7th AIAA Aviation Technology, Integration and Operations Conference (ATIO)
18-20 September 2007, Belfast, United Kingdom

7th AIAA Aviation Technology, Integration and Operations Conference (ATIO)
18th-20 September 2007, Belfast, Northern Ireland

AIAA 2007-7764

"Airspace Playbook": Dynamic Airspace Reallocation Coordinated with the National Severe Weather Playbook

Alexander Klein[1]

Air Traffic Analysis, Inc., Fairfax, VA, 22031

Parimal Kopardekar[2]

NASA Ames Research Center, Moffett Field, CA, 94035

Mark D. Rodgers[3] and Hong Kaing[4]

CSSI, Inc., Washington, DC, 20024

The Airspace Playbook is a set of airspace configuration scenarios that augment the National Severe Weather Playbook rerouting scenarios. Each rerouting "play" would be accompanied with a candidate dynamic airspace reconfiguration. Typically, this would involve adjustments of sector boundaries in increments of existing sector components. Occasionally, these reconfigurations may combine two or more sectors into larger sectors or form dedicated smaller sectors to handle specific flows. The Airspace Playbook concept was examined using the distribution of the average sector occupancy counts during good-weather days and during weather-impacted days when specific rerouting "plays" were used. The sector occupancy count metric is used as an initial proxy for sector workload. Accordingly, airspace re-sectorization "plays" that accompany the rerouting "plays" are developed. The study shows that applying these dynamic sector boundary adjustments that complement reroutes can produce more evenly distributed occupancy counts in affected sectors and also lower their peak traffic load, an indicator of improved workload distribution.

I. Introduction

CURRENT airspace does not change as a result of modifications in aircraft flows due to severe weather. However, these flow modifications often change the number of aircraft operating in certain portions of the airspace. At times, these new flows create a demand-capacity imbalance in some sectors. Such imbalances may be addressed through Traffic Flow Management (TFM) restrictions such as metering and ground delays, although these restrictions decrease the efficiency of operations. Over the years, through field observations and discussions with subject matter experts, it has often been suggested that changes in flows due to severe weather should be tied to corresponding airspace changes.

For example, in current operations, reroutes are implemented as a result of severe weather situations. A battery of reroutes is available based on the changes in the weather; this set of reroutes is detailed in the National Severe Weather Playbook (NSWP). While creating these reroutes no attention is directed at the potential impact of traffic on the airspace where the aircraft are rerouted, therefore an additional demand-capacity imbalance is created in certain parts of the airspace. Traffic demand in some sectors may be higher than their capacity as set by the Monitor Alert Parameter (MAP), so that additional traffic flow management restrictions may need to be implemented; this reduces efficiency and increases delays. In other sectors the demand may be much lower than their MAP values; this creates additional

---

[1] Principal/Owner, 3802 Ridgelea Drive, Fairfax, VA 22031 – AIAA Member.

[2] Associate Principal Investigator, Automation Concepts Branch, Mail Stop 210-10, Moffett Field, CA 94035– AIAA Senior Member.

[3] Chief Technical Officer, 400 Virginia Ave. SW, Washington DC, 20024 – AIAA Member.

[4] Analyst, 400 Virginia Ave. SW, Washington DC, 20024.

inefficiencies. Therefore, the study reported in this paper focuses on the resectorization problem tied directly to the changes in the flows resulting from severe weather.

A number of researchers have been developing concepts and algorithms for dynamic resectorization or airspace adjustments as a result of changing traffic demand.[1,2] These studies primarily propose limited adjustments to sector boundaries as a result of varying traffic demand. However, the concepts presented in these papers do not indicate when the airspace should be adjusted. In this paper, airspace changes are specifically tied to changes in aircraft flows that occur when aircraft are rerouted due to severe weather.

In order to reduce the over-demand or under-demand situations that result from the implementation of a NSWP reroute, it is proposed that the airspace configuration be changed to provide as much capacity-demand balance as possible. This concept of relating the NSWP routes to airspace changes is called the Airspace Playbook. According to this concept, a set of predefined airspace resectorization configurations would be added to accompany the NSWP to increase efficiency. These proposed pre-defined airspace configurations ("airspace plays") would address most of the typical severe weather/congestion patterns in the affected parts of the National Airspace System (NAS). Dynamic adjustments would be made to an initial airspace configuration according to a specific weather/traffic flow situation forecast. The airspace can thus be reconfigured on demand so as to minimize increased workload and maximize traffic throughput.

This paper is organized as follows:

- Section II provides background related to the current state of airspace sectorization and its limitations, as well as efforts within the research community aimed at overcoming these limitations and increasing airspace flexibility.

- Section III outlines the Airspace Playbook concept and discusses its relationship with other Traffic Management Initiatives (TMIs), as well as describes the technical approach for building an Airspace Playbook.

- Section IV applies this approach to specific days and sectors to illustrate how dynamic re-sectorization can reduce peaks (overload) in occupancy counts in weather-impacted sectors.

II. Background

The NSWP is implemented at the FAA ATC System Command Center (ATCSCC). It contains a pre-defined set of alternative routes for cases when severe weather blocks certain portions of the NAS. These "plays" or scenarios are agreed upon between the NAS stakeholders and are available on the ATCSCC website, as well as electronically in a database, thereby providing airspace management procedures for inclement weather that are simplified and streamlined. Instead of always devising case-specific reroutes, airspace users, traffic flow managers and air traffic controllers can simply refer to the "play" appropriate for each case and use it as a common reference point for developing reroutes.

A key functionality in managing capacity is dynamic airspace configuration. Currently, it is limited to sectors within a controllers specific "Area-of-Specialization" (usually a group of 4-6 sectors) that can be combined and de-combined at predefined hours of the day, mostly at shift changes. Occasional airspace adjustments can sometimes be made to accommodate the effects of convective weather systems. However, there is little or no provision for:

- Changing sectorization dynamically or at short notice (to accommodate weather/traffic/spacing patterns);

- Interchanging components of sectors between Areas of Specialization (the minimum "unit" of airspace remains the sector and sector boundaries are redrawn only occasionally in response to long-term changes in historical traffic patterns)[1];

- Interchanging airspace between facilities (i.e., Centers).

Research in the area of dynamic airspace configuration has been ongoing for a number of years. The idea of limited dynamic re-sectorization within a single Area of Specialization was introduced in the mid-90's.[1] A traffic management concept developed for NASA's Advanced Air Transportation Technology (AATT) program, the Constrained Airspace Tool (CAT), included a provision for dynamic airspace resectorization when justified by weather/traffic/spacing conditions.[3]

The FAA examined the impact of inter-facility dynamic re-sectorization on Air Traffic Control Specialists' workload and other factors.[4] The scope of the study was limited to lateral boundary adjustments (in contrast to vertical adjustments which are more challenging to devise) and specific traffic situations that should benefit the most from dynamic re-sectorization, notably a heavy traffic situation and shifting weather patterns. The study showed that the pre-defined regions of airspace that could be reallocated within an Air Route Traffic Control Center (ARTCC) depend on the specific traffic situation. The approach was reinforced in a recent literature review conducted in 2005.[5]

The concept proposed and evaluated in the current study, the Airspace Playbook, builds upon this prior research and takes it a step further. A dynamic airspace reconfiguration solution is developed that is more flexible than the limited re-sectorization discussed above and ties directly to changes in the routes. Therefore, both routes and airspace could be

changed together. This approach is evolutionary and can be considered a bridge toward a much more flexible Dynamic Airspace Configuration in the eventual NGATS end state.

It is important to set the scope of the study in the context of airspace design and NAS evolution. This study introduces an initial dynamic airspace configuration concept that attempts to provide additional capability beyond the current limited dynamic re-sectorization typically used for mid-shift (e.g., 10 pm – 6 am) operations. As a step toward future concepts of making airspace adjustments where needed, this study does not take into account current infrastructure limitations such as radio frequency coverage and controller training considerations. Additional flexibility would be achieved if blocks of airspace belonging to different areas of specialization, or even different Centers, could be exchanged.

III.   Approach

A. The Airspace Playbook Concept

The concept of an Airspace Playbook was first proposed at a Dynamic Airspace Configuration workshop held at NASA Ames. Since the existing NSWP currently does not include standardized airspace adjustments, the Airspace Playbook was proposed as a means to provide a set of predefined airspace re-sectorization scenarios to accompany the NSWP. It would be positioned between two extremes: rigid airspace boundaries or a completely flexible airspace organization that all but disposes of the concept of a "static" or permanent sector. The concept calls for a number of pre-defined airspace configurations ("airspace plays") that would cover most of the typical severe weather/congestion patterns in the appropriate part of the NAS. Dynamic adjustments would be made to an initial airspace configuration according to a specific weather/traffic situation forecast. The airspace can thus be reshaped to minimize any extra workload and maximize traffic throughput. Portions of a Centers' airspace (e.g., complete Sectors or parts of Sectors) can be delegated temporarily to other Centers or sectors when the airspace playbook scenario so demands and if training and frequency considerations are addressed[*].

Each day would begin with an agreed-upon initial configuration. This configuration would be revised every several hours, for instance, every 2 hours (e.g., to coincide with the ATCSCC 2-hour telecon cycle) or perhaps every 4 hours, although more frequent (e.g., hourly) updates are also conceivable. This process would necessarily rely on probabilistic weather and traffic forecast so as to provide proactive rather than reactive airspace management. A quality assurance procedure could review the day's operations post-factum to see if the chosen "plays" were best suited for the situation.

B. Selecting NAS Area to Study

Instead of the entire NAS, the initial focus in this study is on a single ARTCC; specifically, Cleveland Center (ZOB), which is frequently and substantially affected by thunderstorms in the summer and the related shifts in traffic patterns. The area of study is highlighted in Figure 1. The analysis is limited to ZOB high-altitude sectors with the altitude interval of FL230 to FL350. ETMS data, specifically aircraft position reports (i.e., TZ records), for the specific days to be analyzed (see section C) were filtered for this altitude interval.

C. Selecting Days for Analysis

A number of good-weather summer days (reference days) have been selected from the 2006 convective season. An example of such a day is June 13, 2006, where there was very little convective weather in the NAS. As initial indicators of weather impacted scenarios, two bad-weather days, July 19 and August 3, were selected. On these two days, numerous South/West-to-North/East airways were unavailable for parts of the day due to convective weather. All three days are shown in Figure 1.[†] Depending on the location and movement of severe weather areas, traffic can be rerouted in accordance with the NSWP.

---

[*] To a limited extent, this is done today: portions of airspace can occasionally be shared by two different Areas of Specialization within the same ATC Center.

[†] To generate images in the upper part of Figure 1, a fine-resolution hexagonal grid covering the NAS was used for spatial and temporal "binning" of convective weather (i.e., National Convective Weather Detection, NCWD) data. The hexagons, approximately 20 NM in diameter, aggregate data from the smaller 4x4 Km NCWD grid of 5-min convective reports of Level 3 or higher into one-hour time "bins". Hexagons with 10 or more convective report totals for the day are shown in red; brighter red indicates stronger thunderstorm activity (i.e., higher number of convective reports).

On the first of the two weather-impacted days, 07/19 (see Fig. 1b), ZOB experienced overload due to convective weather impacting neighboring airspace (i.e., traffic from the weather-impacted Washington ARTCC, ZOB's neighbor to the south, was rerouted north into ZOB), while on 08/03 (see Fig. 1c), ZOB itself was impacted by convective weather and part of its traffic was rerouted to the south leaving the sector occupancy counts in most ZOB sectors relatively low.
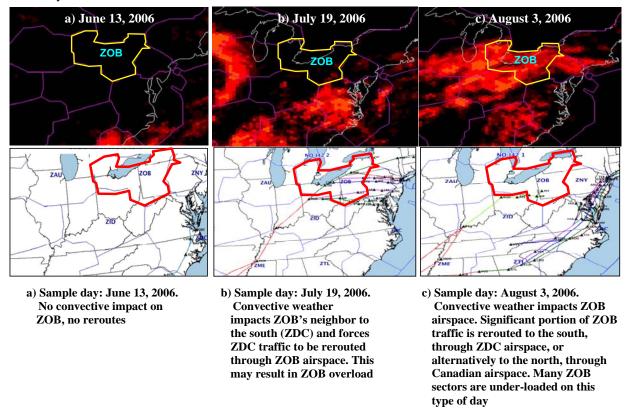

a) Sample day: June 13, 2006. No convective impact on ZOB, no reroutes	b) Sample day: July 19, 2006. Convective weather impacts ZOB's neighbor to the south (ZDC) and forces ZDC traffic to be rerouted through ZOB airspace. This may result in ZOB overload	c) Sample day: August 3, 2006. Convective weather impacts ZOB airspace. Significant portion of ZOB traffic is rerouted to the south, through ZDC airspace, or alternatively to the north, through Canadian airspace. Many ZOB sectors are under-loaded on this type of day

Figure 1. Examples of convective weather and traffic patterns for ZOB (highlighted) on "normal," "overload" and "underload" days

For this study, between 10 and 14 days in each of the three groups was considered. To find days with high convective weather impact, a NAS wide weather index called the Weather Impacted Traffic Index (WITI) was used to quantify the impact of weather and traffic demand on the NAS.[6,7] After analyzing WITI scores for all days of the 2006 convective season, an initial group of about 60 days was identified whose WITI scores were similar to the three reference days' scores. Hour-by-hour animations of convective weather were run for each of those candidate days in order to establish if their weather patterns were sufficiently similar to reference days. The similar days were categorized based on the use of similar or same NSWP routes.

D. Airspace Metrics and Sector Overload / Underload Thresholds

As an initial airspace metric, the Monitor Alert Parameter (MAP) value associated with each sector was selected. MAP values have been established by taking into account the size of the sector (e.g., the larger the sector, the more aircraft it can typically accommodate), as well as the traffic complexity in the sector. In order to establish thresholds for sector overload (or near-overload) and underload, aircraft counts in sectors are examined in relation to MAP values. Figure 2 shows average sector occupancy counts as percentage of MAP value for a set of overload days (for the latter, see Figure 1b).
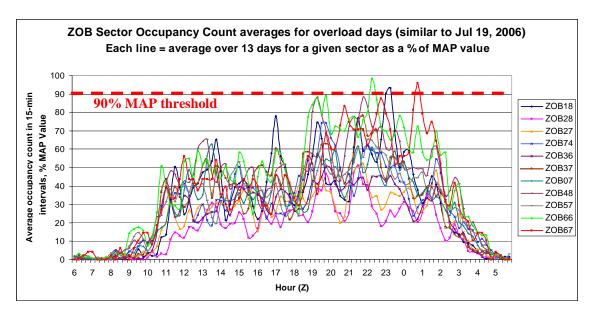
Figure 2. Average ZOB sector occupancy counts for overload days (occupancy counts well in excess of 80% MAP value, exceeding 90% and reaching almost 100% MAP value on some occasions)

Normal sector occupancy counts tend to be around 65-70% of MAP value, with peaks reaching 80% MAP or slightly higher. During overload periods, average counts tend to be around 75-80% of MAP value, with peaks reaching 100% MAP for some of the sectors. During underload periods, average counts tend to be around 45-50% of MAP value, with peaks reaching 60% MAP.

From these observations, as well as from discussions with air operational subject matter experts, the following guidelines for sector boundary adjustments or sector combinations are initially proposed:

- A sector's boundary may be temporarily adjusted or sector size may need to be temporarily adjusted if the sector occupancy count is:
  - above 90% MAP value for at least half of the time in a 1-hr period *OR*
  - above 100% MAP value for at least half of the time in a 30-min period

- A sector may be temporarily combined with another sector if its traffic count is below 40% MAP value for at least 1 hour, as long as the combined sector does not violate the first guideline (see previous bullet point)

- When combining two sectors A and B into one sector C or transferring part of sector A to sector B (i.e., this enlarged sector B is referred to as sector B_a in the next sub-bullet point):
  - As an initial requirement, the resulting traffic count in sector B_a should not exceed 100% of MAP value of **max** (MAP_A, MAP_B); this requirement could be relaxed (MAP value of B_a could be increased).

- Integrity of inbound flows to major metropolitan areas/airports should be maintained.

E. Creating Airspace Playbook "Plays" Coordinated with NSWP

In order to generate a new airspace layout that suits a given traffic/weather/rerouting situation, an airspace optimization tool is required. The NAS Airspace Dynamics Analysis and Partitioning Tool (NAS-ADAPT) software has been used as the main research tool for this study.[6] In accordance with the specified optimization criteria (e.g., equalize sector occupancy counts in all sectors, keep sector boundaries away from major airports and major concentrations of traffic density) NAS-ADAPT produces an optimized airspace layout using an algorithm that grows the sectors starting from their "seed" locations.[8] A specific traffic pattern caused by convective weather may result in a significant shift of the boundary between two neighboring sectors (e.g., a sector impacted by weather has sparser traffic and is therefore enlarged, while a sector to which traffic has shifted becomes "denser" and smaller). For each day, the NSWP was reviewed and specific plays were identified that affected the airspace being studied, in this case ZOB. Typical patterns of required airspace adjustments (e.g., boundary changes, merging sectors, splitting a sector into two) were noted and related to the specific NSWP plays used on the day in question. The result is a series of airspace "plays" that go hand-in-hand with the existing pre-defined scenarios from the NSWP and thus can be planned for, or selected automatically.

American Institute of Aeronautics and Astronautics

IV. Examples of Candidate Airspace Playbook "Plays"

In this section, two examples of airspace "plays" are presented: an overload scenario where the proposed solution is to form a new temporary sector and an underload scenario where two sectors can be combined for most of the day.

A. ZOB Overload – North Portion (Sector ZOB18)

This type of situation is illustrated in Figure 1b. Let us consider a representative day: July 18, 2006. Unchanged (baseline) sector boundaries produce the following estimated sector occupancy counts (Figure 3). The period between 2100Z and 0000Z shows high traffic load in ZOB18 that approaches overload levels as outlined in the Criteria in Section III.

Figure 3. ZOB18 and neighboring sectors (left) and their occupancy counts as percentage of MAP values (right) with unchanged boundaries

When considering candidate boundary adjustments, it is important to keep the following in mind. It would be undesirable to violate the integrity of a major traffic flow in this area (ZOB18_A, Fig. 4, left); the analysis of traffic patterns shows that this is the inbound flow into Chicago. Examining the traffic pattern for the area in question (Fig.4), one could envisage creating a "tube" within sector ZOB18 (possibly also involving sectors above and below it).
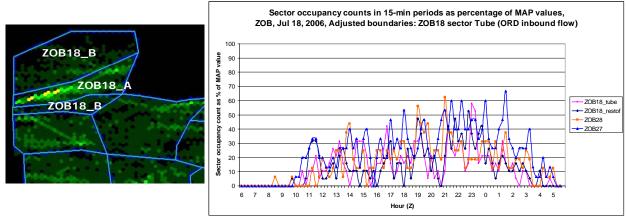

Figure 4. ZOB18 and neighboring sectors and their occupancy counts with adjusted boundaries

This tube would be used solely for handling Chicago inbound flows merging into one; it is designated as ZOB18_A in Figure 4. The southern portion of ZOB18 could either remain in its "residual" successor, ZOB18_B, or could be made part of the "flow sector," or ceded to neighbor sectors as a flexible FPA[‡]. Another solution to consider could be to redesign ZOB18 and its two neighbors to the south, ZOB27 and ZOB28, as a group, creating the "tube" sector and dividing the rest

---

[‡] Fix Posting Areas (FPAs) are standard building blocks for airspace. An airspace sector consists of one or more FPAs.

American Institute of Aeronautics and Astronautics

of the three-sector airspace between two new sectors that retain the rest of the ZOB18/27/28 traffic. This would leave the total number of sectors unchanged but could provide more flexibility in managing traffic in this area.

As far as the time interval is concerned, the indicated flow is busiest during the afternoon hours (1900Z onward); this could be the time period during which the "tube" is used. The resulting sector occupancy counts (Figure 4, right) show a significant drop as compared to the baseline (see Figure 3). Related "plays" from the NSWP typically reroute traffic originally scheduled to fly through ZOB's mid- and south sections further north which impacts sector ZOB18 (thereby increasing its workload).

B. ZOB Underload – West Portion (Sectors ZOB27 and ZOB28)

The "underload" situation arises when convective weather is present in great amounts and for a considerable time in the Center's airspace (see Figure 1c). As an example of this type of day, let us consider July 28, 2006. The corresponding sector occupancy chart for the west portion of ZOB is shown in Figure 5.
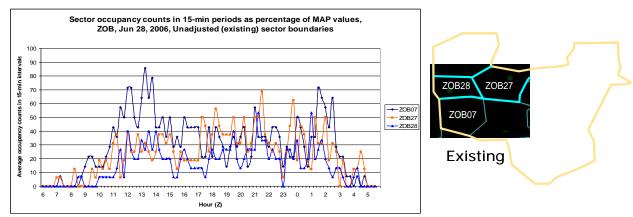

Figure 5. Occupancy counts in ZOB West portion high altitude sectors with unchanged boundaries

Occupancy counts in sectors ZOB27 and 28 are mostly below 40% of their MAP value, so they could be joined for most of the day except the 1900Z – 2200Z period (Figure 6):
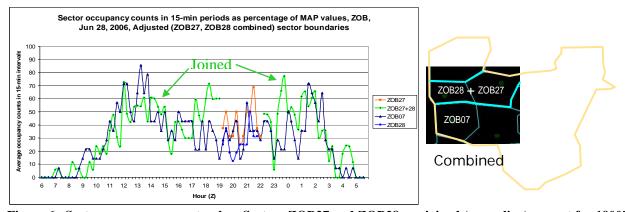

Figure 6. Sector occupancy counts when Sectors ZOB27 and ZOB28 are joined (green line), except for 1900Z to 2200Z period (blue and read lines on chart above)

V. Conclusion

Currently, airspace is not modified as a result of changes that occur in aircraft flows resulting from severe weather. This often results in additional delays created by traffic flow management restrictions. To address this issue an airspace playbook concept is proposed that complements NSWP reroutes. The objective of the airspace playbook is to adjust airspace in a manner that balances demand and capacity as aircraft flows are modified by severe weather. Initial results demonstrate that an airspace playbook complementing the NSWP may be a viable and practical concept to serve as a bridge between the existing airspace management paradigm and the more flexible and dynamic airspace organization

proposed by the NGATS Concept of Operation. However, additional work is needed to expand the airspace playbook to cover several contiguous Centers and multiple convective seasons, as well as to refine airspace boundary adjustment methods. Limitations in some of the currently accepted metrics, like sector MAP values, will require the development of new and/or refined metrics as these new airspace classes and concepts are developed.

Acknowledgements

References

[1]Killian, B., and Benedict, L., "Limited Dynamic Resectorization: A Practical Approach to Adaptive Sectors," MITRE CAASD Working Note #WN 96W00000090, September 1996, McLean, VA.

[2]Cochran, K. D., Brown, W. L., Crone, C. W., Lind, A. T., Petrillo, T. A., Wilhelmsen, H., Wiken, R. T., "Dynamic resectorization in en route air traffic control report 4: Recommendations for near-term limited DR," MIT Lincoln Laboratory Rept. 92PM-En route Infrastructure-004, 1999, Lexington, MA..

[3]Thedford, W., Vivona, R., and Hodgdon, C., "En-Route Constrained Airspace Concept Definition," Final Report, NASA Contract: RTO-07: NAS2-98005, Sept. 1999.

[4]Hadley, J., Sollenberger, R., D'Arcy, J. F., and Bassett, P., "Interfacility Boundary Adjustment," DOT/FAA Rept. DOT/FAA/CT-TN05/19, Washington, DC, 2005.

[5]Stein, E., Della Rocco, P. S., and Sollenberger, R. L., "Dynamic Resectorization in Air Traffic Control: A Human Factors Perspective," DOT/FAA Rept. DOT/FAA/CT-TN00/06, Washington, DC, 2000.

[6]Klein, A., "Day's Weather in the NAS: Visualization of Impact, Quantification and Comparative Analysis." 6th NASA ICNS Conference, Baltimore, MD, URL: http://gltrs.grc.nasa.gov/reports/2006/CP-2006-21-214398/CD_Contents.pdf [cited 3 May 2006].

[7]Sridhar, B., and Swei, S., "Relationship between Weather, Traffic and Delay Based on Empirical Methods." 6th AIAA Aviation Technology, Integration and Operations Conference (ATIO), Rept. AIAA-2006-7760, Wichita, KS, 2006.

[8]Klein, A., "An Efficient Method for Airspace Analysis and Partitioning Based On Equalized Sector Occupancy Counts." *6th USA/Europe ATM R&D Seminar,* Baltimore, MD, URL: http://atmseminar.eurocontrol.fr/all-seminar/6th-usa-europe-atm-2005-r-d-seminar/papers_calendar [cited June 2005].