DEMONSTRATION OF FOUR OPERATING CAPABILITIES TO ENABLE A SMALL AIRCRAFT TRANSPORTATION SYSTEM

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Abstract

The Small Aircraft Transportation System (SATS) project has been a five-year effort fostering research and development that could lead to the transformation of our country's air transportation system. It has become evident that our commercial air transportation system is reaching its peak in terms of capacity, with numerous delays in the system and the demand keeps steadily increasing. The SATS vision is to increase mobility in our nation's transportation system by expanding access to more than 3400 small community airports that are currently under-utilized.

The SATS project has focused its efforts on four key operating capabilities that have addressed new emerging technologies and procedures to pave the way for a new way of air travel. The four key operating capabilities are: Higher Volume Operations at Non-Towered/Non-Radar Airports, En Route Procedures and Systems for Integrated Fleet Operations, Lower Landing Minimums at Minimally Equipped Landing Facilities, and Increased Single Pilot Performance. These four capabilities are key to enabling low-cost, on-demand, point-to-point transportation of goods and passengers utilizing small aircraft operating from small airports. The focus of this paper is to discuss the technical and operational feasibility of the four operating capabilities and demonstrate how they can enable a small aircraft transportation system.

Background

The nation's commercial air transportation system is reaching a capacity plateau, and demand for transportation services continues to steadily increase, with the desire for more people and goods to travel faster and farther, with fewer delays [1]. Nearly 96% of domestic air travelers are forced to fly through fewer than 500 airports, and 70% through fewer than 35 of the Nation's more than 18,000 landing facilities [2]. Statistics show that 22% of the population lives within 30 minutes of major/hub airports, 41% live within 30 minutes of any commercial airport, and 94% within 30 minutes of small community airports [3]. One solution to increasing mobility in our nation's transportation system is to exploit the abundant small community airports across the country [1] (Figure 1).

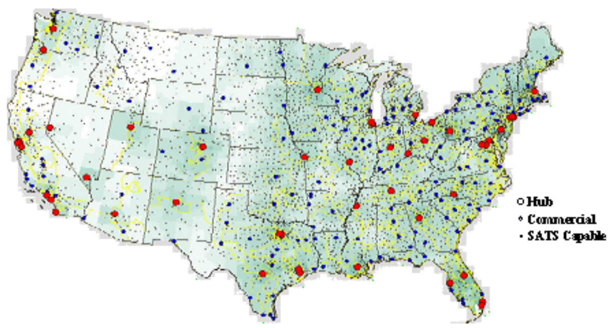

Figure 1. More than 3400 SATS Capable Airports Shown (Public Use, Land-Based, Paved 3000 Ft Runway Minimum, Not a Major Hub)

The SATS vision is that air transportation can meet the needs of more people by assuring the safety, speed, and convenience of point-to-point air travel through a network of under-utilized, community airports. This vision is to enable small aircraft carrying from four to ten passengers to safely and affordably access the more than 3400 under-used rural and suburban airports in near all-weather conditions, in order to increase the total system throughput and capacity, thus revolutionizing personal and business travel.

The SATS project is a public-private cost-sharing partnership among NASA, FAA, and the National Consortium for Aviation Mobility (NCAM). NCAM is a consortium of public and private organizations including 130 members of industry, universities, not-for profit organizations, and state aviation authorities located throughout the United States. The NCAM consortium is structured through six labs: Maryland Mid-Atlantic SATS Lab, North Carolina & Upper Great Plains SATS Lab, South East SATS Lab, Virginia SATS Lab, Michigan SATS Lab, and Indiana SATS lab.

The SATS project has focused its efforts on four key operating capabilities that have addressed new emerging technologies and procedures to pave the way for a new way of air travel. The goal of the five-year SATS project has been to take the first steps toward the long-term SATS vision. The SATS project has fostered research and development of key airborne concepts, technologies, and procedures. The project has conducted an integrated technology evaluation, and validation, culminating in a public demonstration to prove that a small transportation system is viable.

Four Enabling Operating Capabilities

The SATS project has focused its efforts on four key operating capabilities that will increase the accessibility to the small community airports in near all-weather conditions. The realization of these capabilities will make possible for 'more people and goods to travel faster and farther, anywhere and anytime' using small aircraft including micro jets. SATS has leveraged the expertise and capabilities among its partners, and collaborated with other NASA and FAA programs and projects, to enhance the technology development. The four key operating capabilities SATS has focused on are: *Higher Volume Operations at Non-Towered/Non-Radar Airports* where more planes can access the small airports in poor weather conditions; *En Route Procedures and Systems for Integrated Fleet Operations* into the nation's air transportation system; *Lower Landing Minimums at Minimally Equipped Landing Facilities* where planes are less affected by poor visibility; and *Increased Single Pilot Performance* so that the safety and accuracy of pilots are increased.

The technical and operational feasibility of these four operating capabilities have been demonstrated through analysis, Human-in-The-Loop simulations, and flight experiments. Most evaluation entailed an assessment of pilot skills (e.g. Flight Technical Error (FTE)), workload, and situation awareness compared with today's procedures or technologies.

Higher Volume Operation at Non-Towered/Non-Radar Airports

In order to benefit from the go-anywhere, go-anytime, point-to-point flights, both concepts and procedures need to be developed that will allow for increasing the number of aircraft that can fly in and out of small airports when Instrument Flight Rules (IFR) are in effect. The concept of Higher Volume of Operations (HVO) is to enable simultaneous operations by multiple aircraft in non-radar airspace, at and around small non-towered airports, in near all-weather conditions, through the use of sequencing and self-separation algorithms and flight path management systems [1, 2, 4]. Currently, procedural separation operations at non-towered airports restrict traffic flow by allowing only one aircraft to fly either an approach or departure at a time during poor weather.

The HVO concept, pioneered at NASA, is based on two key aspects that include a Self Controlled Area (SCA) and an Airport Management Module (AMM) [4, 5]. The SCA is airspace that is established at a SATS airport (non-towered/non-radar airport) during Instrument Meteorological Conditions (IMC) in which pilots accept responsibility for maintaining self-separation from other traffic and for sequencing on an instrument approach, using procedures and onboard automation (Figure 2).

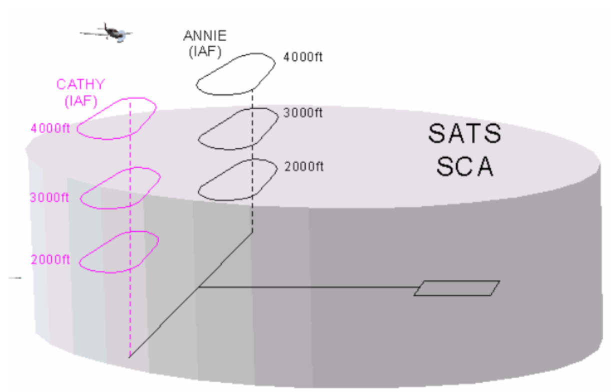

Figure 2. SCA around SATS Type Airport

The AMM is an automated ground module, located at or near the SATS airport, that provides information regarding the SCA status, and sequence number information to arriving aircraft along with the 'fix' locations assigned within the SCA. The fix locations include the Initial Approach Fix (IAF), so that pilot can sequence onto the approach, and Missed Approach Holding Fix (MAHF).

In order to fully execute the SATS HVO procedures within the SCA, the minimum equipage required for the aircraft is:

- Global Positioning System, GPS, receiver;
- Air-To-Ground Datalink Communication [for broadcast and receipt of AMM messages];
- Air-to-Air Datalink Communication [for broadcast and receipt of Automatic Dependent Surveillance-Broadcast, ADS-B, State Messages and Procedure Intent Messages];
- Cockpit Display of Traffic Information, CDTI [Gives the pilots a clear picture of where they are and the location of other aircraft in the area];
- Software to conduct the HVO procedures [Informs the pilots who to follow and where to go by displaying sequencing information from AMM, and utilizing Conflict Detection and Alerting Algorithms].
- Voice communication radio.

The initial step in the HVO concept is, prior to departing controlled airspace, the pilot must send a datalink message to the AMM requesting entry into the SCA. As requests are received, the AMM will accept the request if space is available and notify the pilot, by sending a datalink message back to the aircraft. Once the AMM message is received, the pilot must then contact Air Traffic Control (ATC) to get approval to depart controlled airspace prior to entering the SCA. The SCA will include an instrument approach path, such as a GPS-T, for the pilot to follow. The AMM message will provide information on which aircraft to follow, if more than one aircraft is in the SCA, and which 'fixes' (IAF and MAHF) are assigned to the aircraft. Other SATS equipped aircraft in the area will also be displayed on the screen. The maximum number of aircraft allowed within the SCA is determined by the number of holding patterns assigned to the IAFs.

It is the pilot's responsibility for staying a safe distance behind other aircraft when in the SCA. Conflict Detection and Alerting algorithms have been developed to warn pilots of any potential conflicts with other aircraft as well as warning the pilot if the aircraft is getting off the desired course.

The HVO concept and its procedures have been developed and validated through both simulation and flight tests. The simulations and flight tests indicated that pilots could fly the procedures safely, proficiently, and with acceptable levels of workload and situation awareness [5, 6]. These results also showed that the volume of aircraft into and out of small airports could increase by four times by following HVO procedures compared to today's procedural separation by air traffic controllers [6]. This gain can be realized without an increase in workload or complexity. This impact could have a dramatic effect on our transportation system.

En Route Procedures and Systems for Integrated Fleet Operations

In order for SATS to become a viable transportation system, the National Airspace System (NAS) must be able to support the transition of aircraft into and out of the Self Controlled Areas, and also handle the increased point-to-point traffic between small airports [7-9]. These issues have led to the second key operating capability of SATS which supports developing procedures to facilitate air traffic controller interaction with self-separating traffic around non-towered/ non-radar airports [1, 2]. In addition, preliminary simulation and analytical impact assessments have been conducted for the integration of SATS equipped aircraft into the en route air traffic flows and controlled airspace of the NAS (Figure 3).

During IMC, and under radar coverage, en route operations conform to air traffic control guidance, rules and procedures, where separation is maintained by ATC. SATS aircraft will operate and interface with ATC in the same manner as every other IFR aircraft, while outside the SCA. Before the pilot can enter the SATS SCA to approach the airport, the pilot must receive clearance from ATC to depart controlled airspace. Conversely, when departing a SATS airport, all departure procedures are similar to today's FAA rules, where the pilot files an IFR flight plan and receives a clearance time from ATC. During Visual Meteorological Conditions (VMC), SATS aircraft will comply with the existing procedures for see-and-avoid to maintain separation from other traffic.

Figure 3. En Route Integration into the NAS

NASA Langley Research Center (LaRC) has worked closely with the FAA W. J. Hughes Technical Center (FAATC) to develop and assess the language used between the pilots and the controller for entering and exiting the SCA. Proof-of-concept simulation experiments have been conducted for two east coast regions along with a joint FAATC/NASA LaRC simulation. The two regions chosen were the Philadelphia Terminal Radar Approach Control (TRACON), for its high traffic and complexity, and Danville, Virginia for its relatively low volume and little to no congestion. The simulation experiments included pilots at NASA LaRC and Certified Professional Controllers from both the Philadelphia TRACON and Washington Center. These simulations evaluated the Air Traffic Controllers acceptability of SATS procedures, being able to control SATS traffic into and out of the SATS airports, as well as the ability to flow high volumes of SATS equipped aircraft into the NAS (Figure 4). These simulations were conducted to determine the future feasibility of SATS procedures within the NAS compared to current day one-in/one-out operations. Simulation results into and out of the SCA indicated that SATS would be likely to have minimal or no impact on ATC workload, with the potential to ease future congestion and delays. The preliminary results have determined that the SATS procedures were viable and could prove beneficial for non-towered airports. Most controllers viewed SATS HVO favorably due to the transferring of responsibility from ATC to the flight crew once an aircraft entered the SCA. However, controllers did cite issues that need to be addressed before the SATS HVO concept could be operationally feasible. These issues included the need to more clearly define roles and responsibilities for ATC and pilots, and refine clearance procedures and phraseology into and out of the SCA. In addition, the impact of mixed equipped aircraft (SATS and non-SATS) needs to be further investigated [7]. The FAA acceptability of the en route integration operating capability plays a critical role in addressing the limitation of one-in/one-out operations at small, community airports in low visibility.

Figure 4. FAATC Target Generation Facility ATC Simulation Pilot Lab

Lower Landing Minimums at Minimally Equipped Landing Facilities

For small airports to be part of a viable transportation system utilizing very light jets, the United States needs reliable access to the nation's 3400 small community airports (paved runways of 3000 ft. or more) in near all weather conditions. Analysis conducted within the SATS project has shown that at the more than 3400 public-use runways across the country, only 20% have precision instrument approaches [10]. Current airports without navigation aids and/or instrument approach procedures are limited to VFR minimums for ceiling and visibility, which can be as restrictive as 1000 ft. and 3 miles, respectively [11]. The concept of Lower Landing Minimums (LLM) at Minimally Equipped Landing Facilities is to provide precision approach and landing guidance to small airports in low visibility, through the use of graphical flight path guidance, and artificial or enhanced vision. Enabling this concept could avoid land acquisition and approach lighting costs, as well as the high cost for ground-based precision guidance systems such as Instrument Landing Systems (ILS) [1].

To address this problem, SATS has conducted research and fostered the development of technologies, that strive to lower the landing minima at small community airports; technologies that will be affordable and practical for the general aviation population. The near term goal of SATS is to demonstrate the ability for conducting landings and takeoffs with minimum ceiling and visibility requirements of 200 ft. and 1/2 mile, respectively. Early studies in the SATS Project showed that "if" an approach to precision minimums of 200 ft. decision altitude and 1/2 mile visibility is made possible, this would open up access to 95% of small airports across the United States [12]. Current airports will only need as a minimum a 3000 ft. paved runway. Precision lateral and vertical guidance will be provided by onboard systems [11].

The SATS project has built upon new technologies and approach designs that will allow for more reliable access to the small community airports. Since small community airports can ill afford to purchase and maintain expensive ground infrastructure, such as ILS, SATS has taken the approach to leverage emerging technologies, such as GPS/Wide Area Augmentation System (WAAS), to offset infrastructure costs. SATS began with FAA GPS/WAAS approach criteria and modeled approaches to a number of small airports [13-15], including Danville Regional Airport, in Danville, VA. (Figure 5). SATS has designed Required Navigational Performance (RNP) based instrument approaches for airports with specific characteristics such as mountainous terrain, restricted airspace constraints, noise abatement restrictions, and shortened approach distances. Flight simulations and flight-testing proved the feasibility of these approaches. SATS has addressed other airports with additional specific characteristic challenges to design approaches (such as increased glide path angle, displaced threshold, and curved approaches). Flight experiments conducted with SATS designed RNP approaches has confirmed RNP performance to well within +/- 0.3 nm lateral and +/- 125 ft vertical guidance for non-standard approaches, using advanced guidance technologies, such as Synthetic Vision, Highway-in-The-Sky, Enhanced Vision, and Head-Up Displays which will be described below [15-17]. [18] meets this criteria from Final Approach Fix to decision altitude.

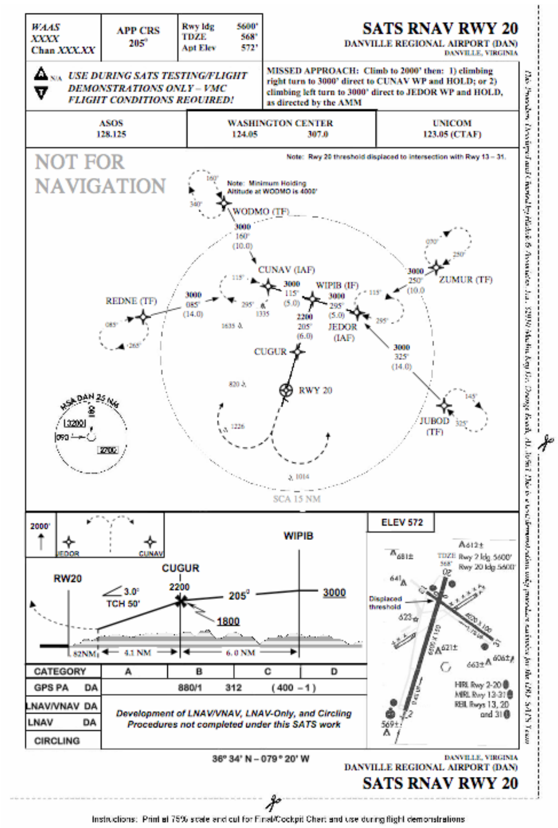

Figure 5. SATS Area Navigation Approach for Runway 20 at Danville Region Airport

Throughout the SATS project, flight path management has been a strong area of focus taking advantage of key airborne technologies to aid in low visibility conditions such as Synthetic Vision System (SVS), Enhanced Vision System (EVS), Highway-in-The-Sky (HiTS), Flight Director (FD) guidance, and Head-Up Displays (HUD). SVS relies on navigation information (GPS or GPS/WAAS) and terrain databases to generate a synthetic view of terrain [19, 20]. One of the goals of SVS is the ability of the SVS display to make IMC operations resemble those conducted in VMC with similar safety and pilot workload [21]. The SATS Labs have developed flight path management displays that allow pilots to fly both en route and approach procedures much more efficiently and accurately than with conventional instruments.

However, to be certified for such an intended use (VMC-like operations in IMC) and thus achieve operational benefits, SVS must be shown to provide a level of safety at least equal to the conventional flight instruments it replaces [21].

Research has been conducted by the Virginia SATS Lab on guidance displays that incorporate an energy management angle-of-attack Flight Director to aid the pilot in manually flying a safe, accurate, and energy-efficient approach for optimum performance when transitioning between en route and the SATS SCA [22, 23]. Three-dimensional flight path guidance cues, such as the HiTS on a Primary Flight Display (PFD) have been studied, that can provide intuitive information to the pilot. This information consists of how to maintain approach to landing, guidance for a missed approach, or climb out for departure proficiencies; which can play a critical role if there are terrain or obstacles nearby.

The North Carolina & Upper Great Plains (NC&UGP) SATS Lab conducted both simulation and flight tests at the Wakefield airport in Wakefield, VA. to demonstrate flight-path accuracy and situation awareness required for approach operations to 200 ft. ceiling 1/2 mile visibility [17]. Leveraging GPS technology, innovative SVS/HiTS/FD displays were flown to assess the increase in accuracy and situation awareness, and reduced workload, over use of conventional instrumentation. The advanced displays provided predictive guidance rather than the conventional reactive guidance (Figure 6). Simulation and flight experiment results of the SVS/HiTS/FD guidance display system showed that the accuracy improved 10-fold, workload was significantly reduced, and situation awareness improved over conventional round dial instrumentation (Figures 7, 8).

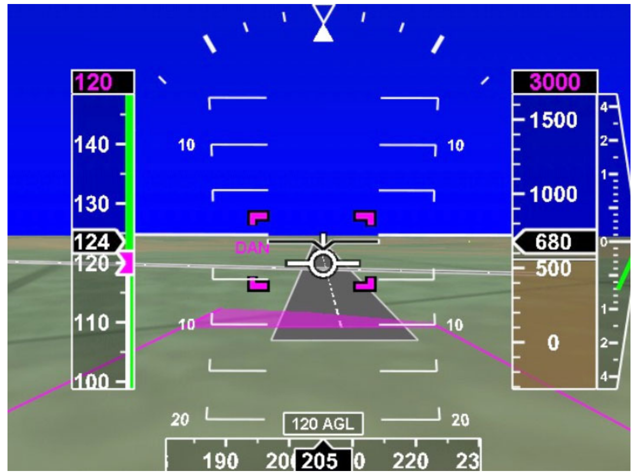

Figure 6. NC&UGP SATS Lab Advanced Display with Flightpath Guidance

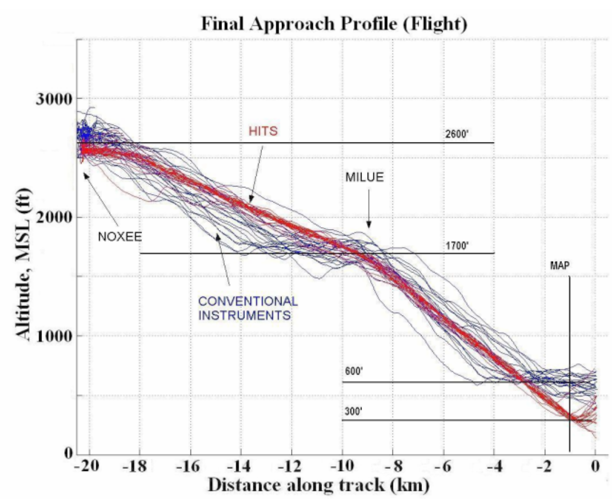

Figure 7. Flight Experiment Profile of SVS/HiTS/FD Guidance Display Compared with Conventional Instrumentation on Approach to Wakefield Airport

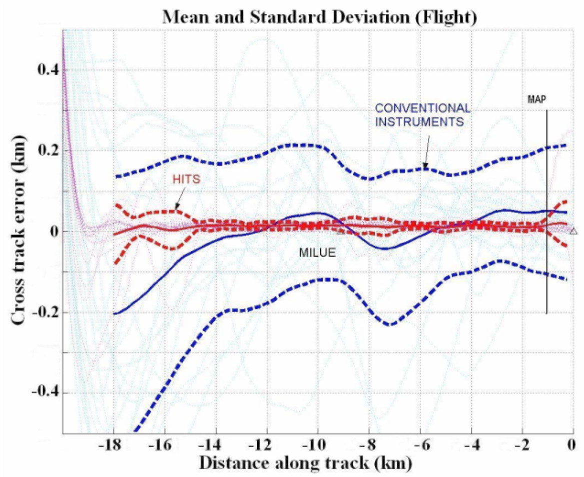

Figure 8. Flight Experiment Cross Track Error Of SVS/HiTS/FD Guidance Display Compared With Conventional Instrumentation On Approach To Wakefield Airport

SouthEast SATS Lab conducted a simulated flight experiment using advanced display concepts on their SmartDeck system [24]. The SmartDeck system provided the pilot with a visual display of the primary flight instrumentation such as airspeed, altitude, and heading, along with a visual depiction of the pilot's flightpath in a HiTS display format (Figure 9).

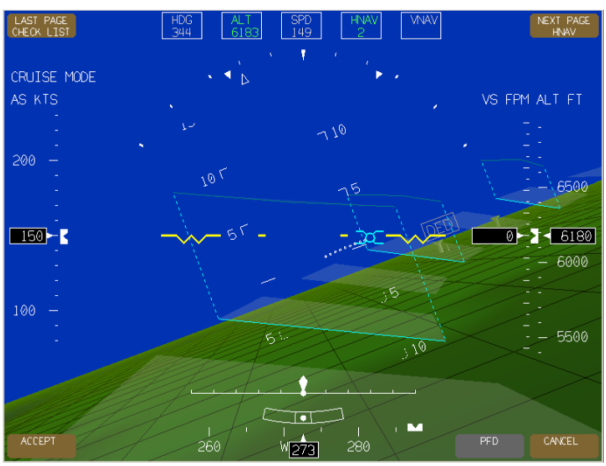

Figure 9. SmartDeck Advanced Display with SVS/HiTS/FD Guidance

Results from the experiment showed that the HiTS provided guidance and situation awareness in such a fashion that low-time single pilots under simulated instrument conditions were able to fly at the FAA Airline Transport Pilot Practical Test Standards (ATP PTS). These standards were met 78% of the time on simulated approaches to Daytona Beach airport in Daytona Beach, FL, as opposed to 55% of the time using baseline conventional displays. This is a significant improvement over the pilots' performance with today's conventional instruments.

Development has been conducted on a dual mode enhanced vision sensor comprised of a low light level Charge-Coupled Device and an uncooled long wave Forward Looking Infrared (FLIR) imager [25]. This Enhanced Vision System (EVS) can allow pilots to see at night and enhance visual penetration through low visibility conditions such as rain, haze, and snow. Work has also been conducted on fusing EVS images with a SVS database, allowing pilots to detect obstacles that are not in the terrain database. An added feature of fusing EVS with SVS is that any database inaccuracies due to either GPS/WAAS or database errors can be detected [26]. Research was conducted into the percentage of EVS or SVS that dominated the display. Simulation testing showed that pilots preferred synthetic vision database fused with lower percentage of enhanced vision information at the start of the approach, with a gradual increase of enhanced vision information as the aircraft neared the runway.

Research and development has also been conducted on a Head-Up Display (HUD). This type of display has primarily been used for military and commercial applications in the past, but has not been affordable for the general aviation community. A low cost HUD has been designed to display critical flight performance information along with flight guidance cues to the pilot in a "head up" manner [27, 28]. This is particularly important while on approach, thus allowing the pilot to maintain the out-the-window monitoring for optimum safety of flight (Figure 10). The HUD is being developed and tailored for general aviation aircraft through the Maryland Mid-Atlantic SATS lab to project real-time EVS imagery of the external scenery. A new FAA ruling (RIN 2120-AH78) has approved the operational use of an FAA-certified Enhanced Flight Vision System with a Head-Up Display to allow a pilot to continue the approach from Decision Height (DH) or Minimum Descent Altitude (MDA) to 100 ft. above the touch down zone elevation [29]. The required visual references of the runway environment or approach light system must be presented on the HUD during the straight in landing instrument approach. This criteria is well within the desired goals of the Lower Loading Minima operating capability of IFR approaches down to 200 ft. minimum.

Figure 10. Final Approach to Tipton Airport Runway with Low Cost Head-Up Display and EVS Imagery for Increased Safety and Performance

Developing technologies that will improve the pilot's ability to consistently and accurately navigate to a reduced Decision Height without the need for costly ground based instrument systems, will greatly improve the ability to achieve near all-weather accessibility to small community airports. SATS transportation system studies have shown that the technologies developed for Lower Landing Minima, along with the RNP approach designs can make access to airports more feasible with restrictions caused by weather, noise abatement, terrain, obstacles, and special use airspace. This will have a significant impact on reducing the number of delays and cancellations, making SATS a significantly more viable transportation alternative.

In fact, system studies have shown that when reliable SATS air-taxi service can be provided at the more than 3400 small airports, there is a 25% increase in the total demand for affordable air-taxi service [12]. In addition, increasing the reliability of accessing small airports with the use of the LLM technologies reduces the cost of providing the service. By reducing cancellations and delays the service providers can reduce the cost of the ticket to the traveler by as much as 15% for terrain challenged regions [30].

Increased Single-Pilot Performance

The fourth key operating capability of SATS is to increase single pilot safety, precision, and mission completion through the use of human-centered automation. An example of this automation is intuitive and easy to follow flight path guidance superimposed on a depiction of the outside world, coupled with onboard flight planning/management systems [1, 2]. This capability focuses on developing technologies that will reduce pilot workload, enhance situation awareness, and offer more intuitive navigation and aircraft control for improved performance and safety.

Some of the enabling technologies to increase single pilot performance are:

- Advanced Displays;
- Integrity Monitoring and Decision-aiding automation;
- Head-up automation.

A number of the key technologies previously discussed in the Lower Landing Minima operating capability fall under this operating capability too (SVS, EVS, HiTS, and HUD) due to enhancing pilots situation awareness and safety.

Advanced displays, such as Multi-Function Displays (MFD), provide navigational tools to the pilot throughout all phases of the flight. One of the technologies developed to increase single pilot performance has been the Virginia SATS Lab low-cost Electronic Flight Bag (EFB). The EFB is a portable electronic device, that provides navigation information, flight planning capabilities, monitors weather, and provides HVO functionality to the general aviation pilot (Figure 11). Flight planning can be conducted from home on the EFB, and then easily transferred to the aircraft for flight navigational operations [31, 32]. The EFB's most predominant function will be to display flight status, performance, and safety data to the pilot. The pilot can select which information to display during each phase of the flight. A "connected" EFB compliments the latest glass flight deck systems in new aircraft. In the next few decades EFBs may be the only glass displays on the thousands of legacy aircraft flying around the world. Possibly in the future, an EFB, an ADS-B system and a datalink radio are all a pilot would require to safely enable the HVO and LLM operating capabilities [33].

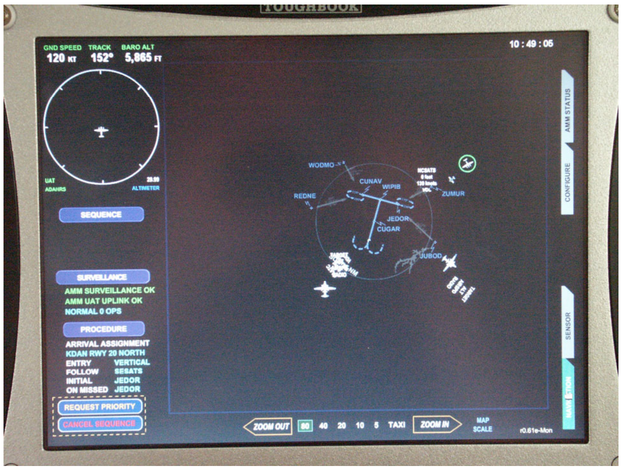

Figure 11. The Electronic Flight Bag Provides the Pilot HVO Functionality and Flight Information at the Danville SATS SCA

In-flight decision aiding tools, such as the Maryland Mid-Atlantic SATS Lab's 'Cockpit Associate', are being developed through the SATS project. The 'Cockpit Associate' can increase pilot's situation awareness by reporting audio-visual alerts on traffic, weather conditions, aircraft health, and approach procedures through the aircraft's audio system and Multi-Function Display [34, 35]. The 'Cockpit Associate' can continuously aid the pilot by conducting situation assessment, conflict detection and alerting, and reporting important notifications, recommendations, and advisories (Figure 12). This decision-aiding tool is being integrated into a Head-Up Display to conveniently notify the pilot on approach of any pertinent information. These decision-aiding devices can lead to improved operational efficiency in low-visibility conditions.

The cockpits of the future may become quite simplified with only a few advanced systems and displays such as these, to meet the flight objectives of the pilots from takeoff to landing. In addition, system studies have determined that single pilot operations can reduce the cost of SATS operations by 16% compared to dual-pilot operations today [36]. This cost reduction could be realized when utilizing SATS capability through an air-taxi service. The savings are realized by reducing the costs associated with paying for certified professional pilots. This cost reduction can make the SATS vision more feasible and marketable.

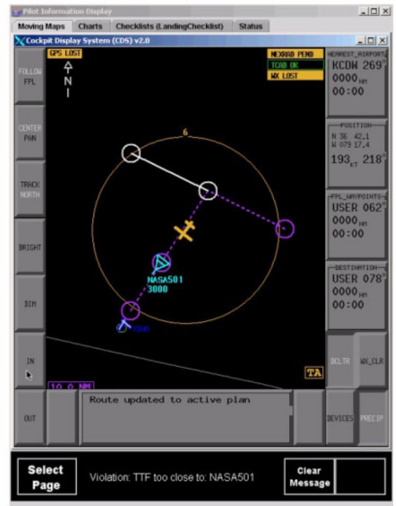

Figure 12. The 'Cockpit Associate' Aids the Pilot in Flying Safely and Proficiently by Conducting Situation Assessments, and Providing Recommendations and Advisories

Demonstration of Technologies

Throughout the five-year effort of the SATS project, both research and development have been conducted on key concepts, procedures, and technologies to strive for the convenience of on-demand, point-to-point air travel using small under-utilized airports. The SATS project culminated with the 2005 SATS Public Demonstration in Danville, VA. on June 5^{th}-7^{th}, by showcasing the accomplishments achieved throughout the project and proving that a small aircraft transportation system is viable. The main tent pavilion was constructed on the south ramp of the Danville Regional Airport specifically for the demonstration (Figure 13). This pavilion housed exhibits manned by SATS engineers and researchers that demonstrated many of the technologies that were integrated to enable the successful demonstration of the four SATS operating capabilities in safe, effective, and affordable systems for small aircraft.

Figure 13. South Ramp Area of Danville Regional Airport, where SATS 2005 Public Demonstration Was Held

The stakeholders at the event were [37]:

- Federal Agency Leaders – Key leaders in Federal Agencies involved in shaping the future of general aviation transportation, such as FAA, DoT, and NASA.
- Local and State transportation/aviation authorities
- Members of committees and organizations relevant to air transportation, e.g., RTCA, GAMA, etc.
- Industry representatives from:
  - Avionics manufacturers
  - General aviation and business aircraft manufacturers
  - Air taxi/fractional ownership businesses
  - Small airport operators
- General public.

The audience had an opportunity to gain an understanding of the SATS technologies through static displays, simulators, presentations, and a live proof-of-concept technology flight demonstration. Static displays describing the concepts, technologies, and procedures were organized by operating capability and functionality. These static displays included posters, videos, hardware, and laptop simulators, and were staffed with knowledgeable technical experts who explained the technologies to interested visitors. Flight simulators were also available to the public to show the intuitiveness and ease of use of the advanced displays, as well as the HVO concept and procedures developed through the project.

A live proof-of-concept technology flight demonstration of the four operating capabilities was conducted on June 6th and 7th to show their technical and operational feasibility. The flight demonstration focused on how the airspace and the many small and underutilized airports in the United States could be utilized if SATS was implemented. During the live technical demonstration, visitors were able to view a digital depiction of a bird's eye view of the airport and surrounding airspace, tracking all SATS participating aircraft along with any pertinent AMM information (Figure 14); cockpit displays; out-the-window or in-cockpit view; and real-time demonstration of flight guidance displays from the technology demonstration flight. The displays and videos were presented on two large screens, and the bird's eye view was displayed during the entire show. Narrators explained what the aircraft were about to do and directed the audience members to specific features on the screens during the flight demonstration (Figure 15).

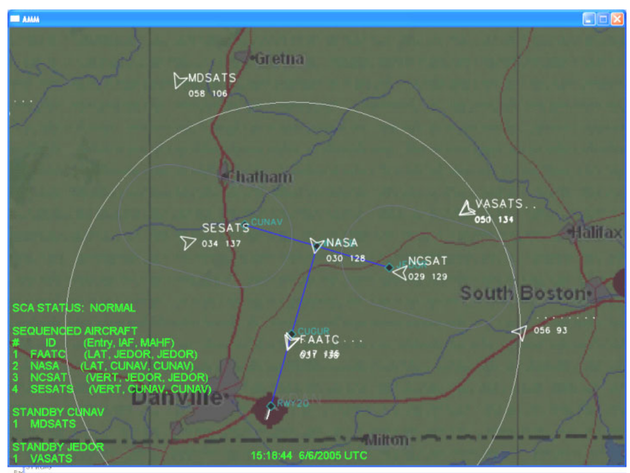

Figure 14. Bird's Eye View of the SATS Multi-Aircraft Flight Scenario Demonstrated at the 2005 Public Demonstration in Danville, VA

Figure 15. Technical Flight Demonstration Presentation Showcasing the Four Operating Capabilities

The technology flight demonstration was a six-aircraft integrated flight scenario conducted by the members of the SATS project. The six SATS aircraft included the NASA Cirrus SR22, the Maryland Mid-Atlantic SATSLab Cessna 402, the North Carolina & Upper Great Plains SATSLab Piper Aztec, the SouthEast SATSLab Cessna 310, the Virginia SATSLab King Air C90, and the FAA Technical Center Convair. In order to conduct the HVO procedures, each SATS aircraft was equipped with:

- GPS receiver;
- GDL-90 Universal Access Transceiver, UAT, 978 MHz radio [for Air-to-Air and Air-to-Ground communications];
- Either a VHF Datalink radio or VHF Long Range Access Point radio [for Air-to-Ground communications];
- CDTI;
- Software to conduct HVO procedures;
- Voice communication radios.

The NASA Digital Applications and Research Test System (DARTS) trailer, located at the Danville Airport facility, housed the ground station (AMM), which received requests and provided the sequencing information to the aircraft via the datalink [37, 38]. A Ground Based Transceiver (GBT) received the ADS-B reception of aircraft to aircraft "squitter". The GBT was used to receive aircraft position only. The aircraft position was sent via Local Area Network (LAN) to the Ground Based Server computer located in the DARTS trailer in order to conduct the AMM operations. The AMM entry request information was provided with the bird's eye depiction of the aircraft within the SCA, during the live presentation (Figure 14).

During the flight scenario, both video and data were telemetered down from the aircraft to the ground station and transferred to the tent venue for the live presentation. The telemetered video and data showcased the labs' and NASA's various technical contributions to the project and significance to the operating capabilities.

The Danville Regional Airport falls into the classification of a SATS-type airport, in that it is a non-towered/non-radar airport. The active runway used for the flight demonstration was Runway 20. Runways 13-31 were closed for the duration of the three-day event. During the flight demonstration, the airport was closed to any arriving traffic, except the six aircraft participating in the flight demonstration.

The flight demonstration was conducted in VMC, although the aircraft flew as though they were operating in IMC. A certified ILS approach to Runway 02, and a GPS approach to Runway 20 currently exist. However, a simulated SCA defined for the Danville airport was constructed that consisted of two initial approach paths merging into a T. A SATS GPS-T approach was overlaid on the ILS approach to Runway 02, and also one was overlaid over the certified GPS approach for runway 20. For the SATS flight demonstration, the SATS GPS-T approach for runway 20 was used (Figure 5).

The flight scenario was constructed to demonstrate the four operating capabilities in an integrated manner. Once cleared by the Safety Officer, the SATS flight director coordinated and managed the SATS flight scenario by having all six aircraft take-off one at a time and fly to their pre-defined transition fix locations (REDNE, WODMO, ZUMUR, and JUBOD) outside the Danville SCA in preparation for the HVO approach to Runway 20 (Figure 16).

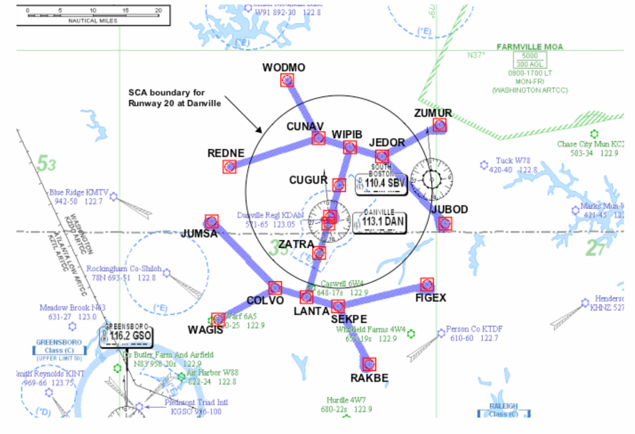

Figure 16. SATS Fix Locations for the Danville Regional Airport, with SCA Boundary for Approach to Runway 20

All six participating aircraft could see each other on their CDTI, with traffic information provided by the GDL-90 UAT air-to-air communications. During the live demonstration, although it was VMC, it was portrayed to the audience that the scenario being flow was developed for IMC in low visibility and that the aircraft were handed off from the air traffic controller into the SCA. Once the flight director commenced the start of the live demonstration, the first aircraft, the FAA Convair, approached the SCA (near the JUBOD transition fix) and requested entry using the air-to-ground datalink. The request was received by the AMM at the ground station and a message with the sequence information was sent back to the Convair, via ground-to-air datalink, granting a lateral entry into the SCA and displayed on the aircraft display. The aircraft was directed to go to the JEDOR IAF, with JEDOR as the MAHF.

The second aircraft to request entry into the SCA was the NASA Cirrus (near the REDNE transition fix). The Cirrus was granted a lateral entry into the SCA, and directed (1) to follow the FAA aircraft on approach, and (2) go to the CUNAV IAF. CUNAV was assigned as the Missed Approach Holding Fix also. Note, the pilots are responsible for following their sequence and maintaining self-separation from other aircraft. Under current standard procedures, since the controller does not have the radar coverage of the Danville airport area, the controller would hold all but one aircraft away from the approach until that one has landed and canceled its clearance. At this point, the controller would then release the next aircraft to execute the IFR approach. During this SATS HVO scenario, up to four aircraft can be on the approach simultaneously, significantly increasing the number of operations possible at the non-towered/non-radar airport.

As the Cirrus approached the IAF, live telemetry of the Cirrus 'within-the-cockpit' view was shown to the audience for the live presentation. The Cirrus MFD was discussed, showing the audience how the pilots had a clear picture of where they were, and the flight environment around them, including the location of the other aircraft in the area.

The following aircraft to enter the SCA highlighted the technologies developed for Lower Landing Minima and Single Pilot Performance in order to guide the aircraft down safely in low visibility. The third aircraft that requested entry (near the ZUMUR transition fix), and was granted a vertical entry into the SCA, was the North Carolina & Upper Great Plains SATS Lab aircraft. During the live demonstration, the aircraft PFD and MFD data was telemetered to the ground and recreated on the screen to show the audience the SVS/HiTS/FD guidance cues, highlighting the intuitive of the displays. The pilot consistently and accurately flew the HiTS approach that was programmed for the Danville airport runway. With the pilot keeping the flight predictor symbol centered in the guidance box, the aircraft could accurately follow the pathway. The MFD gave the pilot a clear view of his current position on the approach path as well as his desired path.

The fourth aircraft to request and be granted a vertical entry into the SCA (near the REDNE transition fix) was the SouthEast SATS Lab aircraft. This aircraft showcased their advanced display, the "SmartDeck", that displays key flight critical data overlaid on SVS with HiTS and FD guidance. This display had other important features such as autopilot, WAAS integrity monitor, and caution and warning display for critical aircraft systems such as engine monitoring. A number of different information pages exist. Some of these include various views of the airport approach or automated checklists.

The fifth aircraft to request and be granted entry into the SCA (near the ZUMUR transition fix) was the Virginia SATS Lab aircraft. For this aircraft, the aircraft state data was telemetered down to the ground to recreate the EFB display that the pilot was using in flight. It was explained that the pilot could select needed information to be displayed during each phase of the flight. During the flight scenario, the EFB displayed a moving map showing all aircraft within the SCA including terrain, weather, and other safety information. In addition, the AMM sequencing information was displayed.

The last SATS aircraft to request and be granted entry into the SCA (near the WODMO transition fix) was the Maryland Mid-Atlantic SATS Lab aircraft. Both the aircraft state data and the HUD with EVS video was telemetered down to the ground. The real-time state data from the aircraft was used to recreate a flight simulation display with the HiTS. The HiTS display illustrated the ease with which the pilot could maintain his final approach with the intuitive display onboard the aircraft. The telemetered video of the HUD display with EVS included the final approach to the Danville airport. The HiTS and the flight information were overlaid onto the infrared imagery from an EVS. The HUD allows the pilot to keep an out-the-window view, so the pilot can quickly spot the runway as the aircraft breaks out of the clouds for landing during IMC.

The 'Cockpit Associate' was also discussed, illustrating how its functionality was used as intelligent automation to provide timely information to aid the pilot. The system reminded the pilot of relevant checklists, and kept track of which items had been completed. The pilot can interact by voice or manually. It uses an advanced knowledge based processor to infer the needs of the pilot based on the flight plan, traffic conditions, airspace, boundaries, airport status, and weather. This tool can make flying as a single pilot considerably easier.

The outcome of the 2005 demonstration was 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 [4]. The flight scenario flown during the live demonstration confirmed to the audience the viability of the HVO concept, by significantly increasing the operational rate at the non-towered/ non-radar airport using self-separation and flight-path guidance technologies. The total time from the first aircraft AMM entry request, from outside the SCA, until all six aircraft had landed was ~31 minutes in the demonstration. In addition, the advanced display technologies demonstrated for the Lower Landing Minima capability, showed intuitive flightpath guidance that could provide the pilot increased accuracy and situation awareness compared to conventional instrumentation in poor weather conditions. It was demonstrated how Single Pilot Performance could be realized through use of onboard decision-aiding automation tools to assist the pilot throughout all phases of the flight.

Transportation engineers at Virginia Tech predicted up to 15 million SATS passenger-trip/year, if an air-taxi service could be provided at a cost of $1.75 per passenger-mile in 2010. When SATS technology matures, costs of $1.25 per passenger mile might be possible increasing the market share to 29 million person trips per year. Today, business passengers traveling in commercial airlines pay $0.90 per passenger-mile in a typical 350 mile trip. However, SATS travelers would save an average of 3 hours per trip based on a nationwide analysis [39].

Conclusions

SATS is a vision for a new kind of air travel. This vision is that air transportation can meet the needs of more people by assuring the safety, speed, and convenience of point-to-point air travel through a network of more than 3400 under-utilized airports in near all-weather conditions. The SATS project has been a research and development venture to foster the development of advanced concepts, technologies, and procedures that will provide a technical and economic basis to develop a small aircraft transportation system that could compliment today's airline system.

The project has focused on four key operating capabilities to take the first steps in making the SATS vision a reality. The four operating capabilities: *Higher Volume Operations at Non-Towered/Non-Radar Airports, En Route Procedures and Systems for Integrated Fleet Operations, Lower Landing Minimums at Minimally Equipped*

Landing, and Increased Single Pilot Performance have been researched, developed, evaluated, and implemented in an integral fashion for demonstration at the 2005 SATS Public Demonstration in Danville, VA. The technology demonstration showcased that a small aircraft transportation system could be both feasible and viable, and could revolutionize how we travel in the future. The four operating capabilities described could pave the way for a time when one can affordably go anywhere – any time – by taking advantage of thousands of small community airports located all across the nation.

The HVO concept and procedures have shown that the volume of aircraft into and out of small airports could increase by four times compared to today's procedural separation by air traffic controllers. The FAA and NASA have worked closely together to assess the viability and feasibility of integrating the HVO concepts and procedures into the NAS identifying the steps that need to be taken next. Technologies researched and developed within the Lower Landing Minimums and Single Pilot Performance operating capabilities demonstrated increasing navigational accuracy, reducing pilot workload, improving situation awareness, and improved safety, thus taking a big step towards the SATS vision of taking advantage of the small community airports in near all weather conditions. Further research and analysis need to be conducted on the procedures and technologies, with intentions of proceeding further to implementation into the NAS and commercialization of products for the aviation community.

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