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Current Airspace Configuration Practices and Their Implications for Future Airspace Concepts

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The Next Generation Air Transportation System (NextGen) envisions a flexible, dynamic airspace structure that is better able to adapt to changing traffic conditions than today's rigid system of airways and airspace sectors. However, to develop effective NextGen airspace concepts, a thorough understanding is needed of current airspace configuration practices, and of the constraints that influence airspace design. This paper describes current-day airspace configuration practices and the factors that affect the partitioning of today's airspace. These observations are based on site visits to air traffic control facilities and subject matter expert critiques of potential future airspace designs. The implications that today's airspace configuration practices have for NextGen airspace concepts are then discussed.

I. Introduction

THE National Airspace System (NAS) is an interconnected system of airports, air traffic facilities, equipment, navigation aids, and airways. The NAS is designed to provide safe and efficient transport of passengers and cargo. A key element in guiding the safe and efficient operation of the NAS is airspace management. Airspace management requires predicting the demand that will be placed on the NAS and its potential capacity. The current NAS architecture is reaching the limits of its ability to accommodate air traffic demand increases. Both the FAA and NASA are studying the safety and efficiency of the NAS at greater throughput levels by looking at system redesign concepts and new technologies to improve air-to-air and air-to-ground communication, situation awareness, and aircraft control. These efforts are responsive to the operational concepts proposed by the Joint Planning and Development Office, which is charged with developing a vision for the 2025 Next Generation Air Transportation System (NextGen). An essential element of this transformation concerns the efficient allocation of airspace as a capacity management technique. The NextGen concept calls for a future system in which daily operations are managed with four-dimensional aircraft trajectories while the airspace structure and controller resources are continually adjusted to meet user needs.[1] NASA is researching the airspace structural adjustments required to manage traffic demands and capacity constraints under its Dynamic Airspace Configuration (DAC) research focus area.

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DAC is a new operational paradigm that proposes to move from the current structured, static airspace to a dynamic airspace capable of adapting to user demand while meeting changing constraints of weather, traffic congestion, complexity, and a highly diverse aircraft fleet.[2] DAC will dynamically allocate both controller resources and airspace structure to meet real-time demand profiles. DAC research consists of three major components: 1) overall organization of the airspace; 2) dynamically changing airspace to meet the demand; and 3) generic airspace characterization. The first component relates to strategic organization of airspace and the creation of new classes of airspace to take advantage of concepts and technologies that are expected to be available by 2025. The second component relates to the dynamic airspace reconfiguration that is needed to accommodate fluctuating demand. The third component relates to generic airspace designs that could promote interchangeability among facilities and controllers by removing structural and functional components of the airspace that would require site-specific training.

II. Motivation

Before introducing new airspace designs within the DAC framework, a comprehensive assessment of current airspace design and reconfiguration practices is warranted to better understand the potential constraints and limitations posed by today's NAS infrastructure. Such an examination provides a better foundation upon which to conceptualize the limitations of the current infrastructure. DAC research can then better devise both air- and ground-based concepts and technologies that will facilitate anticipated future traffic growth in the NextGen environment.

To understand how the NAS can transform from current airspace structures and operational practices to what is envisioned in NextGen, this paper catalogues DAC-relevant airspace components and operations used in the present day. Current airspace reconfiguration practices reveal the limited options in current operations and suggest how sectors and airspace can be reconfigured to address various technological and human factors considerations. DAC envisions the future airspace as substantially more dynamic, changing fluidly with changes in traffic, weather, and resource demands. Understanding the limitations of the current reconfiguration practices is a necessary initial step in the design of effective airspace reconfiguration support tools and operational concepts.

III. Approach

Information on current-day airspace designs and configuration practices was acquired through a combination of literature reviews, air traffic management facility site observations, and discussions with subject matter experts (SMEs), as well as from material presented at a NASA Ames DAC Workshop conducted in February 2007. SMEs were instrumental in providing insights and supplemental information to the literature reviews on airspace redesign and reconfiguration practices. The observed Air Route Traffic Control Center (ARTCC), Terminal Radar Approach Control (TRACON), and Air Traffic Control Tower (ATCT) facilities were chosen for their geographic and operational diversity, and are described below.

A. Cleveland ARTCC (ZOB)

Due to its geographic location, ZOB is responsible for traffic to and from the Chicago, New York, and Washington, DC, metropolitan areas. Thus, a large part of the controllers' tasks is ensuring that restrictions such as miles-in-trail and minutes-in-trail are achieved for flights between these high-traffic airports, as well as for flights departing airports underlying the overhead traffic streams. ZOB is organized into eight *areas*, which each have approximately six *sectors*. ZOB contains low-altitude, high-altitude, super-high, and ultra-high sectors.

B. Jacksonville ARTCC (ZJX)

Major traffic flows in ZJX include arrivals to and departures from Charlotte Douglas Airport (CLT), Orlando International Airport (MCO), Tampa International Airport (TPA), and other southern Florida airports. ZJX also provides services to Hartsfield-Jackson Atlanta International Airport (ATL) arrivals from the southeast. Daily traffic volume is approximately 6,000 – 10,000 flights. Traffic managers reported that the highest volume is during the days near Thanksgiving, and from December through April, with heavy "snowbird" traffic destined to southern Florida from airports in the northeastern United States. ZJX is organized into six areas containing approximately 45 low-altitude, high-altitude, super-high, and ultra-high sectors.

C. Minneapolis ARTCC (ZMP)

Major traffic flows in ZMP consist of arrivals to and departures from Minneapolis-St. Paul International Airport (MSP), as well as some transcontinental traffic. In addition, ZMP contains the western termini for routes through

Canada that are used to offload traffic to and from the northeast United States that would normally transit ZOB. ZMP is organized into six areas, with low-altitude, high-altitude, and super-high sectors.

D. New York TRACON (N90)

Air traffic within N90 airspace is dominated by arrivals to and departures from several major air carrier airports: Newark Liberty International (EWR), LaGuardia (LGA), and John F. Kennedy International (JFK), plus several general aviation airports. The traffic characteristics of each major airport differ markedly: EWR is a hub dominated by a single airline; LGA largely serves domestic flights, and is busy throughout the day; and JFK serves a large number of international and cargo flights, with peak traffic periods in the afternoon and evening. The airspace in N90 is organized into four areas according to the major traffic flows into and out of these airports.

E. Potomac Consolidated TRACON (PCT)

Air traffic within PCT is dominated by arrivals to and departures from several major air carrier airports in the Washington, DC, area: Baltimore-Washington (BWI), Ronald Reagan Washington National (DCA), and Washington Dulles International (IAD). In addition, PCT handles traffic for Richmond International Airport (RIC) and Andrews Air Force Base (ADW). PCT is organized into four areas: Chesapeake (for BWI traffic), Mt. Vernon (for DCA and ADW traffic), James River (for RIC traffic), and Shenandoah (for IAD traffic). All areas handle arrivals, departures, and overflights. Although the areas are organized around major airports, the airport flows are not completely segregated (e.g., a DCA departure may enter the Shenandoah area before being handed off to the Washington ARTCC).

F. San Francisco International Airport ATCT (SFO)

Weather and other disruptive phenomena at SFO frequently induce airport runway configuration changes which, in turn, induce reconfiguration of the surrounding airspace. In particular, during the spring and summer months, SFO often experiences a low-lying marine stratus layer in the morning hours. The marine stratus impairs pilots' abilities to maintain visual contact with aircraft landing on a parallel runway, effectively reducing the runway availability from two runways to one. When the marine stratus is expected to linger through the morning rush hour, traffic specialists at the Air Traffic Control System Command Center (ATCSCC) typically initiate a national ground delay program to balance capacity and demand at SFO.

IV. Current Airspace Configuration Practices

Next, findings from the site visits are presented. Where available, Enhanced Traffic Management System (ETMS) data are provided to support the observations. The findings are organized according to the following airspace configuration processes observed in the field:

- Opening and Closing Sectors
- Dynamic Resectorization
- Special Use Airspace Management
- Airspace Redesign

A. Opening and Closing Sectors

Airspace controlled by an ARTCC is partitioned into several areas, and each area is further divided into sectors. A sector is a fundamental unit of airspace in which one or more controllers have separation responsibility for aircraft. Each sector has a distinct set of communication frequencies and an aircraft passing from one sector to another requires coordination for hand-offs and frequency changes. Due to the current technologies and procedures used to assure traffic separation, the maximum aircraft per sector is limited by the workload that the sector controller(s) can handle, rather than the physical airspace capacity limits.

When traffic volumes drop (e.g., at night), sectors can be combined to reduce the number of controllers necessary to work the airspace. Dynamically combining sectors and splitting these combinations (commonly referred to as "closing" and "opening" sectors, respectively), is a routine daily activity at the observed ARTCCs and TRACONs. Figure 1 shows the frequency of sector combination events by month at selected ARTCCs. At ZJX, for example, approximately 3,000 sector combination actions are performed per month, which translates to about 100 per day.

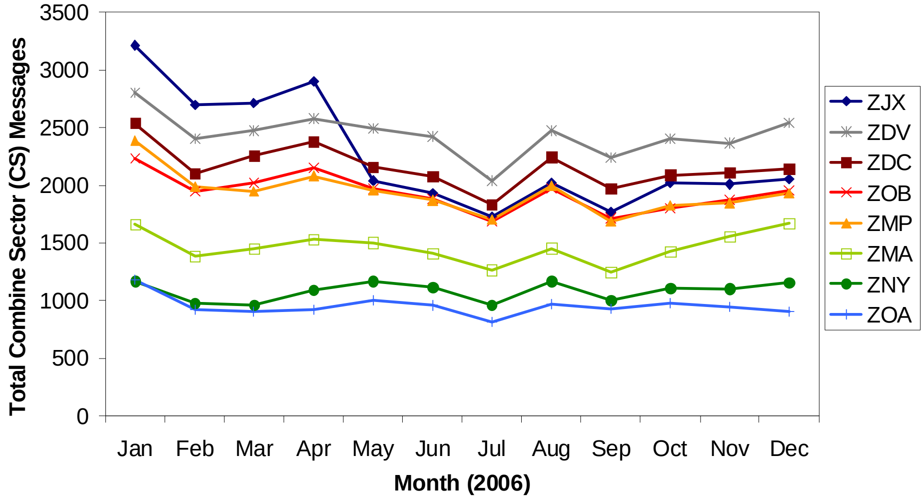

Figure 1. Monthly Sector Combination Events at Selected ARTCCs in 2007.

All sector combining is done within the areas—sectors are never combined across areas. The Area Supervisor has the responsibility to decide when to open and close sectors; adjacent areas have no input in the decision. The decision to open or close a sector is based on such factors as traffic volume (using Monitor Alert Parameter (MAP) values), weather, traffic restrictions imposed by other facilities, equipment outages, reroutes, the proficiency of each sector controller, and the past experience of the supervisor. Controllers usually treat combined sectors as a single volume of airspace when issuing clearances. However, depending on controller proficiency, combined sectors may occasionally be treated as if they were separate sectors, especially if a particular sector combination is not often used. The process of opening or closing a sector only takes minutes to perform. However, to avoid confusion over communication frequencies, sector openings and closures are typically kept in place for a minimum of one hour if possible. Both vertical sector combinations (e.g., combining a high-altitude sector with a super-high sector), and lateral combinations (e.g., combining two high-altitude sectors) are used regularly.

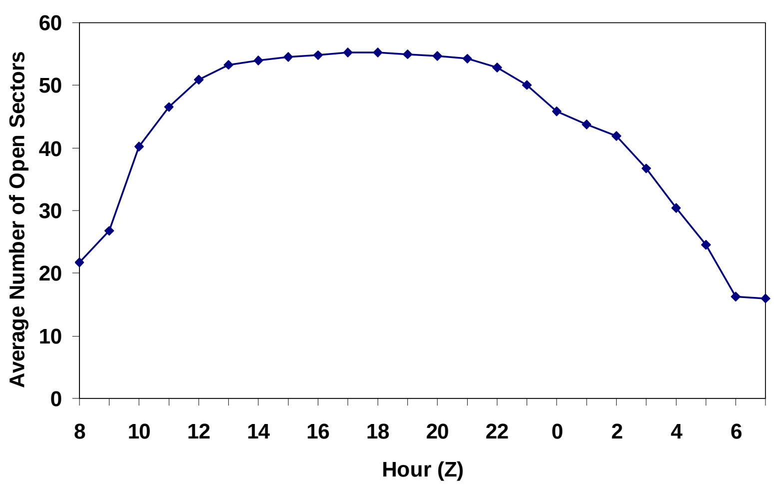

Figure 2. Average Number of Open Sectors per hour in ZJX during July, 2007.

Many sector openings and closings follow a predictable daily pattern, based on known traffic variations. Figure 2 shows the average number of open sectors in ZJX, by hour, during July 2007.

B. Dynamic Resectorization

Dynamic resectorization refers to changes in sector boundaries that occur on a daily (or more frequent) basis, involving sub-sections of sectors, rather than opening and closing entire sectors with fixed boundaries.

1. TRACON Resectorization within Areas

At the TRACON facilities observed (N90 and PCT), dynamic resectorization within areas—in which the sector boundaries within an area change, but the overall area boundaries remain constant—is a common daily occurrence, and is tied to runway configuration changes at the major airports within each TRACON. Each airport configuration has a corresponding sector configuration. Two such configurations for the PCT Flatrock sector near RIC airport are shown in Figure 3.

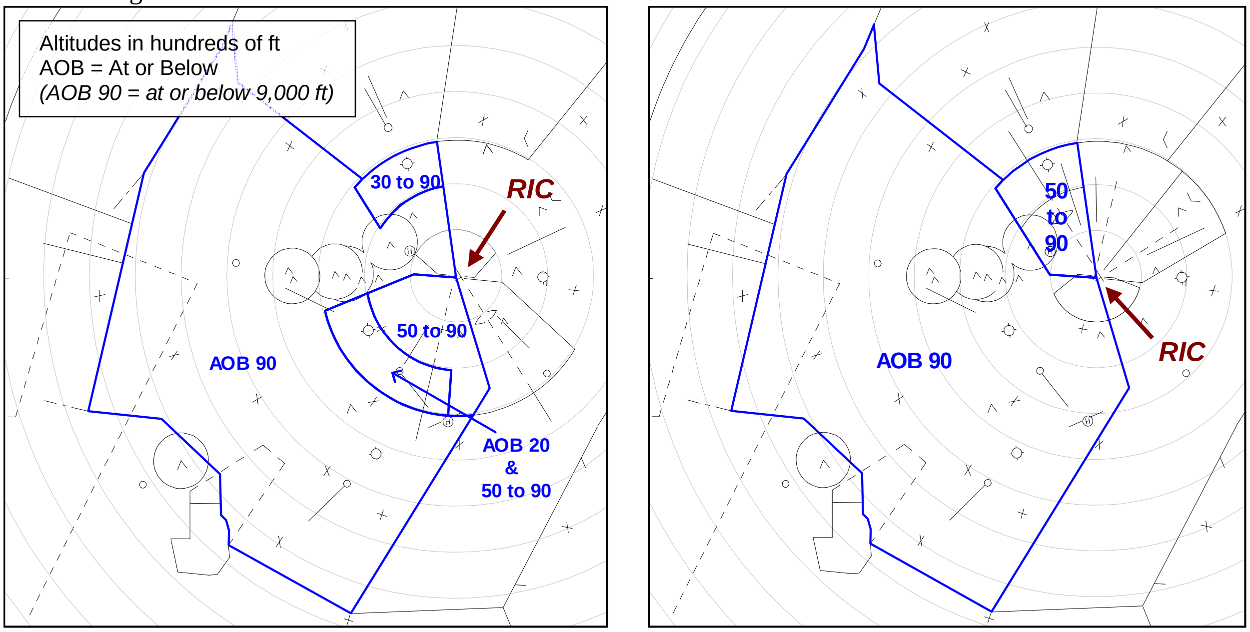

Figure 3. PCT Flatrock Sector Geometry, for RIC North Operation (left) and RIC South Operation (right).

The most frequent driver of airport reconfiguration is a change in wind speed/direction or runway conditions (wet or dry). At SFO, guidelines for choosing a configuration include a dry runway maximum crosswind component of 20 kt, reduced to 15 kt for wet runways; maximum tailwind components are 10 kt for dry runways, and 3 kt for wet runways. Other factors influencing runway configuration include:

- Low Ceiling/Visibility: every approach procedure requires particular ceiling and visibility minima; low ceilings/visibility may require dependent or single-runway arrival operations when parallel runway centerlines are less than 4,300 ft apart (the minimum spacing for independent parallel approaches using standard radar separation[3]).
- Demand Variations: during periods of high departure or arrival demand, a configuration with high departure or arrival capacity may be selected.
- Maintenance: runway or taxiway maintenance may prevent use of certain configurations.
- Special Events: an air show, for example, may block departure or arrival paths.

The party responsible for airport configuration changes (and, thus, dynamic resectorization) varies by facility. At most TRACONs, including PCT, the individual airport ATCTs retain responsibility for choosing the airport runway configuration. At N90, the TRACON Traffic Management Unit (TMU) has final decision authority for airport configuration changes, for two reasons. First, it allows the TRACON to tradeoff delay impacts among airports in order to better achieve system-wide goals. Second, the proximity of the N90 airports to each other necessitates that airport configuration changes be coordinated among airports.

Coordination of reconfiguration activities is done through teleconferences and pairwise phone calls between affected facilities (ARTCCs, TRACONs, and ATCTs). Traffic managers try to identify traffic gaps of 50 nm or more (or coordinate the configuration change in advance so that a gap can be created) to allow for rerouting of airborne aircraft and departing aircraft still on the ground. Nominally, they seek five to seven minutes of buffer between the last departure to clear the airspace and the first arrival in the new configuration. As the proposed configuration changeover time gets closer, they pick the last arrival to start implementing the plan. The timeline or traffic gap can be adjusted as the configuration time gets closer.

High controller workload in the affected sectors requires careful monitoring. Traffic Management Coordinators (TMCs) at the TRACON and ARTCC ensure that the last aircraft arriving and departing on the original configuration are out of the sectors, then change the controller radar displays and start taking aircraft under the new configuration. If the sectors cannot be cleared of traffic, TMCs need to coordinate with controllers to vector or hold the aircraft during the interim. Several TRACON sectors may be affected by airport configuration changes. Area Supervisors need to check with each position to make sure that they are ready for a change. When the controller radar displays change, the sector controllers stay with the "job" instead of the airspace (e.g., departure controller stays with the departures, regardless of the physical sector location).

2. TRACON Resectorization between Areas

Although dynamic resectorization within a TRACON area is a frequent occurrence, dynamic resectorization across TRACON area boundaries is much less common. For example, at PCT, only one instance of dynamic resectorization between areas is employed, as shown in Figure 4; during certain configurations, a 1000 ft shelf of airspace will change hands between the Shenandoah area (responsible for IAD arrivals) and the Mt. Vernon area (responsible for DCA arrivals). Similarly, a single case of dynamic sectorization between areas was observed at N90; during certain configurations, airspace will trade hands between the Newark and La Guardia areas.

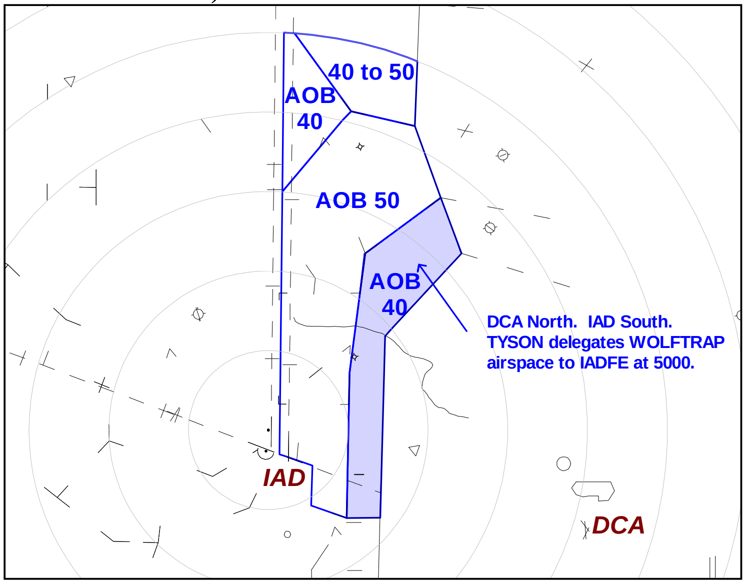

Figure 4. Dynamic Resectorization across Areas in PCT Airspace.

3. ARTCC Resectorization

Dynamic resectorization at ARTCCs is similarly used only in isolated cases. At both ZJX and ZOB, TMCs reported only one instance of dynamic resectorization. At ZOB, a low-altitude sector uses one of two different geometries based on the runway configuration at Detroit. At ZJX, when hazardous weather precludes Orlando arrivals from the east, a small portion of Miami ARTCC airspace is used to vector traffic to the south before turning northwest toward Orlando; this also reduces the number of handoffs between sectors.

4. Point-Outs

One alternative to dynamic sectorization is the use of point-outs. A point-out is used when an aircraft will be in a sector for a short distance or duration. Rather than hand off the traffic to this sector, an adjacent sector will retain responsibility for this aircraft. This prevents the need for two frequency changes in quick succession. It also allows additional flexibility for vectoring and rerouting when hazardous weather is present in a sector. Point-outs are frequently used at both TRACONs and ARTCCs. Point-out coordination may be done in three ways: in person (when the controllers for adjacent sectors are also physically adjacent), by telephone, or via a keyboard entry, which causes a flight's data block to flash on the controller's radar display until the point-out is accepted or rejected.

C. Special Use Airspace Management

Special Use Airspace (SUA) is a volume of airspace reserved for special operations (such as military training or rocket launches) or security restrictions, which precludes or discourages entry by civil aircraft. There are several types of SUA:[4,5]

- Prohibited Area: airspace within which all flight is prohibited for security or other reasons associated with the national welfare (e.g., P-56, which overlies the White House, Capitol, and Naval Observatory in Washington, DC).
- Restricted Area: airspace within which flight is not completely prohibited, but subject to certain restrictions due to operations that may be hazardous to nonparticipating aircraft, such as artillery firing, aerial gunnery, or guided missiles; when active, Instrument Flight Rules (IFR) traffic is not cleared into Restricted Areas, but Visual Flight Rules (VFR) traffic may enter at their own risk.
- Warning Area: airspace that extends from 3 nm outward from the coast of the United States that contains activity that may be hazardous to nonparticipating aircraft; when active, IFR traffic is not cleared into Warning Areas, but VFR traffic may enter at their own risk.
- Military Operations Area: airspace established to separate military training activities from IFR traffic; when active, IFR traffic may still be cleared through a Military Operations Area if IFR separation can be provided.
- Alert Area: airspace established to inform nonparticipating pilots of areas that may contain a high volume of pilot training or unusual aerial activity; all traffic may enter Alert Areas, but should maintain increased vigilance for other traffic.

- Controlled Firing Area: airspace established for activities which, if not conducted in a controlled environment, could be hazardous to nonparticipating aircraft; activities within a Controlled Firing Area are suspended whenever a nonparticipating aircraft approaches the area (determined via spotters or radar).
- Military Training Route: routes which have no reserved airspace, but are charted to indicate the presence of high-speed, low-altitude military training; all traffic may operate in the vicinity of Military Training Routes, but should maintain increased vigilance for other traffic.
- National Security Area: airspace over ground facilities requiring increased security; pilots are requested to voluntarily avoid National Security Areas.
- Temporary Flight Restriction: airspace established to temporarily restrict all or some types of flight; reasons for establishing Temporary Flight Restrictions include Presidential movements, disaster recovery, and major sporting events.

The effects of SUA and the methods for managing SUA vary considerably among the observed facilities. For example, only one SUA is located in N90, a Restricted Area that extends to 5000 ft over the United States Military Academy at West Point; it was reported that this SUA never impacts N90 operations.

In contrast, SUA significantly affects operations in ZJX. Offshore warning areas are located over both the Atlantic Ocean and the Gulf of Mexico. The areas are usually active during the daytime hours, and are controlled by the United States Navy. Due to these warning areas, and the geography of the southeastern United States, a "funnel" effect is created, in which traffic to and from southern Florida is restricted to a narrow band of airspace over the Florida peninsula. This geometry, shown in Figure 5, significantly impacts the ability of ZJX to vector aircraft laterally when weather or traffic congestion is present. At ZJX, personnel have negotiated with the military a set of "corridors" through the warning areas that are safe to fly through. These corridors can be released (i.e., made usable) procedurally. The corridors are not part of the ARTCC flight data processor logic, but they can be drawn on the controller displays and saved so that the outline of their locations can be shown visually whenever the corridors are used.

ZOB personnel indicated that several SUA are active each day in their airspace, and that these can have an impact during high-traffic periods. However, unlike the warning areas in ZJX, ZOB has authority to approve or disapprove SUA activity in their airspace (although they rarely deny a SUA request). Active SUA in ZOB may also affect national flow planning at the ATCSCC, precluding the use of certain commonly-used reroute options.

At the ARTCCs observed, SUA coordination is performed in the TMU by the Military Operations Specialist. Updates to SUA schedules can be provided by the military electronically, or via phone or fax. This scheduling is usually arranged a few hours in advance, although schedules for some SUA are made available weeks in advance. Approximately 30 minutes before SUA becomes active, a flight strip indicating the SUA schedule will be printed at each affected sector, and a message will appear on the controllers' radar displays immediately before the SUA is activated.

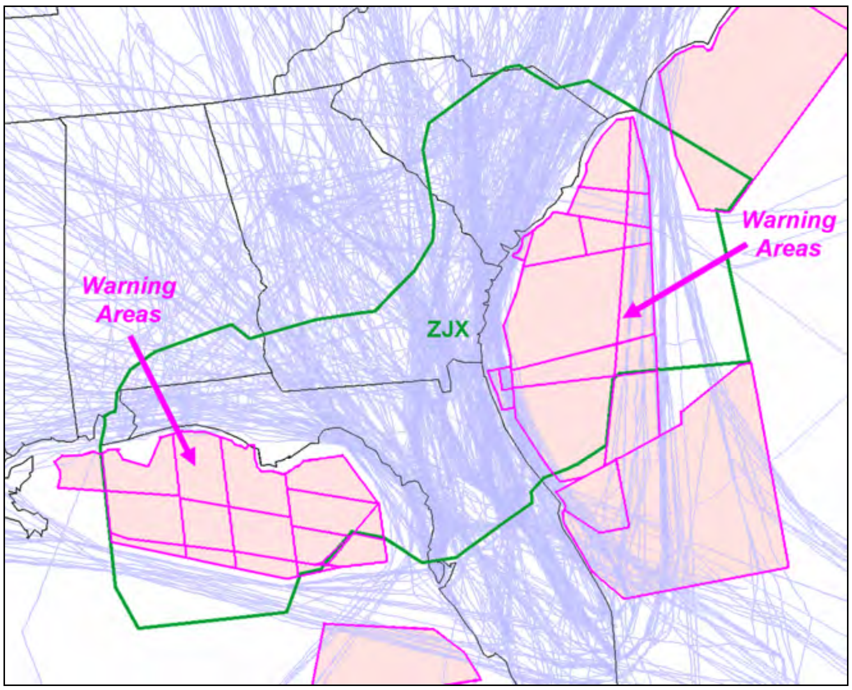

Figure 5. SUA Warning Areas and Flight Tracks in ZJX Airspace.

D. Airspace Redesign

The airspace reconfigurations that have been discussed thus far all happen on a day-to-day basis. In this section, longer-term airspace reconfigurations, such as permanent changes to sector boundaries and route locations, are discussed.

Airspace redesign efforts vary in scope. Minor changes, such as modifications to a Coded Departure Route, can be performed within a single 56-day aeronautical chart update cycle. However, even small airspace boundary changes may require months to years to accomplish. The process for making small route and airspace boundary changes is very collaborative, with a committee of controllers, supervisors, and airspace specialists typically performing "what-if" analyses on airspace design alternatives, in order to evaluate metrics such as conflict probabilities and traffic densities. Candidate designs are then tested with pseudopilots to uncover any potential problems. Each observed facility had in-house capabilities for analyzing airspace modifications. In contrast to these relatively simple design changes, large-scale airspace redesigns require significantly more time and resources to accomplish. Examples of large-scale redesigns are discussed next.

1. Large-Scale Redesign

Two noteworthy recent airspace redesign activities are the High Altitude Redesign (HAR) and the Big Airspace (BA) concept.[6,7] Both activities were FAA initiatives under National Airspace Redesign (NAR) to review, redesign, and restructure the NAS. NAR encompasses both domestic and oceanic airspace, and its overall goals are to decrease delays, improve efficiency, and increase flexibility and predictability for the end users while balancing the access needs of all users and maintaining a high level of system safety.

The BA concept envisioned a merger of existing ARTCC and TRACON facilities in the New York metropolitan area to streamline traffic by reallocating facility rules and redesigning airspace. This concept proposed expanding the use of TRACON separation standards (3 nm lateral separation and current minima for diverging courses) to at least 100 nm from the primary airport and up to flight level (FL) 270, as well as extending visual separation standards above 18,000 ft. This airspace merger concept has since been considered for other major metropolitan areas, such as Atlanta, Baltimore/Washington, Central Florida, Chicago, Northern California, Philadelphia, and Southern California.

The BA concept suggested that an integration of ARTCC and TRACON sectors to strategically control arrivals and departures would reduce the overhead of traffic control and management. Analysis showed that, under high demand or complex traffic situations, the amount of routine coordination events (e.g., transfer of communication/control) were reduced; these reductions seemed to be due to better situation awareness on the part of controllers due to the co-location of controllers who were managing traffic in adjacent airspace, a better design of the airspace, and the timely and accurate transmission of traffic conditions, which in turn contributed to better situation awareness. It was unclear from the study if these benefits would be mostly due to the co-location of the controllers or a better airspace design. This distinction will be important in a NextGen environment, in which physical proximity of air traffic service providers, or the need for it, is not yet determined.

The HAR project was established in 2000 to improve en route airspace capacity and flexibility by introducing new airspace structures in the high altitude en route airspace that take advantage of new technologies to maximize efficiency and maintain a flexibility of routes. The HAR approach to modernizing the NAS is to gradually migrate from constrained, ground-based navigation to a more flexible, Area Navigation (RNAV)-based system. The HAR implementation focused on optimizing and redesigning key airports and associated airspace elements to realize potential benefits as soon as possible while redesigning the national airspace in parallel to ensure that the necessary infrastructure was in place for the future.

One of the main objectives of HAR was to balance flexibility and structure to obtain maximum system efficiency. To achieve this goal, HAR introduced new routes called Q-routes, around merge points and other traffic congestion points. In airspace with enough capacity, HAR allowed user-preferred, non-restrictive routing (NRR)—point-to-point navigation facilitated by new route structures.

Q-routes are RNAV Required Navigation Performance routes that can be placed anywhere, independent of ground-based navigation aids (e.g., VORs). The current jet routes connect from VOR to VOR, thereby inadvertently creating routes that cross and converge, resulting in conflict points between routes. Q-routes, if properly designed, can significantly reduce conflict points through the use of parallel routes with minimal flow crossings. Since Q-routes can be constructed independent of navigation aid locations, additional routes can be added in previously unused airspace, thereby potentially increasing capacity and creating greater efficiencies in traffic flows.

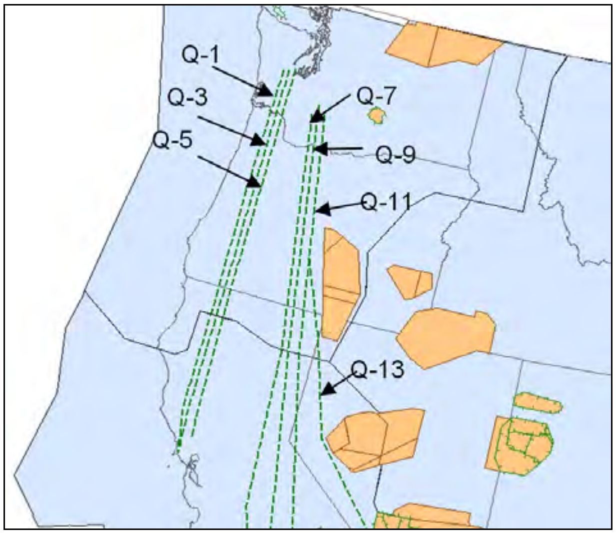

Figure 6. Q-routes in the Pacific Northwest.

Q-routes serve different functions for different regions. For example, as shown in Figure 6, Q-routes in the Pacific Northwest provide three parallel tracks to the San Francisco Bay Area to separate the traffic for the San Francisco, Oakland, and San Jose airports, so that weather-related delays at one airport do not affect the other traffic. In contrast, Albuquerque ARTCC has a large amount of SUA in their airspace; Q-routes there are primarily designed to "thread" between SUA that currently blocks most jet routes, and therefore requires flight plans with excessive deviations. In the Gulf of Mexico, Q-routes are being used as a direct passage between Texas and Florida, where there are no existing jet routes, providing more efficient paths that also relieve traffic congestion. ZJX regularly controls traffic on Q-routes over the Gulf of Mexico and analogous routes over the Atlantic Ocean called "AR routes."

Boetig, Borowski, and Wendling[8] evaluated Q-routes at Oakland ARTCC. Q-routes were rated by the controller participants as highly acceptable (M = 9.2 on a 10-point scale) on a modified Controller Acceptance Rating Scale.[9] The average rating was in the category of "safe, manageable, satisfactory without improvement and with negligible deficiencies." The controller participants also responded to workability questions related to the overall effect of the HAR design. When they were asked about their assessments of HAR design elements, they responded that NRR and Q-routes in general were not significant changes from current operations.

NRR is an enhanced version of the North American Route Program (NRP) that began in the mid-1990s.[10] NRP allows the user to file preferred routing using ground-based navigation aids to give more flexibility in flight planning above FL290, and is identified by "NRP" in the remarks section of the filed flight plan. Controllers leave NRP flights on their filed routes and flight levels unless changes are needed for weather, traffic, or other tactical reasons.

A discussion with a HAR SME provided insight into the rationale for creating NRR, which is similar to NRP. The SME stated that NRP had only limited success in spite of its inherent route flexibility. Aircraft were often taken off NRP routes for one reason or another, so airlines stopped requesting them. The SME stated that the number of aircraft that fly NRP is currently lower than during the earlier years of its implementation. One problem contributing to its lack of use was a lack of clarity about suitable routing in congested terminal areas, creating problems for controllers. Thus, many of the NRP-filed aircraft were taken off their routes due to incompatible entry and exit points near departure and arrival routes. NRR addressed this by adding a concept for using "pitch" and "catch" waypoints to facilitate exit from and entry into congested terminal areas.

Pitch and catch points are used to link the user preferred routes to structures at the beginning and end of a filed NRR flight plan. They are NAS waypoints located at or near common top-of-climb and top-of-descent points, often at the transition points for standard departure and arrival routes. Pitch and catch points are listed in Airport/Facility Directories, and since they are part of the NAS database, they can also be used for NRP routes. NRR flight plans include a different flag in the remarks section: "HAR" or "PTP." NRR routes require one fix per ARTCC traversed. Figure 7 illustrates a possible NRR routing from Newark to San Francisco.

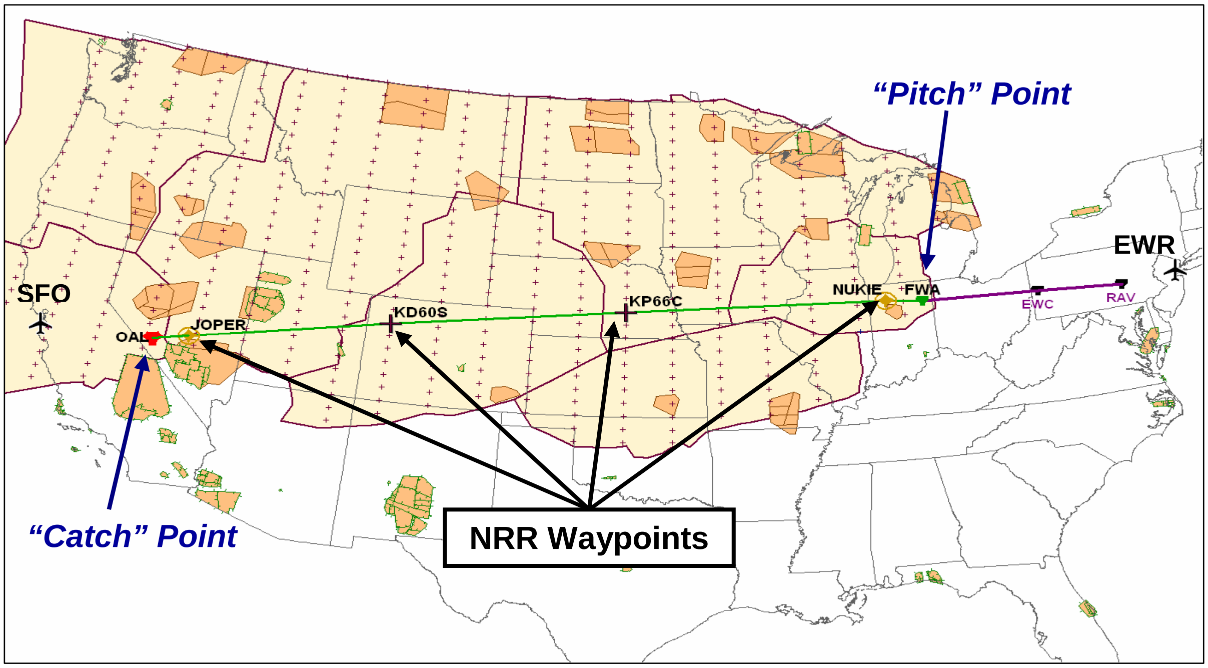

Figure 7. Non-Restrictive Routing from Newark to San Francisco.

2. Redesign Issues

Although increased traffic throughput, higher efficiency, and/or lower workload are usually the primary aims of airspace redesign, a number of other factors must be considered. These other factors can significantly increase the duration and difficulty of the redesign process. Even small airspace boundary changes may require months to years to accomplish. One ARTCC reported that it required one year of negotiations to transfer six miles of airspace from an adjacent facility in order to eliminate the need for point-outs for arrivals on a particular route. Larger airspace redesign projects, such as the New York/New Jersey/Philadelphia Metropolitan Area Airspace Redesign[11], which recently published a Record of Decision for a new airspace design, can take years to finish.

A communications frequency analysis must be conducted when sector boundaries change, in order to assure that adequate signal coverage exists (primarily for low-altitude sectors, where line-of-sight issues must be considered for Very High Frequency communications) and that frequencies do not overlap. For redesigns of low-altitude sectors and TRACON airspace especially, radar coverage must also be considered.

Environmental considerations are also a factor in airspace redesigns. For any redesign of airspace below 10,000 ft, an environmental assessment must be completed. The required level of assessment can take three forms, the most detailed of which is an Environmental Impact Statement (EIS), which requires public participation. To illustrate the effort necessary to complete the environmental analyses required for an airspace redesign project, consider the New York/New Jersey/Philadelphia Metropolitan Area Airspace Redesign. On January 22, 2001, a Notice of Intent was published to inform the public that an EIS would be prepared.[12] Almost seven years later, on September 5, 2007, a Record of Decision was finally released, describing the chosen airspace design.[13]

One consequence of the long durations required to complete airspace redesigns is that the airspace often cannot adequately react to shifts in air traffic service patterns. For example, personnel at one TRACON facility stated that they never fully "caught up" to a new airline that significantly increased flights at one airport during the one and one-half years they were in operation.

3. Sector Design Issues

A significant body of research has been focused on redesigning sector boundaries.[14-18] These tend to be "clean slate" approaches, as opposed to modifying boundaries of the existing sectors or performing highly dynamic resectorization to support a traffic flow management initiative.[19] Both on site visits and during a DAC workshop conducted at NASA Ames in February 2007, constraints and considerations for sector design were gathered from controllers. The findings can be summarized as follows.

- Regional Boundaries: Sector boundaries should not be constrained by regional or local boundaries within the NAS. Currently, sectors cannot span or be merged across ARTCC boundaries, which exist largely for historical reasons. From a purely sectorization perspective, these facility boundaries should be ignored, eliminated, or reset.

- Flow and Flight Profile Alignment: Sector boundaries should be a function of flight profiles and trajectories. To the extent possible, sector boundaries should facilitate coordination and promote overall system flexibility to support user preferred trajectories. To reduce workload in the form of handoffs, today's sectors tend to be aligned with flows, but these can change over time, both in the short run and the long run. Also, sector designs should afford optimum flight profile procedures that enable flights to reach desired altitudes, optimum speeds, and climb/descent rates without interruption for operational or organizational air traffic control reasons.
- Buffered Intersections: Sector boundaries should not be located in proximity to major conflict points, in order to prevent the need for excessive coordination. This requires intersections be kept well within sector interiors.
- Air Traffic Control Functions: Sector dimensions should be designed to accommodate such air traffic control functions as radar vectoring, offset routes, or additional procedures that are deemed necessary.
- Built-in Holding Areas: Sector design should address the establishment of holding patterns without requiring coordination with other sectors or facilities. This will maintain a reservoir of available aircraft for the approach control facility.
- Varying Aircraft Performance: Sectors and routes should be designed to take into consideration a mix of aircraft with different performance characteristics.
- Sector Geometry: Current sector sizes are generally acceptable to controllers, and can be effectively altered by splitting or merging sectors. The geometry of a sector boundary can be suboptimal in several ways. A repeated concern of controllers was traffic crossing at a corner point of a sector; they would prefer that traffic cross the boundary orthogonally. Sectors with acute angles are generally undesirable, as they leave little room to resolve conflicts and tend to generate point-outs. Similarly, unusually thin sectors (e.g., less than 5 minutes of transit time) leave little time for conflict resolution or vectoring.

V. Conclusions and Implications for NextGen Airspace Concepts

The ability to dynamically configure airspace is currently limited, constrained largely by the need for environmental and safety analysis, surveillance and communications coverage, and human factors. At ARTCCs, such reconfiguration largely consists of combining or separating entire sectors. At TRACONs, sector geometries change often, but are chosen from a pre-defined set, based on airport configurations. Human factors considerations greatly influence current airspace configuration practices. Pre-defined sets of configurations are used partly because each configuration requires additional controller training on traffic flows, coordination procedures, and communication frequencies. If the current paradigm of human-performed aircraft separation is retained, NextGen airspace concepts must address these human factors issues.

In addition to traffic flow efficiency, a number of other assessments are currently required to determine the desirability and feasibility of an airspace configuration, such as surveillance and communications coverage, and environmental impacts. Research into NextGen airspace concepts should address the automation of these assessments in order to reduce the lead time required to develop a new airspace configuration. This would allow airspace designers to better respond to the dynamics of the air transportation system (e.g., a new entrant airline).

Airspace redesign and/or reconfiguration will often be driven by the need for new routes due to various factors, such as weather, runway maintenance requirements, or demand variations. Airspace configurations, and the criteria for a "good" airspace design, are driven primarily by traffic flows. In turn, traffic flows in the TRACON airspace are driven primarily by airport runway configurations. This is entirely appropriate, as the basic premise of DAC is to make the airspace better conform to changing needs of airspace users. However, a common finding during the air traffic control facility site visits was that the timing of any airspace changes must be considered as carefully as the change itself. Airspace changes must generally occur during a lull in the traffic demand, as controllers cannot accept boundary or procedural changes at times of high workload. This is a rather large constraint, as it could limit dynamic airspace changes to once or twice per day. Automation and technology will be needed to ease transitions if more frequent changes are required. This suggests that dynamic airspace configuration for NextGen may consist of a set of proven stock airspace configurations. This has the advantage that supporting analyses and studies would have the lead time they need and that controllers could be adequately trained.

DAC concepts that on the surface seem very futuristic are often being performed today, albeit on a small scale. For instance, the notion of multi-lane highways in the sky that do not require strict adherence to existing jet routes has received considerable attention in the research community.[20,21] Q-routes fit exactly this description and are being flown today. NextGen research will consider expanding this concept into a network of tube-like structures with dynamic opening and closing procedures. Though high-performance aircraft are generally the intended beneficiaries of such structures, ZJX personnel suggested that slow-moving, rather than fast-moving, traffic might be forced into a concentrated flow, as they have experienced a significant increase in the number of air taxi operators flying such aircraft.

As another example of DAC-like concepts being performed today, sector merging and splitting was found to be a daily and well-established practice, though sub-sector boundaries remain fixed. SUA management is also handled dynamically in the sense that airspace is opened and closed as needed, but at the timing, duration, and convenience of those reserving the airspace, rather than those being displaced by it. SUA management would benefit from a more dynamic, collaborative process that minimizes inconvenience to non-SUA traffic.[22] Also, the ZJX creation of corridors through SUA suggests greater utilization of SUA is feasible, possibly dynamically over time.

In near to mid-term future operations, there may be new categories of operational airspaces, such as high altitude airspace and super density metroplex operations airspace, which may replace current classes of airspace. More likely, these new airspace classes may overlay on top of the existing airspace classes. As described above, the FAA has already taken some initiatives to implement airspace concepts and the necessary changes to airspace components to facilitate an evolutionary implementation towards NextGen operations. The proposed airspace components and redesign efforts have many parallels with DAC research in both their purpose and the associated constraints in their implementation, except that they are designed for a near-term time frame with fewer equipage and system requirements than assumed in DAC research. Understanding these efforts provides significant insights into designing DAC related airspace components and potential challenges in their implementation.

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