CNS/ATM SYSTEM ARCHITECTURE CONCEPTS AND FUTURE VISION OF NAS OPERATIONS IN 2020 TIMEFRAME

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ABSTRACT

In the future, the demand for air traffic services will not only increase but also will likely shift from scheduled operations towards more unscheduled operations for air taxi, charter, fractional ownership, and on-demand small low-cost aircraft. As the metropolitan areas continue to grow, the satellite airports around major hubs will provide a wide range of flight options for people to fly between their homes and places of business or pleasure. This paper describes an air transportation system's architecture concept and a vision of the future operating environment based on industry trends for air traffic demand and aviation technology enhancements. A multi-facet airport infrastructure is developed to support suburban-direct, spoke-to-spoke, and intra/inter-city Vertical Short Take Off and Landing (VSTOL) operations. A multi-level Communication, Navigation and Surveillance (CNS) architecture is presented that is intended to assure robustness and seamless coverage. The future Air Traffic Management (ATM) system architecture considers end-to-end traffic flow planning and control by National, Regional and Local facilities with a redefined role of service providers as strategic planners and tactical controllers. In spite of a majority of aircraft equipped with enhanced avionics capable of flying 4D Navigation and strategically separated, the operational concepts presented are designed to also provide service to less equipped General Aviation (GA) aircraft as well as the Uninhabited Aerial Vehicles (UAV). Modeling and simulation results are presented illustrating the potential growth in future demand and fleet mix at 30 major airports, as well as airborne/ground movement delays at these airports.

INTRODUCTION

As laid out in the National Airspace System (NAS) Operational Evolution Plan (OEP) [1], the Federal Aviation Administration (FAA) and the aviation community are planning to make significant investment in NAS improvements over the next ten years. These enhancements involve implementation of satellite-based CNS capabilities, and automation of ground systems in order to improve efficiency, safety, capacity and security. However, the OEP assumes that the mode of air transportation operations during this timeframe is expected to continue more or less as it is today, but with significantly increased NAS capacity. The air transportation industry is currently undergoing numerous changes. Based on industry trends, the future passenger and cargo demands will create the need for air transportation operators to serve new markets and more airports. The use of smaller and satellite airports will provide proximity to air travel for more communities, and will offer passengers more options to fly direct point-to-point. As shown in Figure 1, the flying public will seek more flexibility and low cost

Figure 1. Future ATM System Needs

options tailored to their specific needs with flight alternatives based on lowest travel costs, suitable schedules, and easy access to the desired airports. The future air transportation system should provide the aircraft operators the ability to meet the customer needs with minimum overall operating costs. The most important challenge for the future ATM system providers will be to not only provide the operators a high degree of flexibility, access to most airspace and efficient service, but also strengthen safeguards that protect the security of passengers, operating personnel, and continuity of system operations. A number of reports [2-17] have presented future NAS operational concepts by considering significant changes to NAS operations. This paper integrates some of the common themes from these studies into CNS/ATM system architecture concepts. The paper also presents a vision of future NAS and CNS/ATM operational concepts for year 2020 and beyond based on two overarching goals: 1) move anyone, anywhere on time; and 2) know almost anything about everything in almost real time.

Industry Trends and Future Demand

Over the next decade, new aircraft types will emerge that may alter commercial air travel. The demand for Regional Jets (RJ) and new smaller aircraft, capable of operating at shorter runways, will increase significantly as the RJs increase their seat capacities by introducing new models (e.g., E170 & E190, CRJ700 & CRJ900 (with 70-90 seats). However, the new aircraft type that will likely have the largest impact of the future operations will be the inexpensive small business jets.

There are other types of flight operations expected in the next 20 years that might have a noticeable impact on the air transportation system. These include VSTOL aircraft serving intra-city airports and business centers as well as short haul operations. Additionally, UAVs are expected to provide security and surveillance as well as operate for military training purposes. By 2020, the UAVs used for cargo operations are also a remote possibility.

In order to remain competitive with low-cost operators, the network carriers continue to strive to cut operational costs and are changing how they structure their hubs (e.g., de-peaking or increased number of banks). As current airlines' business models are increasingly coming under pressures from the markets, new business models are emerging. One such business model is fractional ownership. The fractional ownership concept originally arose as an option to corporate or individual ownership of private aircraft. Rather than buying or leasing an entire aircraft, the participants in fractional ownership programs purchase a share of an aircraft and pay a fixed monthly management fee. Other models under exploration include travel clubs where passengers fly on flights restricted to "members-only", thereby potentially reducing the hassle-factor of air travel. With the growth in such operations, the future ATM system will have to deal with a much higher percentage of unscheduled demand than today.

Airport Infrastructure to Meet Future Demand

Using FAA Terminal Forecast data [18], by 2020 about 38 percent growth is expected in total NAS operations. However, the major 30 hub airports are expected to handle almost 60 percent more traffic. In order to minimize delays, additional airport capacity will be required after the OEP enhancements are in place, including planned runways at some of these airports. As metropolitan areas continue to grow with the population and business centers move out into the suburbs, many existing satellite airports could provide proximity to businesses and communities, and add capacity to NAS. As shown in Figure 2, currently there are 488 airports in the U.S. other than the 30 major hubs, most with a control tower and all with paved lighted runways longer than 5500 ft. Out of these, there are 194 airports within 50 miles of the 30 hubs that are thus well equipped to serve smaller jets. With the addition of new CNS technologies these airports become extremely attractive as alternates to hub airports. Among the other 294 airports, 122 airports are located close to medium density population centers that could operate as important spoke airports. Many of these airports are already providing spoke-type operations.

Direct flights between suburban satellite airports (i.e., suburban direct) will offer passengers more travel options among high population areas and business centers bypassing busy airports that will balance travel cost and time based on individual needs. Figure 3 shows an example of potential flight options between Washington DC and New York metropolitan areas.

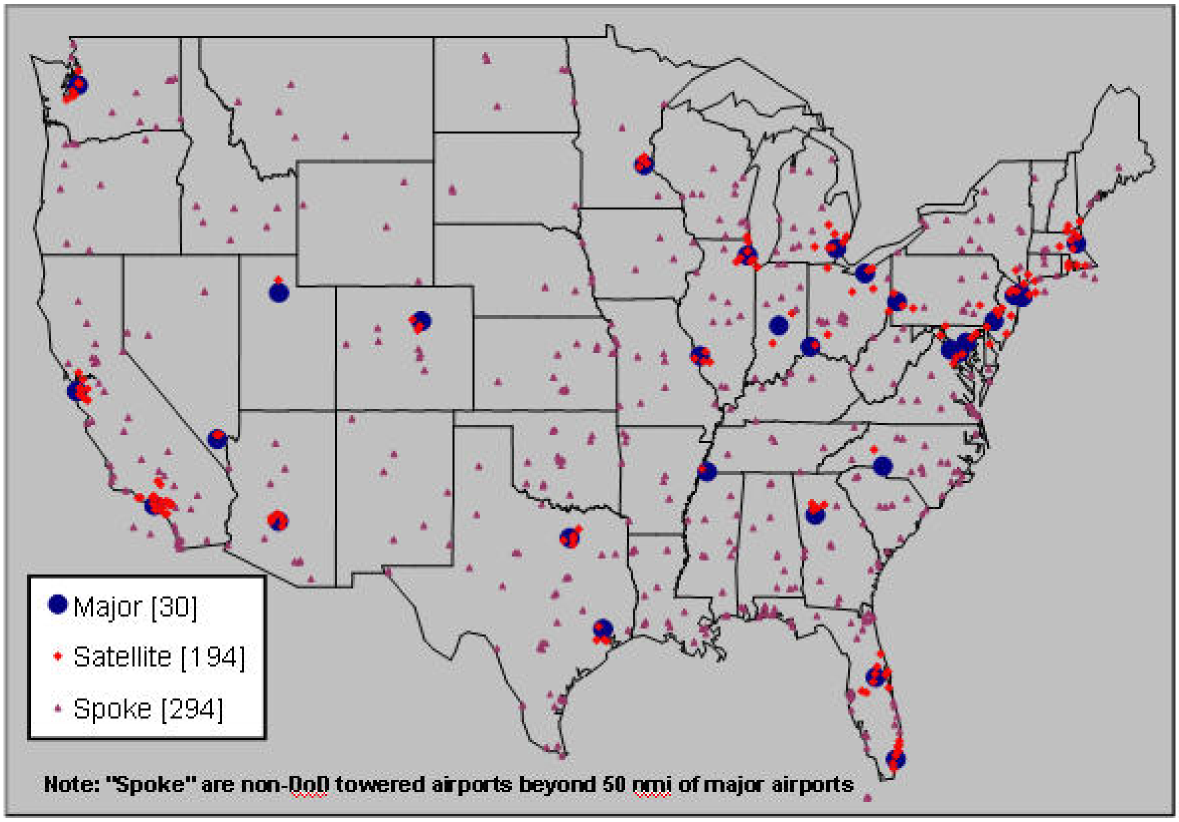

Figure 2. Airports for Adding Capacity

Figure 3. Example of Flight Options Between Washington and New York

In order to provide easy ingress/egress to/from these airports, a multi-modal system may be used, but it involves significant time and funding to develop. As shown in Figure 4, a multi-facet airport structure is defined [19] that not only links hub/spoke and spoke/spoke airports as today, but also connects satellite airports providing suburban-direct services. In order to provide links between downtown and suburban business centers with satellite and hub/spoke airports, VSTOL or helicopter air-taxi operations are considered.

FUTURE TRAFFIC FLOWS

The above trends in demand and the increased use of the airports discussed above are likely to contribute to major changes in air traffic flows. It is expected that the following transformations will emerge by the year 2020.

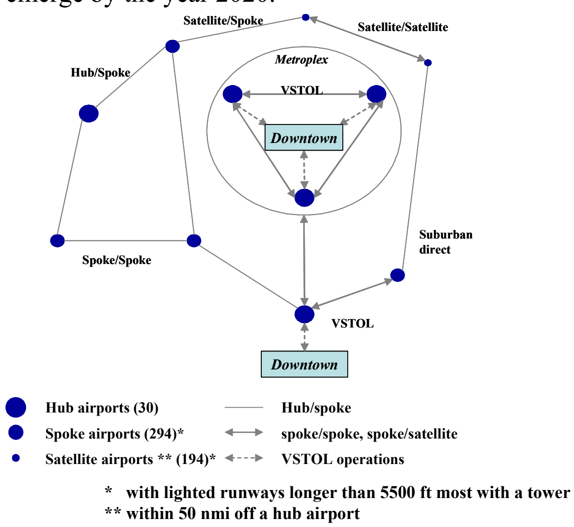

Figure 4. Suburban Direct, Spoke/Spoke and VSTOL Operations

- **Increased Point-to-Point Service:** With fractional ownership, availability of low-cost private jets, growth in low-cost spoke-to-spoke carriers, and major changes in network carrier services, the future traffic flows will tend to be more point-to-point, rather then into or out of major hubs. However, the hub and spoke operations will not likely diminish significantly because the addition of satellite airports would still be a part of the hub airport infrastructure.

- **More Uniform Hourly Demand at Hub Airports:** As the network carriers de-peak their hub schedules to remain competitive with low-cost carriers, there will be fewer demand peaks driven by the airline banking. In the future, while there still will be busy times based on passenger needs, the hourly traffic demand will tend to become more uniform.

- **Higher Uncertainty in Predicting Daily Traffic:** Currently, the majority of operations at major airports include scheduled flights by the air carriers. In the future, due to a significant increase in non-scheduled operations, the daily traffic flows will become increasingly more difficult to predict.

- **More Complex Terminal Airspace and Terminal Flows:** There will be an increased usage of satellite airports in or near metropolitan areas due to the increase in the number of aircraft privately operated (either as corporate, fractional, or charter) and the focus on the final destination of the traveler (e.g., airport closest to the business meeting, vacation home, etc.). The usage of smaller aircraft coupled with the availability of improved CNS technologies will also enable precision approaches to many more airports. Rather then just a hand-full of flights per hour, some of these "bizjet" airports will have almost continuous streams of traffic.

- **Greater Mix of Aircraft Performance:** The performance capabilities of aircraft differ. In future, above Flight Level (FL) 290 there will be aircraft that would prefer to cruise at varying speeds from just over 300 knots to over 500 knots. This does not even consider the possibility of supersonic aircraft which may eventually operate domestically. This mix of desired cruise speeds will present a challenge to planning and control of traffic flows. Today's mechanisms to adjust traffic flows such as mile-in-trail etc. will not be feasible especially for 4D Navigation. Differences in climb capabilities, desired descent profiles as well as CNS capabilities will also present challenges to the future ATM system.

- **Increased Complexity of Collaboration with Operators:** As the number of operators continues to grow, the current mechanism for daily collaboration will need to evolve. As operators of private, fractional, and charter flights contribute increasing percentages of the traffic into congested areas, they will need to be included in collaboration regarding actions to mitigate congestion.

FUTURE CNS/ATM SYSTEM ARCHITECTURE CONCEPTS

The current CNS systems are based on voice communication, ground based navaids and radars. The future seamless CNS services will be provided using a combination of ground based and satellite based capabilities. Current ATM system functions include Traffic Flow Management (TFM) that deals with delaying and rerouting flights due to anticipated congestion at airports or bad weather, and Air Traffic Control (ATC) that keeps aircraft separated from other aircraft, terrain or obstacles. The challenge for the future ATM system will be to dynamically manage all traffic congestion while dealing with a significant amount of unscheduled demand (i.e., demand continually changing over time and space). Table 1 presents the elements of year 2020 CNS/ATM system architecture concepts, including likely changes in the route structure to support 2D, 3D and 4D operations, voice and data communication, precise navigation technologies supporting the desired Required Navigation Performance (RNP) and surveillance provided by data fusion of airborne and radar information. An intermediate architecture for the year 2013 is also presented to illustrate a possible transition path. It is expected that the future concepts will alleviate most ATC restrictions and be able to support uniform separation standards in all weather conditions.

ADS-B:	Automatic Dependent Surveillance-Broadcast
CAT:	Clear Air Turbulence
CDTI:	Cockpit Display of Traffic Information
CRCT:	Collaborative Routing Coordination Tool
DRVSM:	Domestic Reduced Vertical Separation Minimum
ETMS:	Enhanced Traffic Management System
EVS:	Enhanced Vision System
RTA	Required Time of Arrival
TMA:	Traffic Management Advisor
TMC:	Traffic Management Coordinator
URET:	User Request Evaluation Tool
WAAS/LAAS:	Wide/Local Area Augmentation System

Table 1. Elements of 2020 CNS/ATM Systems Architecture Concepts

	2013	2020	Operational Impact
Route Structure	Mostly 2D RNAV	3D with time window	Most aircraft fly 4D, others use speed control
Communications	Data link for routine information and intent VHF for all other comm	Data link for all data/digital voice except time critical communication via voice	Automated data entry and retrieval
Navigation	VOR/DME/ILS with some WAAS/LAAS CAT 1	WAAS/LAAS CAT III with some VOR/DMEs in TRACONS	Extend use of spoke and satellite airports in all weather
Surveillance	RADARs/Limited ADS-B	RADARs/ADS-B	Data fusion
Avionics	DRVSM, FMS with limited CDTI and LNAV/VNAV	WAAS/LAAS, EVS, CDTI, Full VNAV/LNAV with RTA	Make IFR operations as VFR

	2013	2020	Operational Impact
Weather	Downlink winds info	Winds, CAT, Convective wx, top/bottom of clouds, vortex, wind shear	Accurate trajectory prediction and realization
Fleet Mix	Some A/C retire some new added (B7XX, A380, RJs), small business jets	More smaller jets, UAVs	Support future demographic change and demand projections
Operations	Hub/spoke, Regionals, GA	Hub/spoke, spoke/spoke, suburban-direct, intra-city corporate/GA, UAV	Multi-facet aircraft operations
DSS Tools	TMA, URET, ETMS/ CRCT	Fully integrated ATM with Common Database	All users/operators have specific display from same data
Service Providers	TMC, R/D Controllers, Supervisors	Strategic Planners, Tactical Controllers	Reliance on automation for accurate strategic planning
Facilities	ATCSCC, tower, TRACON and ARTCC	National, Regional, Local	Based on seamless CNS

Multi-level CNS Architecture Concept [19]

In order to satisfy continuity of operations, security, safety, and capacity needs, the ground systems are considered to be multi-functional and redundant. For example, the timing for communication systems will be used to generate back up navigation capability. The surveillance service will be provided by a combination of radar, secondary surveillance, and aircraft position reports. Figure 5 illustrates a multi-level CNS architecture concept. The key new technologies are the software radio and a surveillance data network. The software radio and internet networking protocols enable global connectivity independent of the underlying physical channel.

The basic ATM air-ground communication services will be provided via data communications with voice used for real-time, critical, non-routine communication. The communication architecture is based on a global communications grid to maximize the use of internet technology. The global grid architecture is network-centric (i.e., a common global network connects all users who have addresses on the network), extensible (i.e., modular, reconfigurable, and adaptable to technology insertion), and including layered security (i.e., protection matched to perceived threat). New air-ground communication services provided include air-air communications and routing, multicasting, access to strategic ATC information, voice over Internet Protocols (IP), and seamless communication.

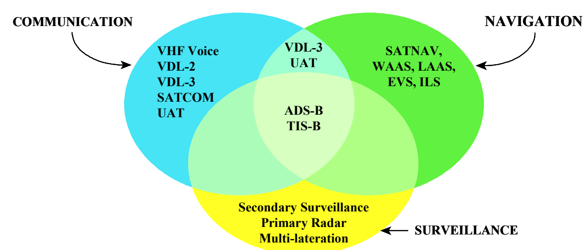

Figure 5. Multi-level CNS Architecture Concept

The navigation and landing service is predominantly provided by augmented GPS and Galileo SATNAV systems. Users desiring all weather operations will equip with an Enhanced Vision System (EVS) to "see" on the airport surface and as an integrity check during the landing operation. Users desiring protection against jamming of SATNAV signals will integrate an Inertial Navigation System (INS) with the SATNAV receiver or derive navigation information from a backup network of navaids.

The surveillance service will be provided by "fusing/integrating" data from all available sources (i.e., automatic aircraft reports, secondary surveillance, multi-lateration of Universal Access Transceiver (UAT) and secondary surveillance signals, and primary radar). The architecture employs a distributed client-server network and establishes connectivity via the planned FAA Telecommunication Infrastructure (FTI). As a minimum, the following surveillance information is generated on each aircraft: ID, 3D position and velocity (both "tracked" and "untracked"), time, aircraft intent, and Quality of Surveillance (QoS). The QoS accounts for the surveillance sources, geometry, accuracy, and integrity. Authorized users/clients select the appropriate information for air situation display, and specialized processing (e.g., conformance monitoring and alerting).

Future ATM System Architecture and Operational Concept [19]

Figure 6 shows a high level transition from the OEP operational environment to the ATM system architecture concept for the year 2020 and beyond. As shown, the CNS systems will evolve into an architecture discussed above. System Wide Information Management (SWIM) will acquire process, store and disseminate latest information on traffic, systems and weather conditions. Because of the communications and surveillance capabilities, the entire airspace except a small airspace (about five miles) around the airport will be managed and controlled by a Regional facility combining the functions performed by current en route Centers and TRACONs. The National facility will manage both routine traffic congestion and weather related flight deviations in near real-time. The Local facilities including the Towers will plan and control in real-time aircraft surface movements and departures/ arrivals.

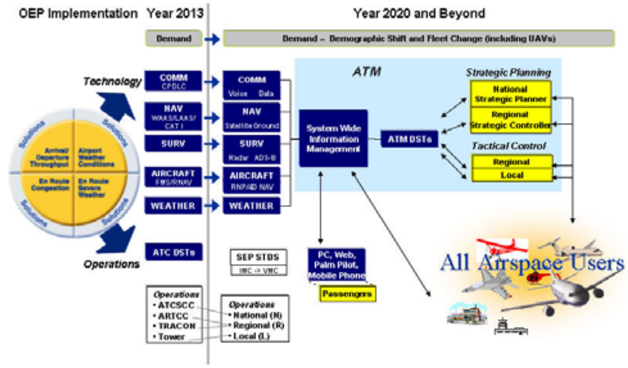

Figure 6. Future ATM System Architecture Concept

In order to deal with aggregate congestion and weather, the strategic planners at the National facility will periodically assess the capacity of all resources in NAS, and identify periods when the projected demand exceeds capacity of NAS resources (airspace/airports). As discussed earlier, the use of satellite airports around major hubs in large metroplex areas and additional spoke airports servicing growing communities will not only add to NAS airport capacity, but also significantly increase flight options. Therefore, the flight operators will have greater control over their flight routes, altitudes and times, as they interact with SWIM to obtain the overall demand/capacity information required to plan their flights as shown in Figure 7. This will allow the operators to collaborate with the ATM system to establish problem-free flight plans (e.g., strategically avoiding significant congestion) from gate-to-gate, thereby maximizing airspace use.

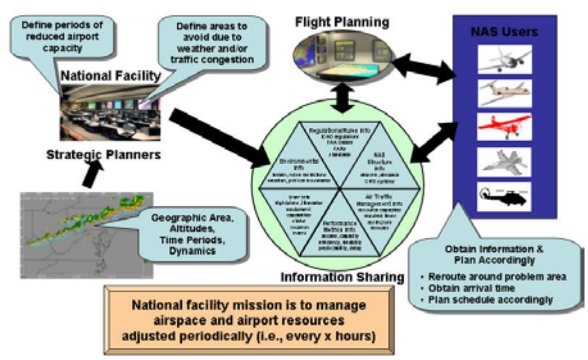

Figure 7. Planning at National Facility

Strategic controllers at a Regional facility will monitor those aircraft assigned to them for problems of a strategic nature. These include situations where flights are not able to follow the agreed plan resulting in one or more flight's trajectory that is not problem-free. The Regional strategic controller may also respond to a situation initiated by a pilot when there is a need to replan the flight's trajectory due to sudden turbulence or aircraft problems but involves no conflict. The strategic controller will monitor the NAS resources assigned to them and will respond to dynamic situations that impact the resource capacity such as severe weather. Also, the strategic controller within a Regional level facility may interact with another strategic controller, within the same facility or within another facility, to coordinate the resolution of the problems that have been identified with one or more flights under the responsibility of the other strategic controller. Consequently, coordination may occur with a strategic controller in another Regional facility when the inter-facility problems occur, as well as coordination may occur with personnel at the National level facility to address predicted regional congestion or other problems that may have an impact beyond the adjacent Regional facilities. By dealing with a number of problems at a strategic level, it is envisioned that this concept will increase responsiveness in dealing with airspace complexity and traffic congestion in the en route airspace thereby alleviating most of the traffic flow restrictions. The consolidated decision-making process by combining the functions of current Traffic Management Coordinators and D controllers will result in reduced decision times. Figure 8 illustrates the concept of interaction among various strategic controllers.

The tactical controllers will be primarily responsible for monitoring the aircraft conformance to the negotiated flight plan and addressing any problems that may arise due to the dynamic nature of the situation. While a tactical controller will continue to work a defined volume of airspace, it is envisioned that the definition of this airspace will be much more flexible than in today's environment. Sector boundaries (including vertical floors and ceilings) will be proactively adjusted to establish a volume of airspace for each sector that balances the workload among tactical controllers within a facility.

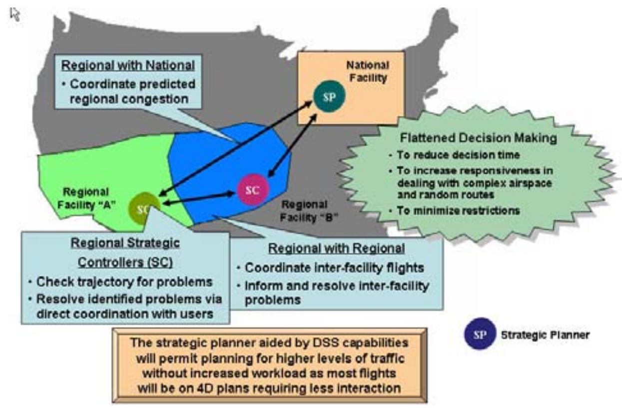

Figure 8. Planning at Regional Facilities, Interaction Between Strategic Controllers

MODELING AND SIMULATION RESULTS

Figure 9 shows the projected number of annual operations at 30 major airports until the year 2020. Historical Aviation Traffic Activity Data System (ATADS) [20] was used to generate demand for the years 1997 to 2002. Demand growth rates based on recent FAA Aerospace Forecasts [18] were used to project annual operations from the year 2003 to 2014.

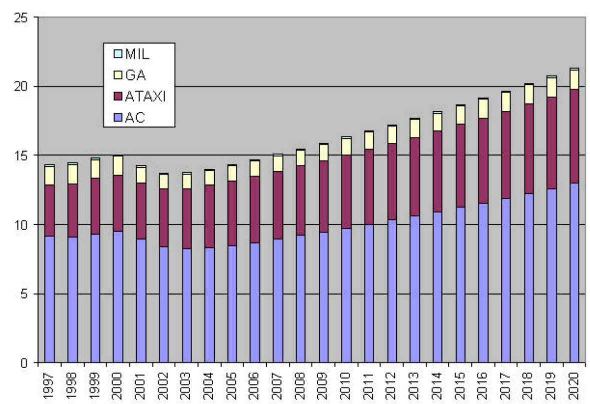

Figure 9. Projected Operations by Service Provisions at 30 Major Airports in Future (in millions)

The year 2014 rate was used and assumed constant for demand predictions from the year 2015 to 2020. These forecasts reflect reduction in demand after 9/11 2001 and strong recovery for high-end GA aircraft. Figure 10 shows the projected number of Air Carrier (AC) and cargo aircraft operating at the 30 major airports. These projections were derived using the unique aircraft tail numbers observed in the Airlines Service Quality Performance (ASQP) data for October 2002, as a baseline. The projected growth over the next 18 years used the FAA Aerospace Forecasts until the year 2014[17]. The 2014 growth rate of 2.9 percent was used and assumed constant for the years beyond 2015. The projections include aircraft retirements and new acquisitions of narrow-body and wide-body jets.

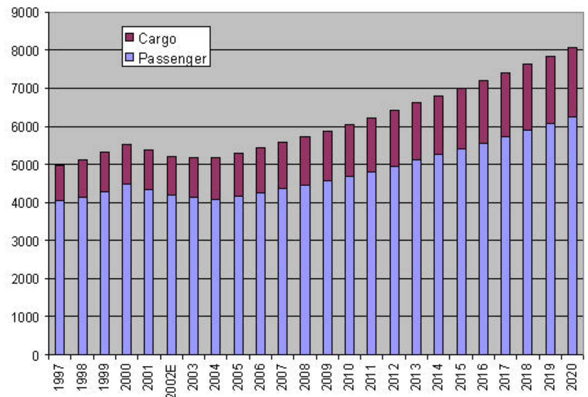

Figure 10. Projected Number of Air Carrier and Cargo Aircraft Using 30 Major Airports in Future

Figures 11 and 12 highlight the corresponding growth in the number of commuter and GA aircraft respectively operating at the above airports. Using these fleet mix and the annual number operations until year 2020, the MITRE/CAASD NAS-wide simulation model was run using current capacities at 30 major airports to measure air and ground delays as shown in Figure 13. Based on the expected improvements in capacity at each of the 30 airports from the OEP upgrades, the figure also show the corresponding reduction in delays. Figure 13 also shows the gradual increase in delays from 2010 to 2020 as the demand grows. Some of the ongoing research activities include modeling the changes in fleet mix and additional capacity provided by 122 spoke and 194 satellite airports to measure the reduction in delays in year 2020. The results are being used for cost/benefits assessment to establish future CNS/ATM system performance goals.

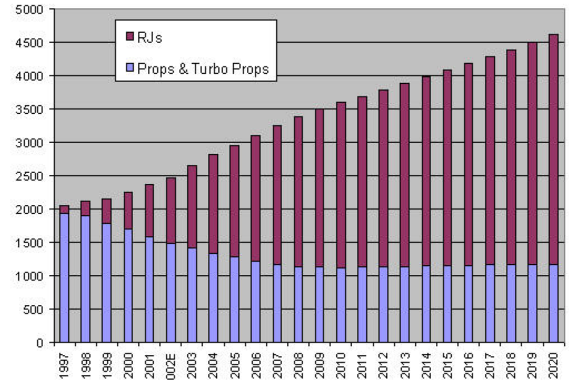

Figure 11. Projected Number of Commuter Aircraft Using 30 Major Airports in Future

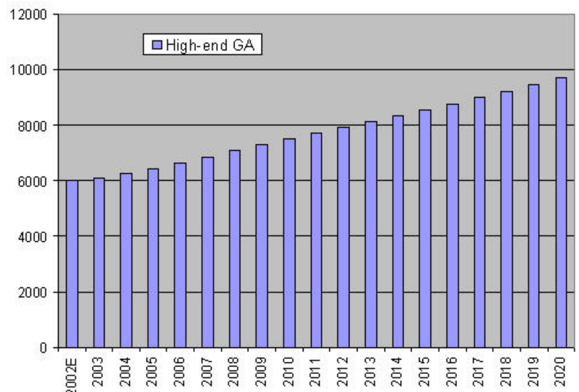

Figure 12. Projected Number of High-end GA Aircraft Using 30 Major Airports in Future

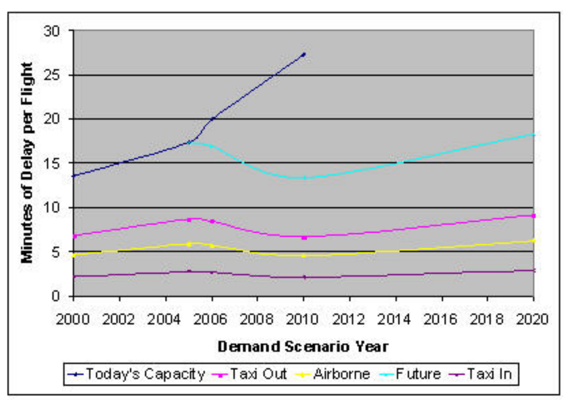

Figure 13. Average Delays per Flight Until Year 2020 (without and with OEP Enhancements)

SUMMARY

The aviation community worldwide has been working for some time to define operational concepts for the future air transportation system beyond the year 2020, and to establish specific performance objectives for future CNS/ATM systems. This paper attempts to integrate some of the ideas explored for the future operational concepts discussed in the literature along with some new ones to develop a realizable vision for the 2020 timeframe. The architecture concepts presented are intended to provide a high degree of flexibility to the users and operators to fly most economically from point-to-point, and equitable distribution of workload among service providers by adjusting airspace boundaries according to demand. Based on the analysis of airport characteristics in the U.S., 488 airports other than the 30 major airports are identified that could relieve potential congestion at major airports and provide more flight options to the flying public. Modeling and simulation results indicate the reduction in delays with planned OEP upgrades until the year 2020, and how the growth in future traffic would affect air and ground delays. Current and further research will determine the impact of the concepts presented, along with the additional airports, on reducing delays. The cost/benefit assessment and overall performance evaluations will help establish viability of the future vision and the architectural concepts for the 2020 timeframe.

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