

# Development of an Airborne Internet Architecture to Support SATS: Trends and Issues<sup>1</sup>

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## ABSTRACT

NASA is undertaking the development of the Small Aircraft Transportation System (SATS). SATS could play a major role in decreasing the doorstop to destination times for travel and shipping. It is conceived to meet four major objectives: higher volume at non-towered/non-radar airports, lower landing minimums at minimally equipped landing facilities, increased single crew safety and mission reliability, and integrated procedures and systems for integrated fleet operations. SATS is to be prototyped in the 2005 timeframe.

A key enabling technology for such a system is the development of an *Airborne Internet* to provide aircraft to the ground, ground to ground and aircraft to aircraft communications in support of air traffic management, fleet operations, and passenger support services. A critical first step in attaining the desirable capabilities of an airborne Internet is a well-conceived architecture. The architecture must be robust enough to enable the concept of operations envisioned for the 2025 timeframe yet flexible enough to support prototyped using technology and systems available in the 2005 timeframe.

This paper addresses some of the trends and issues involved in developing an Airborne Internet capable of achieving this goal. Understanding relationships between these trends and issues and the objectives and functional requirements of the program will allow various participants in this complex program to keep activities in proper perspective. The architecture process provides a robust framework to add functionality, systems and equipment. It must also describe the linkage to the existing National Airspace System.

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## 1. INTRODUCTION

The hub and spoke system consisting of a handful of major air carriers servicing only the largest of the country's airports is at or near saturation. Travel delays are costing the US economy hundreds of millions of dollars in lost time and revenue. To address this problem, NASA has conceived of the Small Aircraft Transportation System (SATS). This system is envisioned to use a combination of technologies in an attempt to create a set of small (4 – 10 passenger) aircraft and associated systems capable of providing efficient, economical air travel to the nation's smaller, under-utilized airports.

Supporting this new transportation concept is an Airborne Internet (AI).

“A client-server-based architecture will provide information services on an “Airborne Internet” to support collaborative air traffic management. Aircraft and landing facilities will be interconnected nodes in a high-speed digital communications network providing instant identification and information services on demand with seamless linking to the global transportation system.” - Bruce Holmes, SATS Program Manager, NASA

To facilitate discussion and analysis of the SATS requirements, it is instructive to define three epochs of time:

Epoch 1: (Now – 2005) is defined by the need to have technologies available for inclusion in the SATS concept demonstration scheduled for 2005. Candidate technologies include those available today, e.g. VDL Mode 2/3, ADS-B, and ATN; technologies that will become available during that time period, e.g., LAAS, WAAS, and NEXCOM; and technologies that may be available or will become available but are not normally considered for aviation, e.g., IRIDIUM.

Epoch 2: (2006 – 2025) is defined by desirable technologies, which could become available during this epoch if the development, procurement and

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provisioning is begun within Epoch 1. These technologies will be required to fully develop the SATS concept.

Epoch 3: (2025 – future) is defined by those technologies which will be required beyond 2025 to support the realization of the full SATS concept.

This is the hypothetical “mature-state” architecture of an Airborne Internet that could support the full range of SATS Communication, Navigation, Surveillance, and Weather applications.

But, before expensive deployment projects can get underway, issue identification and requirements analysis are necessary to avoid poor architectural level designs that are difficult and costly to implement.

This paper introduces an approach to developing an Airborne Internet Architecture and presents some trends and issues that must be considered in developing the AI concept.

Given that the project has just begun, the results presented here are preliminary.

## 2. SATS: CONCEPTS, OBJECTIVES, PROGRAM

NASA is taking leadership in developing technologies for a **Small Aircraft Transportation System (SATS)** that could play a major role in helping to relieve large airport congestion and provide reliable, convenient, safe environmentally compatible air transportation service to rural and outlining communities, as well as revolutionizing the national transportation system. The AGATE and GAP programs have taken a quantum step in this process through the development of affordable, easy to use, environmentally friendly aircraft and propulsion systems. This investment is already benefiting the flying public through much more affordable, informative and readable avionics systems and will soon cause a revolution in small aircraft with the introduction of a whole new class of aircraft; safe, comfortable, affordable small jet aircraft. To bring the SATS vision to its full potential of a personal transportation alternative, however, will require major technology enhancements to the national air space (NAS) system, and another order of magnitude advancement in affordability, performance and environment impact for aircraft systems.

The initial 5 year objective (FY01-05) will address the President and Congress’ charge to NASA and the FAA to “prove that SATS works”. It is focused on demonstrating technologies to enable the use of existing small community and neighborhood airports, without requiring control towers, radar, and more land use for added runway protection zones. The key to such a system is a robust extremely reliable automated communications system. Such a system must be capable of passing large amounts of data between aircraft and various ground systems as well as between neighboring aircraft in a reliable fashion.

To this end, NASA Glenn Research Center, through its

partnership with NASA Langley Research Center, is pursuing a key enabling technology area: *Airborne Internet*.

The *Airborne Internet* will leverage open standards and protocols for a client-server network system architecture that are in development in the telecommunications industry for increased bandwidth for mobile applications. SATS research will leverage the developments in NASA and FAA Airspace System Capacity (ASC) research on Distributed Air Ground (DAG) collaborative decision-making. SATS research will focus on defining the functional allocations between clients and servers for all navigation, communications, and surveillance information necessary for aircraft operations including sequencing, separation, and conflict resolution.

Continued growth in air travel across all segments of aviation in the national air space (NAS) system is placing severe demands of the already constrained system and the underlying Communication-Navigation-Surveillance (CNS) infrastructure. Current NAS operations are primarily conducted via analog voice communications, radar surveillance, and ground-based navigation aides. Although a number of efforts are underway to modernize the NAS, the majority of these efforts are targeting the commercial air transport segment operating under the traditional hub-and-spoke model.

To meet the forecasted need, the consolidation and integration of communication, navigation, and surveillance technologies, systems, and services will have been initiated through a client-server internet-like model. A demonstration of integrated services via satellite-terrestrial hybrid communications architecture will benchmark the capability, efficiency, and safety of a digital airspace infrastructure. This infrastructure development will be the maturing of the *Airborne Internet* to enable the full SATS vision.

## 3. ARCHITECTURE DEVELOPMENT

### METHODOLOGY

An architecture defines the structural and collaborative relationships of system components. Often described using views (e.g., functional, component, implementation, temporal, user), the architecture provides information to guide system and software developers during initial development and inevitable system improvement activities. In addition to defining the functional and physical relationships between system components, an architecture often provides design guidance in an attempt to achieve other desirable objectives such as efficient resource utilization, incremental development, verifiability, use of COTS products, ease of maintenance, and system extensibility.

Our approach to developing a SATS Airborne Internet architecture consists of the following steps:

- 1) Understand the SATS operational concepts
- 2) Define system level requirements
- 3) Investigate and evaluate the external environment
- 4) Identify trends and issues that must be addressed
- 5) Apply modern system design techniques, i.e., design patterns to identify key design elements
- 6) Document the result and submit for review

*Understand the SATS operational concepts* – Everyone tends to relate to SATS in a unique way. It is more a new way of thinking about air transportation than a technical concept that beckons to be explored. This leads to a variety of definitions of what SATS is – or should be. To bound the AI architecture problem we developed a set of system operation assumptions. A sampling of these key assumptions are listed below:

- Pilot – Until such time as highly automated systems can be fully tested and certified, SATS aircraft will have at least one qualified, instrument rated pilot on board. Because of the level of automation on board, the SATS system will enable this pilot to be much more proficient and able to fly in nearly all weather conditions into a large number of minimally equipped airports.
- Airspace – SATS aircraft will share airspace with non-SATS aircraft. This implies a minimum level of system compatibility and equipage in both SATS and non-SATS aircraft. SATS aircraft en route will operate in Class A airspace, SATS aircraft landing at small/medium sized airports will operate in Class C, D, or E airspace.
- Avionics – in addition to the minimum set of avionics required of normal IFR<sup>2</sup> aircraft, SATS aircraft will have on board additional avionics equipment to enable the pilot to operate in near all-weather situations. If SATS is to be prototyped in 2005 and operational in 2025, this equipment will need to be compatible with systems used by commercial and general aviation airports to not require expensive new ground support systems not currently planned by the FAA.
- Flight rules – to meet its objectives, SATS aircraft will need to be able to access small and medium sized airports. These same airports currently support VFR<sup>3</sup> traffic. Flight rules will have to be modified to support a mixture of IFR, VFR and SATS traffic.

*Define system level requirements* – Specific, verifiable requirements for a SATS communications system must be developed. The communications system is unique in that it is both an end system and an enabling infrastructure. As an end system it must provide pilot-controller, pilot-pilot, and pilot-flight operations communications. As an enabling infrastructure it must support applications associated with navigation, surveillance, and other functions.

Requirements need to be developed in the traditional areas of communication, navigation, and surveillance, including both avionics and ground infrastructure, consistent with the infrastructure defined in the task below. System level requirements also need to be developed for onboard flight management and sensor/actuator systems capable of providing the level of support necessary to achieve the SATS goal of two crew performance with a single crew member. Other requirements will include support for passenger support systems

*Investigate and evaluate the external environment* – SATS, although a revolutionary transportation concept will have to work within the National Airspace System (NAS). This is true both during SATS prototyping in 2005 and during full-scale development, in 2025. The NAS itself is evolving necessitating developing an understanding of the capabilities of NAS over time. This can be very tricky as the NAS is subject to many forces that are political, not technical, and as such is difficult to predict. For example, there are currently three competing technologies to provide aircraft position reporting. Clearly, there is agreement that position reporting is desirable, but which technological approach will survive is like trying to choose between VHS and Betamax before the marketplace has spoken.

*Identify trends and issues that must be addressed* – To be successful, SATS must function within the context of technology evolution and systems development. A summary of some of the trends and issues are presented in the next section of this paper.

*Apply modern system design techniques* – SATS presents an ideal opportunity to apply object-oriented design techniques for the collection, analysis and documentation of system architecture. Elements of the resulting design include:

- design patterns to identify key components of the design
- layers of abstraction to minimize coupling of user level functionality to implementation details
- exploitation of natural cohesiveness, common software functional patterns
- communications protocols between major functional objects

*Document the result and submit for review* – Peer review is a vital step in the development of an architecture for a system as complex and safety critical as a new aircraft transportation system.

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<sup>2</sup> Instrument Flight Rules

<sup>3</sup> Visual Flight Rules

## 4. TRENDS AND ISSUES

An important part of any analysis is the identification of trends and issues that may impact the system development. This is especially true for SATS, as it must coexist with other aircraft in the National Airspace System (NAS) for several years to come.

Trend – Capacity constraints of the current hub/spoke system are leading to a desire to take advantage of excess capacity of small/medium sized airports. Issues to be considered include:

- Most small and medium-sized airports have limited if any instrument landing equipment. Meeting the SATS objective of landing during “all weather” conditions will require that these airports be equipped with sufficient augmentation and communications support equipment to provide separation during arrivals and departures at these airports.
- Overcoming today’s “one-in, one-out” rule at smaller airports will require improved surveillance systems so that SATS aircraft cannot only separate from each other but maintain separation from non-SATS aircraft. Today’s NAS supports a large variety of aircraft with an even larger variation in the configuration of onboard avionics. SATS aircraft will need to co-mingle with these less well-equipped aircraft. This requires that the SATS aircraft assume primary responsibility for separation. SATS aircraft will need to be able to determine the position of their aircraft relative to non-SATS equipped aircraft.
- Integrated onboard communications, navigation, surveillance and flight management systems are needed in the cockpits. Navigation systems will require a level of augmentation that demands a real-time data link between the cockpit and ground support systems.
- To support the objective to have single crew cockpits perform as proficiently as two crew cockpits, auto-land or autonomous operations will eventually be required to compensate in the event of pilot incapacitation or failure. A requirement for remote control would require that the communication system support hard real time communications between the flight management system and the ground-based controller/pilot

Trend – Frequency congestion and competition for spectrum is driving the need for data link connectivity between pilots and ground personnel. Although there will likely always be a voice communication requirement, numerous communications functions such as flight planning, clearance delivery, requests for weather, etc. can be better performed via data link, freeing up congested voice channels. Issues to be considered include:

- Current voice communications are broadcast over channels being monitored by other aircraft in the vicinity, in similar situations, e.g., arriving at an airport. Pilots are trained to monitor communications between other pilots and controllers to obtain “situational awareness” of procedures in effect, locations and status of other aircraft, and spacing and sequencing. To the extent that such communications are transferred to point-to-point data link messages alternative mechanisms will need to be provided to aid other affected pilots maintain the level of situational awareness provided by the broadcast approach.
- Data link has been under development for nearly 15 years. The process of arriving at an agreement on the approach is complicated by the large number of stakeholders with an interest in the outcome: airlines, avionics manufacturers, communications service providers, civil aviation authorities, pilots and controllers unions are just a few of the groups involved. Because of the need for SATS to interoperate with the larger population of aircraft, SATS must maintain compatibility with the larger fleet and therefore is somewhat restricted in the approach it can take.
- If to meet one of its operational objectives, SATS defined the need to develop a new capability requiring ground system support, it would be a lengthy process to get that capability defined, procured, installed, certified and operational. Recent experience with deploying new aviation systems suggests deployment could take anywhere from 7 to 25 years. New communication systems, e.g., data link, tend to take longer than automation or navigation systems. For SATS to achieve its goal of system operation by 2025, any new systems will need to be identified immediately.

Trend – SATS is designed to tap into a latent demand, a demand for timely and efficient transportation not being met by today’s aviation industry. Scenarios postulated about how SATS aircraft may be owned and operated include, corporate fleets, programs similar to today’s fractional ownership, “rent a jet” programs, or part of a freight delivery organization. This raises the following issues:

- Such corporate flight operations may place an even greater burden on an Airborne Internet than the traditional safety functions of communications, navigation, surveillance, and weather and thus become the driver for the range, latency, bandwidth, and quality of service attributes of an Airborne Internet. Aircraft and crew scheduling, package tracking, maintenance support, ground air coordination, and competitive offerings could place significant demands for data messaging.
- Corporate fleet aircraft may require significant bandwidth connections to support executive access to ground based data and voice infrastructure while en route to multiple destinations. Medical organizations

might link vital signs of critically ill patients to ground based medical facilities. News organizations may compose stories, do research, or conduct interviews while en route. Law enforcement or regulatory organizations could conduct research, collaborate with colleagues, or prepare for interviews while en route to a crime scene. A suitably equipped fleet of SATS aircraft could collect and report weather or other environmental data in real time while being used for other purposes noted above.

- Separate solutions to meet the needs identified above will lead to further frequency congestion, unnecessary cost, and complexity. A general purpose Airborne Internet that can accommodate a wide variety of communication requirements including quality of service, security, latency, and bandwidth is required. Compatibility with a quickly evolving ground based infrastructure is a must.

Trend – Recent events have caused a heightened awareness of security issues that will drive the SATS aircraft and their communication systems to incorporate additional security provisions not originally envisioned for those systems. Issues to be addressed include:

- Much of today's ground air communication is conducted in clear text, including the emerging ADS-B system. Given the purpose of ADS-B was to let others know where you are, broadcasting position information seemed like a good thing to do. However, such a practice a vulnerability to a terrorist who might use the information to target aircraft with an anti aircraft weapon.
- Today's commercial air traffic control information is also done "in the clear," and could theoretically be spoofed, jammed or be interfered with. Moving this information from voice to data presents new opportunities for tampering with the data in an undetected fashion. Communication and authentication security mechanisms will be required to prevent/detect such tampering. Some of these mechanisms will be implemented in the end systems; others will place requirements on the Airborne Internet itself.
- Given that a stated goal of SATS is to make an aircraft that easy to use, it may be desirable to validate who is about to operate and/or who is currently operating a SATS aircraft. Given that an unauthorized person is detected operating the SATS aircraft, measures might be taken to arrest control from that person and direct the aircraft to a safe location either autonomously or via remote control. Such actions will place a heavy burden on the Airborne Internet to monitor and possibly control such action.

Trend – The TCP/IP based Internet is ubiquitous. It is highly likely that many of the ground-based systems will use TCP/IP networking protocols to communicate among distributed elements of the system. The question of whether

the SATS air ground communication systems should also use TCP/IP protocols to communicate raises the following issues:

- Although SATS is intended for use primarily in the US, its communication systems will undoubtedly be influenced by what is happening internationally. The need for compatibility across the NAS, the desire for commonality within the fleet operations, and the desire of avionics manufacturers to achieve economies of scale will push toward commonality. The current International Civil Aviation Organization (ICAO) defined ATN network is ISO protocol based. The standards have been under development for a long time, and have momentum within the aviation community. At the same time there is the near universal acceptance of the Internet. Interoperable protocol stacks exist for almost every operating system, there are a large number of personnel trained on its use, and a large amount of software is written to use it. Using it for air ground communication would simplify the task of interconnecting with ground-based systems.
- The arguments for using TCP/IP are similar to the arguments used to justify the use of COTS in specialized systems such as avionics or air traffic control. They include lower initial costs, less expensive training and ability to take advantage of new developments. The reality is that the aviation field does not and cannot move at the pace of the commercial, non-aviation, ground based systems because of issues of safety, international compatibility, multiple stakeholders and politics. Initial costs are a relatively small part of the total life cycle costs. Training and support costs while significant are dominated by the costs need to train and understand the unique applications. Communications are a small part of the overall problem. And, primarily due to the costs of achieving certification, the aviation community cannot afford to chase the latest developments in technology at the same pace as ground based, commercial systems.
- An argument for using ISO over TCP/IP is the measure of "security" to be gained from using a unique albeit openly defined communication standard like ISO for air ground communication, a sort of "security by obscurity" argument. Without widespread use and limited availability of the software to implement ISO protocols, they present a more difficult challenge to the would-be hacker. Fewer opportunities to gain experience, fewer implementations, fewer colleagues familiar with it, all tend to raise the bar for someone interested in taking advantages of any vulnerabilities it may have.
- Alternatives exist and need to be studied to permit TCP/IP and ISO to coexist. They include dual stacks, tunneling, and gateways. These alternatives could be used to transition from ISO to TCP/IP or they could form the basis for a dual implementation to take

advantage of the features of each approach. There is a safety and security argument to be made for functional separation of the traffic used for safety critical systems from non safety critical ones.

We've presented a partial list of trends and issues to be considered when defining the need for an Airborne Internet to support SATS. Next, we present the roadmap for future development of the architecture of the AI.

## 5. ROADMAP OF FUTURE ACTIVITIES

We intend to continue applying the methodology defined above to develop Airborne Internet alternatives, analyze the advantages and disadvantages of each alternative and arrive at a recommendation. Then, working with other SATS organizations we will refine the architecture and document it for use by system developers. Key elements of the architecture will be prototyped and evaluated to better understand their applicability to SATS. Estimates of performance and cost will be made. A separate security assessment will be produced.