle of incidence formation of ice.

3.2.4 Enhanced Icing Safety

The first rule in general aviation icing safety is avoidance of known icing conditions. This will be aided by improved fine-grid aviation weather data collection, analysis, real-time dissemination to aircraft, and fine-grid weather forecasting. As icing incidents and fatalities persist for general aviation, research remains essential in icing prevention and protection. Therefore, the goals for enhancing general aviation icing safety are:

- Affordable and effective in-flight anti-icing and de-icing capabilities.
- Better information about the susceptibility of wings to stall due to frost, snow, and ice while on the ground, and the proper management of those conditions.

Despite years of research and engineering, the problem of icing on general aviation aircraft has not been satisfactorily solved. Lacking these resources today in general aviation, pilot judgment is the major factor in safe operations in icing conditions. For pilots of light airplanes, often the best decision is to not fly into possible icing conditions, which means that flights are cancelled, making the airplane less reliable as a transportation tool. Affordable and effective de-icing and anti-icing capabilities for small aircraft are essential areas of research. Ice adversely affects both airframes and engines. On airframes, ice adds considerable weight and aerodynamic drag while severely reducing the lifting capability of wings. Ice on propellers reduces thrust and induces dangerous vibrations. Engine inlet ice chokes off combustion and cooling air. While equipment is available for many airplanes to allow flight into known icing, no system yet exists to reliably prevent or remove ice from all aircraft surfaces and engine components in the most severe icing conditions. Consequently, ice-related accidents continue to occur each winter.

Jet transport aircraft typically have superior anti-icing capabilities because their engines provide substantial excess heat that is tapped to heat the leading edges of wings and tail surfaces. These aircraft are also designed to have high thrust in order to fly at a very high altitude, which enables them to climb rapidly through the lower altitudes where icing occurs. Once at their high cruise altitudes, icing is almost never a problem. These advantages are simply not available for very light jets, or for light, propeller-driven airplanes, whether piston or turboprop powered.

The most common ice protection system for light aircraft use pneumatic leading edges to expel the ice or inject antifreeze solutions to remove the ice. These systems are heavy, expensive, costly to maintain, reduce performance, and have undesirable operating limitations. Several exotic technologies have been tried with little success. Oddly, simple and inexpensive technologies such as leading edge shields, mechanical scraping mechanisms, electrical thin films, internal leading edge MEMS technology hammers, and acoustic drivers have received relatively little attention. Research to explore these simpler but potentially effective technologies may bear considerable fruit.

3.3 Ease of Operations

The third target area is Ease of Operation. This area is particularly important for small aircraft operations with a single-pilot, as compared to two-crew operation used by large airline and air charter operations. The highest priority research topic in this area is Intuitive Aircraft Operations. Research is recommended on haptic flight control systems (that provide sensory feedback to the pilot) and on intuitive displays that can enhance aviation safety by providing aircraft performance envelope protection. This research should also include the development of more affordable display media, such as head up display (HUD), head-worn displays, effective head-down displays, and synthetic voice/voice recognition. Research directed at the development of automated flight planning capabilities, emergency auto-land, resilient recovery functionality, fly-by-wire control laws with an affordable fully-coupled auto-pilot, and automated pre-flight and weight-and-balance technology is also recommended.

There are three major goals under this target area and they include:

- Enhanced Single pilot performance
- Single-pilot operation
- Aircraft automation

3.3.1 Enhanced Single Pilot Performance

The conventional focus for the enhancement of single-pilot performance has been to develop systems that provide greater situation awareness to the pilot and make the tasks associated with the operation of the vehicle easier. This is indeed a noble goal and the benefits that have been realized by these efforts in a short period of time are quite impressive. Thanks in large measure to the efforts of NASA AGATE and SATS projects, new technologies have greatly enhanced the capabilities of light aircraft, including:

- Greatly improved primary flight instruments that are more intuitive and are far more reliable than the original mechanical instruments that they replace;
- GPS based navigation systems and associated path following functions that provide much more accurate position and velocity information than could be realized with older navigation systems;
- Flat panel displays showing a myriad of information including moving map, graphical weather and terrain, adjacent traffic, route management, highway-in-the-sky flight guidance aids, etc.;
- Full Authority Digital Engine Control (FADEC) that reduces the task of engine management to a single lever and sophisticated diagnostic systems to identify engine anomalies early.

Now that these new technologies are reaching maturity, the focus of avionics development needs to move beyond sophisticated situation awareness, ease-of-use technologies, and examine how avionics can be used to address the inherent lack of human redundancy that occurs when the first officer is eliminated from the cockpit. One premise is that while ease-of-use technologies make the task of flying easier, thus reducing the risk of pilot distraction and loss of situation awareness, the technologies fall short in really providing the level of oversight and human redundancy provided by the presence of the first officer. In some instances, the automation may actually lead to dangerous situations stemming from pilot complacency due to over-reliance on automation. Therefore, notwithstanding modern technologies, single-pilot operation is still inherently riskier than two-pilot crew operation, as discussed next.

Avionics are envisioned that can fill the void created by the lack of the first officer for single-pilot operation. Ultimately, the vision for this type of automation is to provide a system that can participate in meaningful Cockpit Resource Management (CRM) with the pilot in command. In such a system, not only does the pilot have oversight of the automation, but also the automation is granted some limited oversight of the pilot. Such oversight could be manifested as terrain warnings, flight decision-making warnings relative to inclement weather, flight planning and fuel management assistance, flight envelope warnings and/or protection, and automatic recovery from unusual attitudes. In the extreme case of total pilot incapacitation, the automation would be able to assess the situation and invoke emergency auto-land capabilities. This larger vision is well beyond the scope of any one effort, and requires considerable research to fully investigate all of the issues. As a first step, the focus should be on the key initial component of a system that aims to replicate first officer capability: an auto-flight system that can fly an aircraft through its entire flight envelope, provide envelope protection advisories, and recover from uncontrolled flight.

3.3.2 Single-Pilot Operation

It is difficult to quantify the level of risk associated with single-pilot operation as opposed to a two-pilot crew because statistics directly comparing single-pilot operations to multi-piloted aircraft are not available. However, some insight can be obtained from examining 2003 aircraft accident rates shown. Examining the type of operations relative to their safety record, it is clear that FAR 121 and FAR 91 corporate operations are by far the safest. FAR 121 operations are required to be operated by two-pilot crews. Most FAR 91 corporate operations use two-pilot crews although, depending on specific aircraft requirements, it may not be specifically required. Comparing these operations to on-demand air taxi shows that the FAR 135 operations have a much greater accident rate even with the presence of a professional pilot. General aviation (all-types), where there is not necessarily a professional pilot, has an even higher accident rate. There are several factors that may make FAR 135 operations more dangerous. These factors include lower performance aircraft with less capable avionics, the use of less capable airport facilities, and the fact that these aircraft are often flown by a single pilot. Since multiple factors are involved, single-pilot operation cannot be singled out as the definitive safety concern; however, it is indicated to be a factor. Rockwell Collins performed a pointed analysis of single-pilot operations when they examined Cessna Citation 500 accidents [28]. This aircraft is a light jet that is approved for single-pilot operation, but is more likely to be flown with a two-pilot crew. There have been four fatal two-pilot crew accidents and five fatal single-pilot accidents for this aircraft.

While no firm numbers exist on the ratio of crewed-aircraft to single-pilot flight hours, Collins estimates that crewed flight hours is at least 3-4 times higher than single-pilot operation. Since operation of the aircraft requires a type rating and insurance companies require high levels of experience in this aircraft (e.g. 2500-3500 hrs), it is reasonable to assume that the single-pilot operators are as qualified or more qualified than pilots of the two crew aircraft.

When single-pilot accidents are examined, one can surmise that they would not have happened if another qualified pilot were on-board. Examining the accident histories reveals that the pilot of one of the Cessna Citation 501 accident aircraft was too slow on final approach. Another pilot lost control on departure in IMC. One aircraft was lost during maneuvering on a clear day. Another Citation 501 was lost during a failed instrument approach and hit a mountain. Most of the accidents involved some form of loss-of-control and controlled-flight-into-terrain, adding credence to the need for automation to protect the pilot from exceeding the aircraft's flight envelope.

A trend in aviation industry continues to push advanced technologies and affordability from military and commercial systems to general aviation. Examples of this include avionics such as GPS receivers, moving maps, weather broadcast, auto pilot, data link communications, enhanced vision system, paperless checklists and handbooks, and most recently head-up displays. Nevertheless, most aviation systems operate as independent or barely integrated systems. While contemporary flight management systems can provide significant workload relief, they also introduce new issues and dangers such as mode confusion, operator detachment, compliancy, skill erosion, workload spikes, and interface complexity. Overcoming these issues within the context of single-pilot operation requires fundamental improvements to the functional capabilities of control automation and how it supports and interacts with the pilot.

3.3.3 Aircraft Automation

The goal of general aviation aircraft automation is characterized as an intelligent flight deck that promotes the attributes of portability, affordability, safety, open architecture, seamless communications, navigation, surveillance, and NAS interoperability. Objectives of automation advancements for general aviation are to:

- Prevent loss-of-control accidents;
- Provide integrated support for future airspace capabilities (e.g. RNP, higher volume operations);
- Simplify supervision and tasking of flight control automation;
- Maintain safety of flight in the event of pilot inaction, incapacitation, or blunder;
- Structure the roles, responsibilities, and interaction between pilot and vehicle to create shared situation awareness and robust error detection and recovery;
- Reduce the need to learn and retain highly specialized skills and knowledge; and,
- Provide an extensive foundation for integration of future technologies.

Research in automation for general aviation should include open architecture, virtual co-pilot, envelope protection, fully-coupled auto-pilot, auto-land, and real time WAAS approach procedure design.

3.3.3.1 Open Architecture

An open architecture for software avionics, aviation databases, and communications (including wireless) is needed to stimulate these advances and facilitate cockpit systems integration. Open architecture for general aviation aircraft will enable the manufacture of lower cost commercial off-the-shelf automation applications. This would permit portability of avionics among aircraft of different types, and ease of interface with on-board avionics, systems, and databases. It would facilitate access to standardized aviation databases available on-board or via data link. Open architecture could enable avionics' recognition of its vehicle, on-board devices, sensors, and accessible information whether static or dynamic. It should be self-certifying when moved from one aircraft to another, and provide the necessary FAA-qualified test results and reports. Integration of these innovations would encapsulate an intelligent single-pilot automated cockpit. Research in this area should consider standard avionics interfaces to allow real-time sharing of sensor data and database information among multiple avionics systems which would reduce redundancy of systems such as embedded GPS sensors, multifunction displays, and aviation map databases, all of which add weight and interface complexity.

3.3.3.2 Virtual Co-Pilot

Open architecture for integrated avionics systems would permit virtual co-pilot operations to improve single-pilot safety, reduced workload, monitoring of aircraft performance, and presentation of recommended actions for communication and navigation. Recent research with virtual co-pilot technology has demonstrated the potential for significant safety improvements through monitoring pilot performance, aircraft systems, airspace rules, and other traffic within a self-control area. Also demonstrated was the potential for workload reduction through the performance of routine tasks via the virtual co-pilot, such as flight planning, display map-scaling, checklist automation, menu selection, data link communication of standard messages, and voice recognition/synthetic voice, to name a few.

Voice recognition and synthetic voice (VR/SV) technology is continually being improved and the applications are now gaining acceptance. Both technologies can be used for the controller as well as the flight crew. VR/SV must enable functionality for the flight crew and controller such that they do not need to operate in a heads-down manner. A feedback mechanism is also needed to provide assurance that VR commands are properly recognized and that an incorrect recognition is prevented.

Pertinent virtual co-pilot issues include flight critical certification, performance accuracy, timely availability of data sources, and multi-modal intuitive display of information, data link communication standards, and knowledge-base vs. rule-based intelligent language system. Research should be extended to include free flight operations through every phase of flight within the NAS.

3.3.3.3 Intelligent Auto-Flight Systems

In the previous section evidence was presented suggesting that loss-of-control is a major factor in many aircraft accidents. It is evident that the distractions that lead to loss-of-control are even more significant when a single-pilot has to deal with the situation solely. Furthermore, since rudimentary envelope protection devices, such as stall warning indicators, g-meters, and angle-of-attack indicators already exist; it is clear that the distracted pilot already overlooks these warnings. Therefore, it seems evident that there is a need for a much more active system that can prevent accidents by interceding when a pilot blunders into an unsafe condition. This system could be envisioned as an envelop-protection system with the following features:

- Full auto-flight capability with auto-throttle

- Identify and recover an aircraft from unusual attitudes
- Identify turbulence and automatically modify auto-flight performance to maintain level flight
- Recognize engine over stress and limited fuel conditions
- Identify operational performance limits relative to density altitude, outside temperature, field length, and obstacles
- ‘Run in the background’ during both manual and automatic flight and provide active envelope protection
- Identify pilot incapacitation, take control, and return the aircraft to a safe state
- Emergency auto-land capabilities

3.3.3.4 Envelope Protection and Automation

New aircraft like the VLJ have opened the jet market up to small business and new owner/operator pilots. The pilots that are operating these advanced aircraft may have a relatively low number of flight hours. To maintain a high level of safety, a flight control system with envelope protection would be very advantageous. A Flight Management System (FMS) could be designed that effectively monitors the operation of the aircraft relative to its design flight envelope and ensures that a low-time pilot does not attempt maneuvers that could damage the airframe. The potential for a stall/spin accident could be minimized, if not avoided completely, by designing an FMS with envelope protection. A low-time instrument pilot could also be protected from disorientation with a “smart” FMS.

General aviation has the highest rate of aviation accidents due to operation of the aircraft outside of its performance limits. This often occurs during high stress situations such as engine-out, convective weather, wind shear, and IMC. Research into automation is needed to protect the pilot from inducing unsafe attitudes, engine settings, and unusual rates of change. One such area of research should include haptic stimulus and response. The haptic system is based on the metaphor of a well-trained horse and rider. The metaphor has two key aspects. First, the vehicle has a “horse-like” degree of situation awareness, intelligence, transportation capability, and autonomy. And second, like a horse and rider, the aircraft and pilot interact through a multi-modal interface that includes a strong, bidirectional haptic (sense of touch and kinesthesia) component. This physical connection provides the operator with a natural means of feeling and directing the actions of the automation with minimal use of visual and cognitive resources. Implementation will require fly-by-wire control laws to simply flying to automobile-like operation. Given the general conservatism of the industry, users, and regulators toward new flight control technology, a viable, long-term strategy must support incremental introduction of new technologies in less critical applications and/or with known backup systems and procedures. Once sufficient operational flight experience has been accumulated, next generation systems can increase the functional criticality of the technology. The haptic system concept provides a high-degree of flexibility to tailor the human-machine relationship.

3.3.3.5 Autopilot with Auto-Throttle

An auto-throttle is required to implement the envelope protection described in the preceding section, or at least the advanced version. If active envelope protection is enabled, a combination of autopilot to manipulate the control surfaces and an auto-throttle to control the engine performance will be necessary. Auto-throttle or a Full Authority Digital Engine Control (FADEC) will be needed for auto-land operations. An affordable fully-coupled auto-pilot would resolve many of the complexities associated with precision approaches by low-time or non-professional pilots. Without an auto-throttle, the pilot must give constant vigilance to the reference airspeed on approach. Combine this with cross winds and gusts, and the ability to maintain the proper pitch directly affects the approach speed. Smaller airfields with varying runway lengths and approach glide slopes add to the complexity of energy management for the approach. Having an affordable fully-coupled auto-pilot for general aviation aircraft could improve the safety of VMC and IMC operations. Issues relating to general aviation aircraft include certification, affordability, low-weight electromechanical control devices, reliability, ease of retrofit, sensor type and interface, and fail-safe architecture.

3.3.3.6 Emergency Auto-Land

Approach and landing continues to be one of the most challenging phases of flight. Auto-land for general aviation aircraft is needed to increase safety during this phase. While pilots of all experience levels are susceptible to an approach and landing accident, it will be the low-time instrument-rated pilots that drive the accident statistics. A real benefit to a low-time pilot would occur when the weather at their destination drops below their personal minimums. Instead of a 1000’ ceiling, the weather has dropped to 200’ and the pilot is not comfortable. The auto-land system would allow the flight to be completed safely. The technology is available to design an auto-land system for general aviation, but the safety needs to be proven in order to allow certification of such a system. Air-carrier auto-land requires approval from ATC. To allow auto-landing at non-towered airports, operational procedures that assure safety must be developed and demonstrated. Consideration should be given as to whether this capability should be allowed for routine landings, or should be permitted for emergency landings only.

In the case of an incapacitated pilot (severe illness, severe disorientation, loss of consciousness, loss of flight control surface functionality), an attempted safe landing is of utmost importance. Integration with a haptic system described earlier could provide a mechanism for “sensing” that the pilot is not responsive to desired control inputs, and then have the fully-coupled auto-pilot take over the flight controls. Results of recent “resilient recovery” modeling have demonstrated that a sophisticated flight management system and fully-coupled auto-pilot can successfully fly an aircraft to a safe landing to the nearest suitable airfield with control surface damage, such as a stuck rudder or flap. Such work could also improve general aviation survivability when counter intuitive flight control laws would apply and mitigate pilot induced control errors. The only other method for survivable emergency recovery is an aircraft parachute, but the aircraft suffers damage on impact. The criterion for auto-land is to achieve a near-normal landing with minimal structural damage (e.g. landing gear damage could be acceptable). Issues relating to auto-land capability include certification for emergency use; open software architecture for ease on interface with other on-board systems, sensors, and databases, FMS, Electronic Flight Instrument System (EFIS); knowledge of the airspace boundaries, flight rules, terrain, obstacles, weather, suitable landing areas, aircraft system health (fuel, etc.); accurate runway elevation detection (radar altimeter) for precise flaring; and, “resilient recovery” flight control algorithms and management system to maintain flight with structural damage.

3.3.3.7 Real Time WAAS Non-Precision Approach Procedure Design

Within the FAA Flight Inspection office, they are undertaking the enormous task of creating and certifying WAAS approach procedures for the over 3,000 airfields in the contiguous U.S. Until this is complete for all acceptable approach ends of each airfield, there will be runways that lack precision approach equipment and are inaccessible in IMC even if the aircraft is equipped with GPS/WAAS navigation receivers. To meet the demand for general aviation, and ensure safety of IMC approach operation to as many runway ends as possible, research should consider airborne capabilities for dynamically creating GPS/WAAS approach procedures. It is generally accepted that the capability for creating GPS/WAAS precision approaches in real-time on-board the aircraft is a highly complex mix of accurate and up-to-date terrain database access and certification rules, accurate and current knowledge of the airfield runway facilities and foliage, and complex approach/missed approach airspace algorithm certification for each aircraft type.

Since dynamic real-time precision WAAS design in the cockpit may not be realistic within the next decade or two, an alternative to traditional protracted methods for precision approach design and certification, research should consider extending existing non-precision approach (NPA) procedure design automation for use in the cockpit. For airports and runway ends without a GPS/WAAS approach procedure, this technology could aid a pilot in assuring a safe emergency landing to an appropriate landing area. It could also be of aid in selecting an appropriate airfield and runway for a safe emergency auto-landing, given the aircraft was properly equipped. Issues affecting this technology include establishing standards for acceptable minimum decision altitudes for automated real-time NPA GPS/WAAS procedure design; access to current certified databases of terrain topography, airfield/runway facilities and topography, and obstacles surrounding an airport; certification of software and algorithm functionality for designing non-precision GPS/WAAS approach procedures in real time for each aircraft type; and, interface to an FMS.

3.4 Community Compatibility

The fourth target research area, Community Compatibility, addresses the concerns of the community, particularly for those living in close proximity to an airport.

3.4.1 Small Aircraft Safety Improvement

Improving the safety of small aircraft operations in and around small airports and in the NAS is the critical community compatibility goal. Unfortunately small aircraft operations do not currently enjoy the same safety record as has been achieved by airline operations. Small Aircraft Safety Improvement is the highest priority technology area that must be addressed. This is important from a reality, as well as a perception point of view, if the SATS vision is to be achieved. Research is recommended to develop acceptable methods for quantifying the safety of small aircraft at small airports. Research is required to examine the benefits derived from: a) aircraft health monitoring systems, b) pilot training, and c) flight safety systems analysis in all phases of flight. Real-Time Safety Health Monitoring should be developed to improve aircraft safety, dispatch reliability, and to reduce maintenance cost and time. These real-time systems can enhance safety of flight via aircraft in-flight health monitoring. The development of open standards and protocols for health monitoring systems is needed. Low-cost, light-weight, nondestructive, unobtrusive, wireless, embedded sensors should be developed for monitoring the aircraft structure. An interface needs to be developed for integrating information from the aircraft avionics, engine sensors, flight control and structural stress sensors, data link communication, flight management system (FMS), and auto-pilot.

Small aircraft and small airport security concerns must also be identified and resolved. An airport infrastructure security roadmap should be developed in close cooperation with the FAA and Department of Homeland Security (DHS). This roadmap must examine technology advances which should allow small aircraft to operate efficiently in the NAS, including operations within the ADIZ, as currently encompasses Washington, DC. Small aircraft and small airport security infrastructure requirements need to be evaluated. The development of an encrypted ADS-B based security identification system for small aircraft appears very promising and should be quickly pursued, including conducting field tests and developing standards for airborne small aircraft identification procedures.

3.4.2 Small Aircraft and Airport Security

To improve the operating economics of small aircraft and the users of small airports, expedited flight through secure airspace is very important. The cumbersome procedures currently required to fly in or through the Washington ADIZ are an extreme example, but it is anticipated that other similar airspace may also be defined in other locations. One technology that can provide the necessary security, without being unduly burdensome, is a security technique that can provide authentication of a given aircraft and its pilot. NASA Glenn Research Center has sponsored research to demonstrate this technique, using the UAT data link.

The operational concept is that the aircraft avionics (the ADS-B equipment) will contain a tamper-protected secret key. The pilot enters a PIN upon initializing the avionics. As the aircraft flies, the ADS-B transmissions would be “signed” using the avionics key and the PIN. This would be done using standard and established authentication algorithms. The ground (or airborne enforcement) equipment can verify the signature by knowing the key and PIN used. As a participant flies into an airspace-requiring authentication, the surveillance system would automatically recognize the ADSB reports as authentic and indicates such to the controller or enforcement official. It would then assure that the aircraft and pilot are on the approved or “vetted” list. It would not be necessary to make voice contact to be cleared into the area. In present VFR operations, voice contact is required, and many pilots have to circle outside of the airspace until they can break onto the frequency or for their flight plan to be verified.

The advantages will be primarily achieved by small aircraft users that wish to traverse the ADIZ, or by users of small airports near or under the ADIZ. The new capability will save flight time, and the pilot will not have to contact as many players in the system (possibly none). As mentioned before, it is anticipated that other airspace with security restrictions will develop, particularly with the increase of small aircraft usage. With automatic authentication possible, it will be more practical for the NAS designers to generate corridors through secure airspace, which will further increase the value to small aircraft operators so they do not have to circumnavigate the secure airspace if it is on their path of flight.

Research in this area will involve the drafting of detailed operational changes and working with the Department of Homeland Security (DHS) and with the FAA to come up with an agreeable set of procedures. Once the agencies agree on the operational details and approve them, the standards bodies will recognize it as an operational need and can get it into the standards so that equipment can be certified. The process of establishing the operational need and adopting the standards takes about five year s in general. Economic analysis must also be done to assess the cost (to manufacturers) of the changes and whether they will provide the market with capable equipment.

3.4.3 Aircraft Noise

The methodology to study noise and emission impacts of aviation activity is well understood for airport and terminal area procedures [29]. Less research has been done at predicting noise and emissions in the en route phase of flight. A nationwide assessment of noise and emission impacts of aviation related activity is needed. This analysis requires consideration of displaced modes of transportation and characterization of induced intercity trips. The analysis requires spatial representations of where sources of pollution exist and their dispersion in the lower atmosphere.

New technology aircraft can have relatively small noise impacts at airport through a combination of advanced engine technology and carefully planned procedures. A preliminary assessment of very light jet noise impacts at airports determined that rural airport noise contours could increase 1-3% if SATS VLJ technology is widely accepted. Metropolitan airport noise contours could increase by 4-7%. It is important to put these numbers in perspective. The contours of metropolitan airports like Teterboro in New York could see reductions of 40% in their noise contours if all Stage 2 technology aircraft are phased out. New aircraft technologies that encourage replacement of older and noisier vehicles will help reduce the noise impacts at some airports.

The challenges caused by aircraft noise are very clear:

- Environmental concerns drive many local airport decisions to accept small aircraft
- Aviation activity is generally perceived as a large source of pollution.

The increased use of small community airports will require that the noise impact be minimized. The reduction of engine and airframe noise continues to be a subject for considerable research. In order to be applicable for SATS type aircraft, additional noise reduction technology development needs be focused on the quest for quieter small aircraft. For any given airframe, significant noise alleviation can be achieved by using advanced approach and departure trajectories. Steeper, curved trajectories can significantly reduce the noise “footprint” and avoid noise sensitive areas.

3.4.4 Aircraft Emissions

In addition to noise, research on small aircraft emissions also should be conducted to minimize the impact on the community. Because small aircraft operations are very diffuse, their contribution to the air quality concerns for a given community may be minimal, but the situation as a whole should be examined.

The contribution of small aircraft emissions to the overall global system should be evaluated in terms of the location where the emissions are deposited (altitude, latitude, longitude), the amount of the emissions, and the time of the deposit.

3.4.5 Small Airport Land Use Impact and Infrastructure Assessment

The goals of the efforts in the area of airport infrastructure include:

- Develop and validate procedures and technologies to further increase capacity of small airports
- Examine the safety of procedures developed in part (a) towards implementation as part of the NGATS integrated plan
- Study and recommend the appropriate airport infrastructure improvements needed to support a distributed small aircraft transportation system capable of providing service to 3,400 public airports.

The Danville demonstration of the SATS program provided strong anecdotal evidence of capacity gains at non-towered airports using flight deck coupled with satellite and airport-based surveillance technologies. The saturation capacity of a single-runway airport without a control tower under Instrument Meteorological Conditions (IMC) varies from 3 to 5 aircraft arrivals per hour and 10-12 departures per hour. The capacity of the same airport with ADS-B and High-Volume Operations (HVO) technologies demonstrated by the SATS Project (assuming 100% fleet equipage) could increase to 9-13 arrivals per hour and up to 18-22 departures per hour. The NGATS integrated plan is to increase the capacity of the NAS beyond the 30% proposed by the FAA in the next ten years. Procedures developed by the SATS research and implementation vision could help achieve that goal.

3.4.6 Real-Time Safety Health Monitoring Systems

The goal of real-time safety health monitoring systems area is to develop systems to monitor the overall health of an aircraft in real-time, report and advise of critical trends and routine maintenance actions, interact with the flight management system for optimal and safe flight performance and data link health parameters to maintenance centers and repositories for action and archive. Proposed research will develop an affordable in-flight aircraft health monitoring system in cooperation with engine, avionics, and airframe manufacturers that provides evaluation and assessment of overall aircraft health and recommended maintenance actions based on centralized data collection, archiving, and analysis of a population of general aviation aircraft.

Commercial and military aircraft manufacturers have led the areas of engine health monitoring, health and usage monitoring systems, and structural fatigue monitoring sensors. The trend in general aviation toward digital avionics, digital sensors, and integrated systems yields an opportunity for also improving the health monitoring of the general aviation aircraft in a similar manner. The current practice in industry and the FAA requires the scheduled replacement or refurbishment of parts based on hours of operations, visual inspection of wear, chemical analysis of fluids, and other diagnostic measures. These practices are largely successful for continued safe operations, but do not necessarily contribute to a body of knowledge that could lift general aviation to a higher plateau of maintenance performance.

Technology is already in place for in-flight digitally sensing many critical piston engine components and graphically presenting performance parameters and trends to the pilot. Self-diagnostic routines are also operating within individual avionics systems. Reporting and archiving of these parameters while in-flight to a centralized processor for further analysis, reporting, and integration with a FMS does not presently exist. Furthermore, sensors for monitoring control surface stress and control links stress in-flight do not exist for general aviation, thus are an opportune area for advanced research. Such aerodynamic stress monitoring could enhance safety by detecting anomalous control surface/linkage behavior and recommendation of alternative pilot-control responses.

The other area of vital importance is an organizational element involving the engine, avionics, and airframe manufacturers in the collection and analysis of these data. Such an organic system of automated data collection, analysis, and reporting could lead to design refinements to improve overall reliability, failure prediction, failure mode correlation, averted unsafe operations, and reduced maintenance and operating costs. Consideration should also be given to monitoring of backup systems and elimination of false alarms in a safety health monitoring system. This research is all the more important due to the longer and harder use of general aviation aircraft than designed. The cost of maintenance, repairs, new aircraft, fuel, and operation contribute to the extended use and service of an aging fleet.

A technology developed in the SATS project known as the Advanced Data Fusion Processor demonstrated the potential for a centralized on-board processor to record digital data streams from many standard aircraft interface types in real-time, and provide key data simultaneously to other avionics devices and display systems. Such a system would be needed on the aircraft to integrate with existing avionics, EFIS, FMS, airframe stress sensors, and data link radio. Real-time data link of health parameters would not be necessary but could be used for reporting imminent failure modes and scheduling of time-critical maintenance actions.

3.4.7 Small Aircraft Ride Quality

Another area of major concern that can impact the desirability of the SATS concept is ride quality. Small Aircraft Ride Quality Improvement needs to be addressed. Today, passengers often find the ride quality of small aircraft to be significantly inferior to that of large commercial transports. This occurs because small aircraft are designed with lower wing loadings (which are susceptible to gusts) and they operate at lower altitudes where the atmosphere is more turbulent.

Research should be conducted to evaluate the improvements that may be possible with a Ride Control System (RCS). Most RCS research to date has been carried out for military aircraft, or for structural load alleviation in large commercial transports.

RCS systems are known to perform best with “predictive” information that is obtained by measurement of atmospheric gusts ahead of the aircraft. The potential for developing "look-ahead" sensors to detect gusts prior to aircraft encounter needs to be examined. High-fidelity dynamic models need to be developed for representative new aircraft, e.g. VLJ's. The RCS research should focus on an affordable sensor/actuator suite, including solid state IMU's, short-range look-ahead Lidar, and limited authority active flight controls. RCS algorithms need to be developed and the achievable improvement needs to be quantified. Flight testing will undoubtedly be required for RCS validation and pre-certification. It is also recommended that the potential for active seat control technology be examined.

4 Summary

In late 2005, the National Institute of Aerospace gathered national experts from industry, academia, and state organizations to develop a national strategy for research and development to achieve the Small Aircraft Transportation System (SATS) vision of safe, reliable, and affordable air transportation for every community in America. That strategy calls for continued research and development in the following areas:

Service Reliability
SATS integration into the National Airspace System (NAS) was identified as the highest priority technology advancement that must be worked. Within the current NAS, a SATS technology equipped aircraft with advanced flight deck technology comparable to today's commercial airliners would be routinely vectored around by air traffic control to avoid passing through higher density traffic areas. These unnecessarily circuitous routes increase fuel usage, waste time, add to operating expense, and result in increased ticket prices. Procedures to provide recognition of the capabilities possessed by SATS equipped aircraft and special routes for SATS equipped aircraft through congested airspace (where equipped aircraft can take the responsibility for self-separation) need to be developed and field tested, in close cooperation with FAA.

Weather Safety
Research is recommended on systems that will protect the aircraft when operating in adverse weather conditions. The ability to provide weather information via data link to the cockpit is currently being embraced by the pilot population. What is needed now is the development of smart systems that can interpret all the available weather information quickly and provide timely advice to the pilot on intuitive displays, especially when the pilot workload is often high.

Enhanced weather forecasting methods are necessary that can improve forecast accuracy, particularly at the lower altitudes and for the remote areas where small aircraft often operate. Technology enhancements to provide fine-grid weather forecasting for lower altitudes and remote areas will contribute directly to improved flight path efficiencies, reduced diversions, and uninterrupted continuity of air service.

Accurate airport weather sensors are needed where SATS aircraft will be operating. Affordable technology solutions should be researched that focus on advanced AWOS and runway surface condition sensors. This research should also include sensors that measure the visibility and ceiling along the intended approach path.

Aircraft icing continues to plague the operation of small aircraft, since they typically operate at the lower altitudes where icing occurs. Research is needed focusing on the development of improved icing forecast capabilities, icing detection, icing prevention, and efficient and affordable icing removal systems.

Ease of Operation
This research area is particularly important for small aircraft operations with a single-pilot, as compared to two-crew large airline operations. The highest priority research topic in this area is

to develop more intuitive aircraft operating systems.

Research is recommended on haptic flight control systems (that provide sensory feedback to the pilot) and on intuitive displays to enhance aviation safety by providing aircraft performance envelope protection. This research should include the development of more affordable display media, such as head-up displays, headworn displays, head-down displays, and synthetic voice/voice recognition systems.

Research directed at the development of automated flight planning capabilities, emergency auto-land, resilient recovery of functionality, fly-by-wire control laws with an affordable fully coupled auto-pilot, and automated pre-flight and weight-and-balance technology is also recommended.

Community Compatibility
This area addresses the concerns of the community, particularly for those living in close proximity to an airport. Small aircraft safety improvement is the highest priority technology area that must be addressed. Research is required to examine the benefits which can be derived from:

- highly integrated aircraft health monitoring systems,
- improved pilot training methods,
- a rigorous system safety analysis which examines all phases of small aircraft flight operation.

Small aircraft and small airport security concerns must also be assessed and resolved, in close cooperation with the FAA and the Department of Homeland Security (DHS). It is imperative that this assessment includes an examination of the potential technology advances that can allow small aircraft to operate efficiently and securely in the NAS, including operations within an Air Defense Identification Zone (ADIZ), as currently encompasses Washington, DC.

The challenges caused by aircraft noise and emissions can also have an impact on the desirability of increased small aircraft operations at previously little used community airports. Aviation activity is generally perceived as a significant source of pollution, i.e., both noise and emissions. If not addressed, these environmental concerns can inhibit many local airports from accepting small aircraft, particularly jet aircraft.

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