Optimizing the Continental United States Air Refueling Infrastructure

GRADUATE RESEARCH PAPER

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AFIT-ENS-MS-16-J-027

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT-ENS-MS-16-J-027

Optimizing the Continental United States Air Refueling Infrastructure

GRADUATE RESEARCH PAPER

Presented to the Faculty

Department of Operational Sciences

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics

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June 2016

AFIT-ENS-MS-16-J-027

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Abstract

The current air refueling infrastructure over the continental United States was first created in 1963 and, while having incremental changes through the years, has not been recently analyzed for system utilization and redesigned (if required) based on updated demands, aircraft bed-downs, and changing weather patterns. Additionally, changes in airspace management brought on by modern aircraft, increasing volume in air traffic, increased on-board navigational performance, and the obsolescence of ground based navigational aids are pushing massive redesigns on overall airspace management. This research analyzes 2014 training and operational data to provide current utilization rates and also proposes a holistically redesigned infrastructure that optimizes the amount of time available for air refueling operations while minimizing the impact to commercial aviation and operational necessity. This analysis identifies that 98% of the CONUS AR track usage was performed on only 62% of the current AR track infrastructure and, as a result, proposes the elimination of 35 existing AR tracks. Further, this research proposes an alternate optimized infrastructure structure that provides standardization and deconfliction with NextGen concerns and other airspace issues enabling greater utilization of flight hours towards training and operational objectives.

To my wife and son

Acknowledgments

I would like to express my sincere appreciation to my faculty advisor, Dr Jeffrey Weir, for his guidance and support throughout the course of this thesis effort and Dr Felicity Vabulas and Dr Gwynne Johnston who both took the time out to provide an outsiders opinion of this research. The insight and experience was certainly appreciated. I would, also, like to thank my sponsor, Mr Steven Pennington, from Headquarters, Air Force for both the support and latitude provided to me in this endeavor.

Taylor J. Johnston

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Optimizing the Continental United States Air Refueling Infrastructure

I. Introduction

The current airspace architecture above the continental United States (CONUS) is based on pre-global positioning systems (GPS) and modern in-plane navigational equipment accuracy. The infrastructure is based on "highways in the sky" that link ground based navigational aids that are most often Very High Frequency Omnidirectional Beacons (VORs). The highways exist between VORs providing a path from the airport of origin to the terminal area of the desired airport. Inside and around this architecture, the Department of Defense (DoD) (in conjunction with the Federal Aviation Administration - FAA) created military operating areas (MOAs), warning areas, and air refueling (AR) tracks. These were based on the training and operational requirements of the DoD based on the laydown of the force. GPS and improved on-board navigational equipment (combined with the ever increasing cost of maintaining the ground based navigational aids), however, have rendered this infrastructure mostly obsolete. This obsolescence impacts the ability for the United States Air Force (USAF) to efficiently execute operational and training objectives and reduced profit margins in the commercial sector.

There is a national effort to modernize the airspace—known as NextGen—which includes upgrading navigational performance and reliance on GPS. This presents both challenges and opportunities. With NextGen and an increasing dependence on satellite based aircraft avionics, some current AR tracks may, in fact, restrict the efficiency of the National Air Space System (NAS). On the other hand, based on the opening of the Air Traffic Control (ATC) System with the introduction of NextGen, new areas for optimized

AR tracks will become available allowing for greater efficiency in Air Refueling. Some bases (Travis AFB, Altus AFB, and Milwaukee AGB) have constructed their own AR tracks to meet their needs. However, there has not been a holistic look to redesign the entire AR Track System.

To that end, this research will focus on the utilization and efficiency of our current AR Track System and possible improvements that can be made. It necessitates a holistic redesign based on the increased navigational standards and introduces optimization to curb costs and increase training value. The historical architecture did not account for the current annual magnitude of USAF flying, seasonally adjusted weather patterns, or force structure changes to include cuts and re-basing of both tanker and receiver units. Many of the current AR tracks have been rendered obsolete or, at a minimum, terribly inefficient.

In order to ascertain whether or not the current AR structure is in need of repair, this research analyzed 2014 Mobility Air Forces (MAF) flights to provide an assessment of annual utilization totals. Additionally, the 2014 data analysis will also provide the most common base pairings from which to form an alternate optimized infrastructure. The optimization model for an alternate infrastructure can then be divided into three distinct sections: First, it will provide an analysis of the current AR system. Secondly, it will present a multi nonlinear optimization using current and proposed infrastructure to provide proposed AR tracks (also utilizing the common base pairs identified in the previous section). Thirdly, it will compare the proposed tracks against the projected NextGen airspace to provide a system that is advantageous to all stakeholders (DoD, Commercial Aviation, FAA, DoT).

The historical analysis identifies that 98% of the CONUS AR track usage was performed on only 62% of the current AR track infrastructure and, as a result, proposes the elimination of 35 existing AR tracks. Further, the alternate optimized infrastructure structure proposed by this research streamlines the 91 existing tracks down to 42. This alternate optimized infrastructure provides a common framework across the CONUS and ensures the mutual benefit of the USAF and commercial interests.

Research Objectives/Questions/Hypotheses

The objective of this research is to use an optimization model that holistically redesigns the AR track system above the continental United States (CONUS). This model should account for current and future basing decisions for tanker and receiver aircraft, incorporate current data on which AR tracks are being used most often (training versus operational), minimize the total fuel spent by tanker and receiver aircraft getting to and from the AR track, and also minimize the impact to the proposed NAS under NextGen.

This research will address the following questions along the path to a holistic redesign:

1: Based on historic usage, what are the most common tanker/receiver base parings that practice AR over the CONUS?

2: Based on historic usage, which current tracks can be eliminated regardless of the conclusions of the redesign?

3: Based on current and projected basing, where are the optimal tracks that can be utilized between tanker and receiver bases? (This question is limited to the most common base pairings identified in the first question)

4: Weighing historical usage and proposed NAS redesign, where can AR tracks be placed to optimize efficiency for the USAF and commercial aviation?

The underlying hypothesis to this research is that the current structure of AR tracks in the US is not optimized for fuel efficiency, operational usage, and minimizing impact to commercial aviation. By evaluating the historical of the AR track infrastructure and the most common base pairings, we can uncover areas of opportunity to holistically redesign the AR track system above the CONUS.

Research Focus

The current CONUS AR Structure depends on hundreds of AR tracks and anchors distributed across the country (see Appendix A for a visual depiction). In order to create a reasonable scope of analysis for this paper, the model will focus its analysis on the "classic" users of AR tracks - heavy aircraft (i.e.no fighter bases) in both Air Combat Command (ACC) and Air Mobility Command (AMC). Additionally, this research will only focus on the CONUS system and will not address AR tracks in Hawaii or Alaska. The airspace concerns within the CONUS are not mirrored in Hawaii or Alaska as the amount of commercial traffic and possible conflict with AR activity is drastically lower.

Furthermore, AR Anchors (areas designated across the CONUS versus tracks in the sky) will not be addressed in this study. The 75 AR Anchors, however, represent 36% of the AR tracks currently in CONUS and deserve further study outside of this research. While AR Anchors also represent an impediment to the implementation of

NextGen Airspace, historical data does not allow pure analysis of usage, as AR Anchors can also be used for tanker tactics, techniques and procedures (TTPs) practice without the presence of a receiver asset. Therefore, there is no way to accurately assess their usage across the spectrum using the methodologies that are employed in this paper.

Visual Flight Rules (VFR) helicopter AR tracks will also not be addressed in this study. VFR helicopter routes represent an entirely different problem set to the implementation of NextGen, but a less significant one, as their altitudes do not interfere with the large segment of commercial traffic. VFR AR tracks account for 16% of the AR tracks, but none of those 34 tracks (and 1 anchor) exceed 10,000ft above mean sea level (MSL).

The comparison against the NextGen airspace will be done using the current city parings of American Airlines (being the largest commercial airliner) as a representative sample of commercial aviation desires.

Assumptions/Limitations

One might posit that the acquisition of historical data is a relatively simple proposition as, due to policy, every AR sortie is tracked with the AMC fuel tracker. Additionally, the Global Decision Support System version 2 (GDSS2) that is used for mission assignment tracks each air refueling mission in the USAF. Indeed, the Mobility Air Force's Operations Data (MAFOPS) data warehouse combines data elements from the fuel tracker database and GDSS2 and multiple other sources in order to cross reference the data and ensure the accuracy of the data, but air refueling missions are tracked by the receiver owning organization, not the base that the specific aircraft departed from. This means there is no path to identify in the database the exact location that the receiver took off from. The methodology had to assume that the departure was from its home location. Similar databases have also proven unreliable, and may not have been utilized if there was only a training "token" offload (i.e. training was accomplished with no fuel passed from tanker to receiver). Therefore, when compiling the historical base pairings, this research makes the assumption that the base the receiver has taken off from is the Air Refueling Contact Information.

Each current AR Track has its own idiosyncrasies due to the way it was designed (based on its appropriated navigational aids at the time). In order to provide a consistent model, it is necessary for this research to make other assumptions. First, the length of AR tracks and their direction currently vary wildly. The model will therefore assume that all AR tracks will be 300 nautical miles (NM) long and maintain the same directional heading the entire length of the track. (See Chapter II for current FAA restrictions on length). The major implication of this assumption is that the standardization of a track length prohibits a level of flexibility and adaptability to each air sector.

The model is also crafted around the current airspace restriction as described in Chapter II. This includes a 25NM lateral airspace restriction that is the result of the inaccuracies of existing onboard navigational systems. With increases in onboard navigational system capabilities due to requirements to meet Reduced Vertical Separation Minima (RVSM) and Required Navigational Performance (RNP), this assumption could be lifted and the model will allow for the modification of the minimum lateral distance between air refueling operations and other aerial traffic.

Further, in optimizing for time spent to/from the AR track, block speeds and fuel flow numbers for AMC aircraft are taken from the planning numbers located in Air Force Pamphlet (AFPAM) 10-1403 *Air Mobility Planning Factors.* For ACC aircraft whose specific information is not located in the AFPAM, the planning numbers were solicited from either the airframe specific Air Force Tactics, Techniques and Procedures 3-1 publication, a Weapons Officers in the respective platform, or Headquarters ACC. These numbers are then further refined to account for historical wind data at their location. These calculations are limited because they utilize planning factors and not specific aircraft performance data.

Another assumption of the model is that the AR training is the only aerial training that the aircraft in question will be performing. It does not account for follow-on training at a specified location/base/range that the receiver might be heading towards or from. The optimization is done for a round trip from the tanker and receiver's respective bases. However, by forcing all AR tracks to be 300NM long, it enables easy access from a rather long track to any area/airport along the specified AR track. Therefore, while it is not an explicit concern of the model, the length and location of the newly optimized track may accommodate the follow-on training.

The optimization will also be limited as it will not try to move any restricted or warning areas that are currently being used by fighter bases. These warning areas prohibit the direct flow of a lot of commercial traffic, and may also impede full optimization of a new AR structure.

Another limitation of the model is the use of the basic Pythagorean Theorem versus the Spherical Pythagorean theorem. The Spherical Pythagorean Theorem states that on a sphere of radius R, any right triangle ABC with C being the right angle satisfies:

$$cos(c = R) = cos(a = R)\ cos(b = R)$$

Equation 1

(1)

(The Geometry of the Law of Cosines, 2016)

However, as R approaches infinity, the formula mirrors that of the formula for the flat plane. Due to the Earth's radius being 3,959 miles (Williams D. R., 2016), this research makes the decision to implement the standard Pythagorean theorem vs. the Spherical Pythagorean Theorem. The implication of this assumption is that the geographic end points of the AR track based on the standard theorem may differ by less than 5 miles from a model based on the Spherical Theorem.

The final assumption in this research is that the historical AR trends are a predictor of future activity. Advancements in Live Virtual Construct (LVC) training and simulator-to-simulator linking may push more and more training events out of the cockpit and into a simulation environment. Distributed Mission Operations (DMO) has, since 1999, gradually pushed the training environment into the virtual world, and AR training is heading in the same direction. By 2017, the goal is for all AMC major aircraft weapon systems to be connected to the Distributed Training Center (McAndrews, 2009). The implications LVC and DMO operations to the results of this study are unknown at this time, as the fidelity and ability of these programs is an ongoing process. For example, the rendezvous and rejoin procedures for continuation training events can be accomplished in the simulator, the specific act of “contact” (where the tanker and receiver actually touch) can only be accomplished via live fly.

Implications

This study follows an optimization model whose implications will not only influence USAF AR operations (36,000 flights per year), but the operations of civilian carriers (an average of 8 million flights per year). For the USAF, the optimization does not result in the elimination of flight hours, but the better utilization of said hours. The shorter amount of time spent getting to the track allows for a greater amount of time spent doing AR training. This greater utilization of flying hours towards the overall training objectives enables the MAF and CAF to achieve higher training levels, and thereby increased overall readiness.

On the contrary, this model is designed for the holistic optimization of fuel spent/flying hours spent by all aircraft in the system. Due to the excessive burn rates of receiver aircraft (such as the C-5 or C-17) versus the fuel burn rates of tanker aircraft (KC-135), the allocation of flying hours will most probably have to be redesigned as a result of this research. This redesign will push more hours towards the tanker and more away from the receiver aircraft (again due to the cost per flying hour for each of the aircraft). The secondary consequence of reallocating these hours is the service life of the aircraft involved. Currently the tanker fleet is the second oldest fleet in the USAF inventory, and by placing more hours on the fleet (as the fleet is cheaper to operate) the life expectancy of the fleet will be decreased.

On the civilian side, commercial cargo and passenger services currently plan to fly around AR tracks. Their flight plans and fuel loads are created with a buffer to go around AR tracks when required, as they cannot specifically plan on the active times the AR Track is being utilized. By eliminating some of the conflicts for the more frequent commercial traffic, commercial aviation will able to fly more directly to their route. This means they will be able to count their savings in the millions of dollars in flight time saved, and fuel cost to carry.

II. Literature Review

The history Air Refueling Tracks in the United States is missing and the structure is based on antiquated USAF basing.

In Richard Smith's seminal book on the History of Inflight Refueling, much attention is spent on the technical advances made by specific individuals and aircraft involved. From the first refueling made on June 27th, 1923 to today, air-refueling has indeed made remarkable strides. Refueling has gone from manually placing a hose between bi-planes with men yelling to each other and going less than 100 knots to today's air refueling which is conducted at 300 knots and sometimes being done without the aid of radios or lights at night. However, while the book mentions multiple times the training required from the early days of the B-50 and the KB-29 to the B-52 and KC-10, it does not mention the areas that they were assigned to train: AR tracks and Anchors (Smith, 1998).

Ostensibly, tracks were created in the sky near the major training and operational bases to enable pilot proficiency and operational capability. The fifth annual report of the Federal Aviation Agency (FAA – It became the Federal Aviation Administration in 1966) describes the following:

> Military aerial-refueling operations can be accomplished with greater efficiency in airspace use as a result of a new concept developed and implemented during the reporting period. The practice has been to set aside a large area of airspace for such operations-which then might or might not be used in its entirety. The new concept calls for aerial refueling to be conducted on published pre-coordinated tracks, protected by an airspace envelope like that given any other user of the air traffic control system.
>
> (Federal Aviation Agency, 1963)

The following year's report from the FAA describes the improvements in the system over the year.

Training requirements for military aerial refueling are being met and gains in efficient airspace use are being realized as a result of new procedures initiated earlier and widely implemented during the reporting period. In the past, extensive areas, of which only small portions were actually used, were set aside for these training operations. Under the new concept, air-to-air refueling is carried out on pre-coordinated and published tracks which require considerably smaller allocations of airspace.

(Federal Aviation Agency, 1964)

In considering the design of the airspace mentioned, it is important to note that in 1961, Strategic Air Command (SAC) had 1,018 tankers (503 KC-97s and 515 KC-135s) and Tactical Air Command (TAC) had an additional 130 KB-50 tankers (Smith, 1998). This is 2.5 times the amount of aircraft in today's inventory of roughly 457 KC-135s and KC-10s meaning that the system designed in 1961 is not in line with current usage. While there have been slight modifications done throughout the years, neither the FAA, the USAF, AMC, ACC, or Air Force Global Strike Command (AFGSC) historians have any data indicating a holistic reshaping of the AR system.

Current structure of Air Refueling Tracks in the United States indicate specific design requirements but complicated "ownership"

The current structure, policies and procedures for AR tracks in the CONUS are governed by Chapter 10 of FAA Order 7610.4S *Special Operations, dated April 3rd 2014.* Figure 1 (below) shows the notional orbit pattern and airspace concerns around a given AR Track. For a more complete analysis of the airspace required to be reserved for air refueling operations, refer to Figures 1 and 2. These figures indicate a desired 100 nautical miles between an Air Refueling Control Point (ARCP) and an Air Refueling Initial Point (ARIP). The figures also indicate a maximum lateral spacing requirement of 25 NM between the AR track and other aerial assets as referred to in the assumptions of the model. These two numerical factors are crucial to the design of a new track system (but can be modified in the construct of the model).

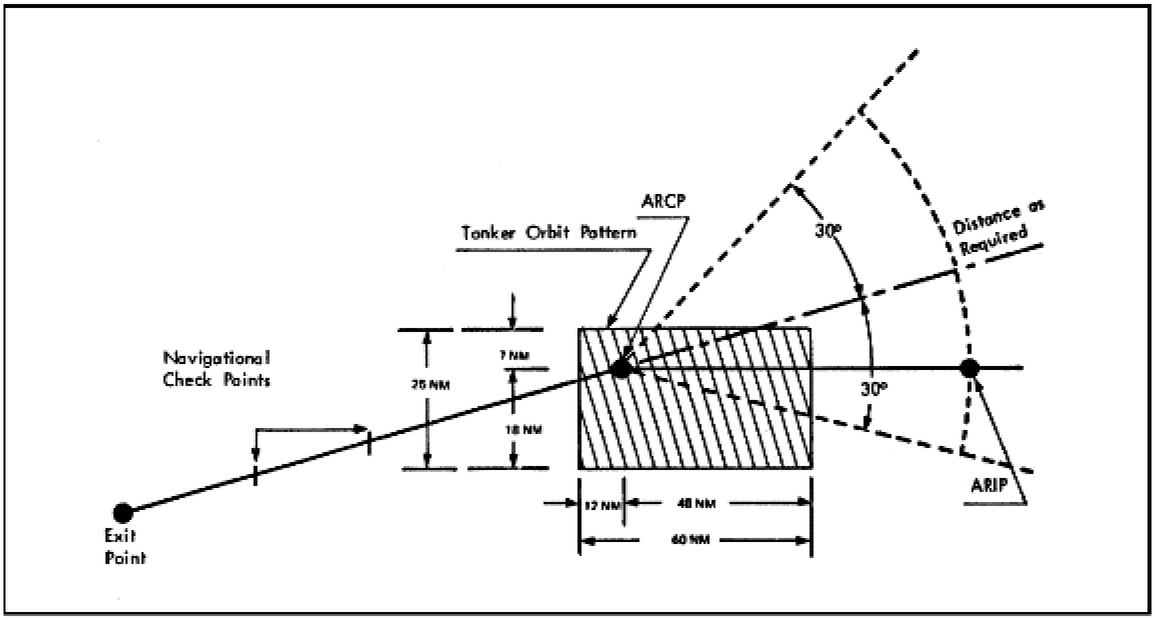

Figure 1: AR Track Design

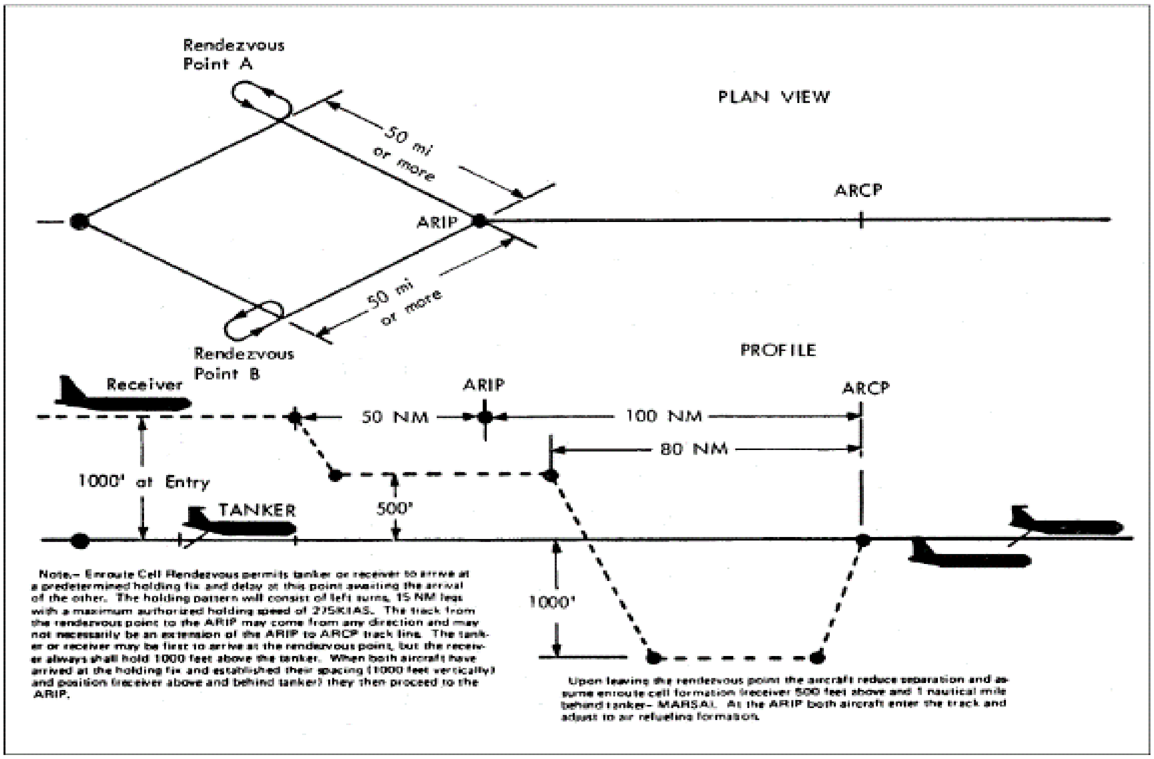

Figure 2: Plan and Profile View of AR Track

While these two figures represent the current architecture, it is important to note that the lateral separation required in Figure 1 can be reduced with the enhancements in onboard navigation equipment. Historically, as aircraft performance equipment has become more accurate, aircraft have been allowed in closer proximity to one another.

As stated, FAA Order 7610.4S dictates the structure, policies, and procedures for a standard track, but the listing and depictions of the entire track system are not published by the FAA or the USAF. They are instead published with coordination from both organizations by the National Geospatial-Intelligence Agency (NGA), which is a combat support agency under the DoD. Tanker and Receiver aircrews get their geospatial information (latitudes, longitudes, altitudes) and communication frequencies for specific

AR tracks from NGA publications (NGA Aeronautical Services). It is important to note, though, that while the NGA publishes the specific AR Track information in the area planning documents, they do not maintain the authority to manipulate the AR tracks (NGA Aeronautical Services). The ability to manipulate the AR tracks is delineated in FAA Order 7610.4S and must be done via the unit who "owns" or controls the specific AR track to the FAA.

Next Generation Airspace Initiatives are ongoing but face issues

According to 2012 testimony before the Subcommittee on Aviation, Committee on Transportation and Infrastructure, House of Representatives by the Director of Physical Infrastructure Issues, Gerald L. Dillingham, the FAA predicts "that, by 2025, the annual number of airline passengers in the US will increase from about 700 million to 1 billion and the number of flights associated with that will increase from roughly 80,000 to 95,000." (United States Government Accountability Office, September 2012) The FAA has partnered with other governmental agencies (Departments of Commerce, Defense, Homeland Security, Transportation and NASA) as it is a vastly intricate effort. This effort requires multiagency integration from aligning procedures/standards to creating and maintaining a new infrastructure that is based on GPS and network centric operations.

This projected increase in flights and the capability increases in navigational equipment resulted in the creation of NextGen, a program designed to upgrade the entire aerospace structure, from ground based procedures, equipment and structure to aerial procedures, equipment, and structure. Initial planning for NextGen started in 2003 with its first plan being released in 2004 when congressed passed the Vision 100 - Century of Aviation Reauthorization Act. This act placed timelines on having NextGen in place by 2025 with a midterm implementation date of 2020. The NextGen Priorities Joint Implementation Plan divides the NextGen initiative into 4 distinct focus areas, Multiple Runway Operations, Performance Based Navigation (PBN), Surface Operations, and Data communications. The current targets of the PBN focus area have been Metroplexes in Northern California, Atlanta, and Charlotte. The main objectives have been "designing and implementing automated flight paths, airspace redesign and obstacle clearance". The main benefits include "shorter and more direct flight paths, improved airport arrival rates, enhanced controller productivity, increased safety due to repeatable and predictable flight paths, fuel savings and a reduction in aviation's adverse environmental impact." The PBN initiative has yet to focus on the enroute structure (as this paper is focused on) as there are more tangible and immediate effects to modify the Metroplexes one by one instead of a complete redesign of the enroute airspace (Federal Aviation Administration, October 2014).

The FAA's desire to adopt the new navigational performance standards has encountered differing sets of issues within DoD, and even inside the USAF. On one hand, the MAF, is routinely based near large metro areas (e.g., Travis AFB in the metroplex of Northern California), and operates in and around civilian traffic. On the other hand, the CAF (fighter/bomber) aren't usually based in large metropolitan areas and they also don't often venture outside their MOAs or warning areas. MAF aircraft (especially tankers) are also some of the oldest (and least technologically developed) aircraft in the USAF fleet, which flies in direct opposition to the desire to change airspace. Therefore, the FAA has had to address not only the navigational standards of the MAF and its close proximity, but also the CAF's use of blocks of airspace (MOAs/Warning areas) that impede commercial traffic. In order to assist in the resolution of these issues, the USAF has asked the RAND Corporation five times over the last seven years to develop tools to help the USAF by coming up with possible solution sets that will be beneficial to all parties involved.

In 2011, RAND studied a similar problem to AR Track optimization in their analysis to Preserve Range and Airspace Access for the Air Force Mission. Ranges and associated airspace enable the USAF to "develop and test new aircraft and weapons systems, evaluate tactics, and train aircrews and supporting personnel" (Williams, Conley, Robbert, & Boon Jr, 2011) which aligns perfectly with the purpose of the AR Track Infrastructure. In the introduction to the study, RAND also acknowledges that in the era of NextGen, military ranges and training become "more visible and subject to the demands of other air traffic for airspace". Like the data limitations outlined in this paper, RAND found that the current scheduling and management of the ranges and airspace do not lend to a consolidated, integrated solution, and, in fact, impede any development of a concept of operations for activity under the NextGen framework (Williams, Conley, Robbert, & Boon Jr, 2011).

The most recent study performed by RAND developed an aviation energy assessment toolkit which combined USAF, FAA, and wind data to provide insight into the most optimal paths USAF aircraft can take between airfields in order to reduce the amount of hours flown and fuel burned. It resulted in optimized routes between common takeoff and landing airfields. This optimization can be incorporated into the proposed model in order to provide both meteorological input, and historical data (Muharrem Mane, September 2015).

Summary

To illustrate the problem set involved, MacDill AFB can be considered a perfect example. In 1963, MacDill became a TAC training base, and housed F-4 and F-16 aircraft until 1994. MacDill trained 50% of the F-4 and F-16 aircraft pilots throughout utilizing training areas off the gulf coast, and had no need for any AR Tracks. In 1994, the base saw the end of its F-16 training mission, and in 1996, the base was assigned KC-135 aircraft. With this new aircraft assigned, there was no concurrent creation of an AR track to support training missions between MacDill and a receiver base. To this day, MacDill tankers travel an excess of 1 hour to link up with receivers at Charleston AFB for training (this was executed 119 times over the calendar year). This hour to/from the AR track represents possible time for the tanker and receiver aircraft to be training, but is spent droning to get to an inefficient location based on data in 1963.

III. Methodology

Introduction

This paper will address the research questions about AR track usage by employing historical data and a custom-built optimization model to project future practices. It analyzes the historical activity of 2014 as a representative example of usage to identify operational necessities, AR tracks that aren't used, and the most common base pairings. It then applies an optimization model to the most common base pairings and offsets those results against each other and to that of the commercial activity of American Airlines.

Historical Analysis

This research focused it historical data query on the MAFOPS database. The data base was queried for the following data fields with the following restrictions:

Table 1: Database Information

Data Element	Source	Filters
Mission Identifier	GDSS	
Actual Takeoff Date/Time	GDSS	Between 1 Jan & 31Dec 2014
Actual Landing Date/Time	GDSS	Between 1 Jan & 31Dec 2014
Departure ICAO	GDSS	US Only
Aircraft Design	GDSS	
Actual AR Contact Organization	DS235	
Planned AR Track	DS135	
Planned ARCT Date/Time	DS135	
Actual AR Track	DS23	
Actual ARCT Date/Time	DS23	
Mission Priority	GDSS	
Mission Classification	GDSS	

These data elements were filtered to remove any duplicate information. Furthermore, due to the scope of the research, the AR tracks were further filtered to remove Altitude Reservations (ALTRVs), Warning Areas, Military Operations Areas (MOAs), Random AR tracks. The nature of AR tracks also proved to be slightly troubling as AR tracks are currently directional and can be listed in the data base multiple ways. The use of the AR track could be annotated in the database as (for example) AR111 (just the AR listed), AR111E (the AR Track flew in the easterly direction), AR111W (the AR Track flew in the westerly direction), or AR111EW (the AR flown in both directions). The airspace reserved is the same (minus maneuvering airspace at the beginning depending on direction) and therefore for the purposes of the research, the AR Track specific data includes of all the variants.

In all, there were 10,200 AR sorties accomplished by the USAF over the CONUS in 2014. These sorties were further analyzed for their specific operational perspective (training or operational), and the breakout for each individual AR Track can be found in Appendix B.

As described previously, the AR Contact information had to be transposed to an airport data set in order to inform the second section of the methodology. There were 137 unique AR contact organizations for the 10,200 sorties, and each contact organization was assigned to the airfield of their home location. The pairings between Tanker and Receiver were analyzed and the breakout can be found in Appendix C.

Optimization Model

This research utilizes a multi-nonlinear optimization model to gain efficiencies in airspace usage in order to increase training time available in a given sortie. This is beneficial as the reduction of drone time to and from an AR Track will increase the amount of time allowed for training (assuming the same total amount of flight hours). In designing the geometric model for an optimized AR track, two solutions for a track were considered. Understanding that the AR Track is simply a pre-identified line in the sky, one has to consider how to draw that line. "Method 1" involved placing the AR track perpendicular to the tanker and receiver bases. This solution, while mathematically simple, proved infeasible for bases within 400 NM as the trigonometric equation proved unsolvable. Method 2 focused on offsetting the AR Track to one side, and used varying angles to ensure the optimization. Again, the mathematical focus was to find an optimized path in the sky that minimized the time to and from the AR track for the pilots/aircraft involved.

In the instance where there are multiple aircraft operating from the same base, the fuel burn calculations were performed using the aircraft that burned the most amount of fuel. For example, Offutt AFB is home to the E-4B and the RC and WC-135 aircraft. The E-4B burns 30,000lbs of fuel per hour whereas the RC/WC-135 burn 12,000lbs/hr. In this instance, the E-4B was used to calculate the ideal location of the AR Track. This logic was similarly applied to Travis and Dover (C-5 vs C-17) Air Force Bases. The two methods and their resulting optimization models are displayed below:

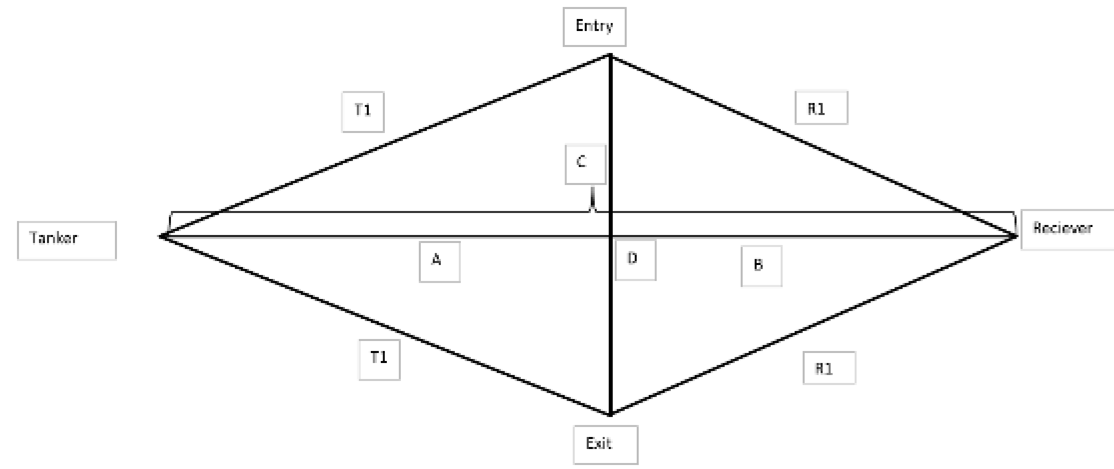

Figure 3: Method 1 Optimization

$$MIN\left(\frac{T_{ff}\ \times (T1\ x\ 2)}{T_{ias}}\right) + \left(\frac{R_{ff} \times (R1\ x\ 2)}{R_{ias}}\right) \quad (2)$$

Equation 2

$Whereas$:

$A_{fuel} = B_{fuel}$

$C_{Dis} = A_{Dis} + B_{Dis}$

$EntryExit = 300\ NM$

$C(EntryExit) = 90°$

- ff = fuel flow in Pounds per Hour
- ias = Indicated Airspeed in Nautical Miles per hour

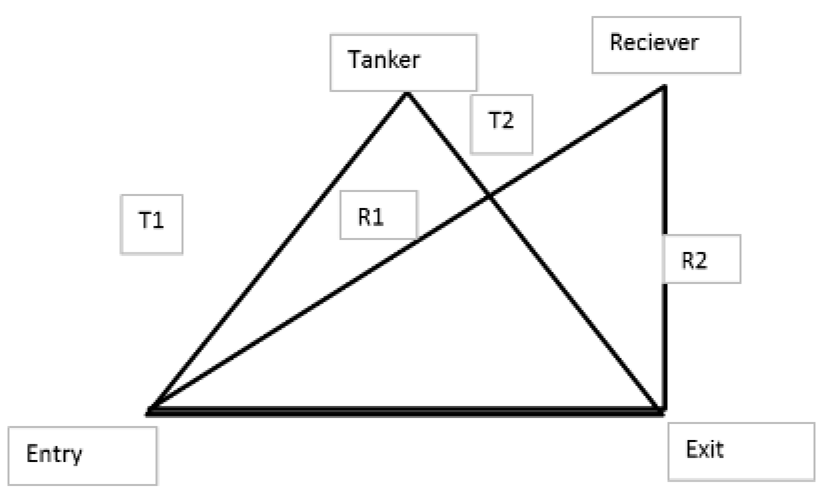

Figure 4: Method 2 Optimization

$$MIN\left(\frac{T_{ff}\ \times (T1+T2)}{T_{ias}}\right)+\left(\frac{R_{ff}\ \times (R1+R2)}{R_{ias}}\right) \quad (3)$$

Equation 3

$Whereas$:

$\sum R\ Angles = 180°$

$\sum T\ Angles = 180°$

$50 < \sin\ (R1Entry) < 1000$

$50 < \sin\ (T2Exit) < 1000$

$EntryExit = 300\ NM$

- ff = fuel flow in pounds per hour
- ias = Indicated Airspeed in Nautical Miles per hour

The two optimization models were then compared against each other to give the lowest amount of fuel burned getting to and from the AR Track. The result of this comparison is a specific idealized path in the sky between a base pairing. This is accomplished for all the most common base pairings as identified in the historical analysis. Furthermore, the resultant idealized tracks between the most common base pairings must then be compared against each other for conflict. If a conflict in airspace exists, the individual idealized tracks must be offset from each other using their frequency of use as a primary driver for movement. Additionally, they must be adjusted depending on their relationship to the surrounding airspace and NextGen concerns.

Comparing the Optimized solutions to NextGen desires

The theory behind NextGen Airspace, as stated in Chapter II, is to enable more direct flow of aircraft between take-off and destination and to enable tighter tolerances between aircraft that are in the airspace. The ideal tracks that were identified via Method 1 or Method 2 did not take into account the airspace desires of commercial aircraft that might also want to use that airspace. Although most USAF AR training occurs during daylight hours, nighttime contacts (to include Night Vision Goggle training) are an essential piece of AR capabilities. In order to ascertain an appropriate sample of commercial traffic, this research compared the stateside schedule of American Airlines (AA) with the ideal tracks. This sample was taken as the CONUS AA infrastructure is made up of seven different hubs that provide the hub and spoke model that covers the entire CONUS. Their size provides a representative example of the 4 major commercial carriers that provide the majority of commercial traffic throughout the CONUS.

The NextGen PBN initiative discussed in Chapter II focuses on rearranging departure and arrival routings within a given Metroplex instead of the current standard arrival Routings (STARs) and departure procedures. In constructing a holistic design for the new AR track system, one must either account for the current NAS structure or any future concepts in the NextGen redesign. This study will focus on the proposed structure enabling an enroute decent along an idealized path (as the Metroplex initiative is striving for). Therefore, the placement of the optimized AR Track must avoid a circle of airspace along the optimized transit between airports that incorporate a planned enroute decent into an airport.

This cannot be done two dimensionally, but must be executed three dimensionally using a standard descent path calculation for a standard aircraft. To calculate the optimized descent path one must take the planned altitude to lose and multiply by three and add to a 10-mile final approach path. For example, in order to avoid the optimized AR track when descending from a normal cruising altitude (35,000ft MSL) to sea level, the track must not exist along a flight path outside of 71 miles (which ensures a 5-mile separation from the optimized AR track). This calculation must be done at each airport as the descent required from 25,000 ft. Mean Sea Level (MSL) to a 6,000 ft. MSL field (42 miles) is different than the descent required to go to a field at sea level (depicted in Figure 5).

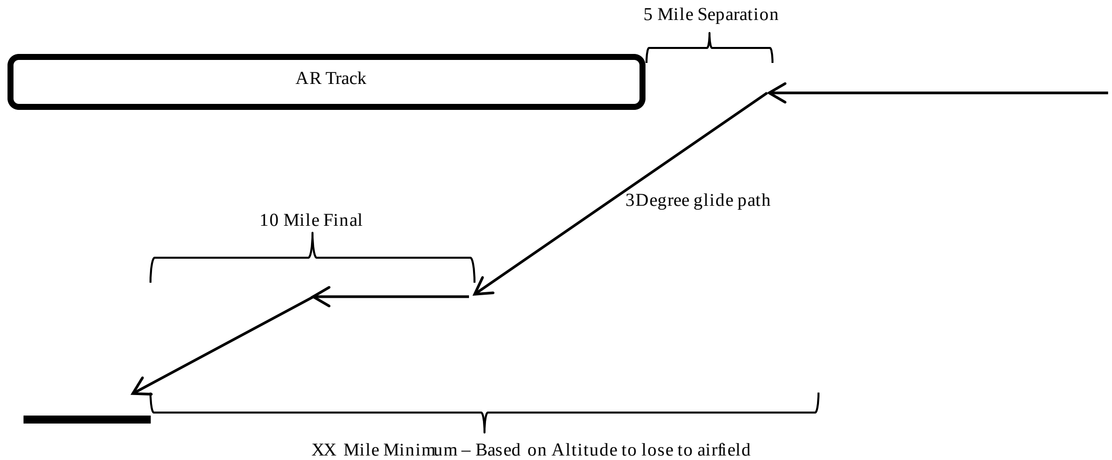

Figure 5: Civilian Descent Requirements

Comparing the Optimized solutions to Commercial Aviation desires

Following the methodology that compared the optimized solutions against each other and against the desires of NextGen, this research identified the need to compare the optimized solutions against a civilian carrier. American Airlines (after the merger with US Airways) is the largest US commercial passenger carrier and represents a fair sample size to compare against the proposed ideal AR tracks. AA publishes their entire schedule monthly, and that schedule was pared down to the flights involving their seven hubs across the US: Charlotte, Chicago, Dallas, Los Angeles, Miami, New York, and Philadelphia as the traffic originating from these hubs comprises 98% of their total domestic traffic. The associated city pairings for the seven hubs were then placed on a map and overlaid against the ideal tracks. In order to ensure separation from both flights and AR tracks, a 5-mile corridor was established on either side to ensure lateral separation. This methodology ensures that that the proposed optimal AR tracks minimally conflicted with the commercial traffic using current navigational performance standards.

Other Airspace Requirements

Further compounding the requirements of the commercial aviation fleet are other subsets to the NAS. Specifically, CONUS airspace is divided for control purposes into 20 different Air Route Traffic Control Centers (ARTCCs). These centers exercise control over the air traffic in their given geographical region (see Appendix C). In order to simplify the control over air traffic, aerial activity (such as AR) does not usually cross these boundaries. The role and dimension of ARTCCs in the NextGen NAS, however, has not been addressed or defined. In order to adhere to the practice of limiting the amount of aerial activity between ARTCCs, the optimized AR tracks must also be moved accordingly.

The final airspace limitation that the optimized AR tracks must adhere to is the current system of Special Use Airspace (SUAS). SUAS areas include Danger, Prohibited, Restricted, Warning, and Military Operating Areas (MOAs) that are defined areas based on various requirements from national security (National Capitol Region) to military training (Pilot training areas). The areas are fixed points in the sky, and while they may adjust slightly with NextGen, their adjustment (as outlined in Williams et al, 2011) is far from being addressed. Therefore, any optimized AR Track must be further adjusted to account for the current location of these SUAS areas (Appendix D).

Summary

While this research achieves a holistic redesign, the implementation of this research will most likely be done on an incremental program. This research provides a holistic solution/comparison between the 61 ideal optimized AR tracks and the multitude of restrictions previously mentioned across the vast expanse of the CONUS while still maintaining an incremental solution. In order to achieve an incremental solution, each ARTCC was reviewed independently. This break down allows for the customization (and possible elimination) of these 61 individual AR tracks across the 22 individual sectors.

IV. Analysis and Results

Historical Analysis

The historical data identifies 16,444 different AR sorties that were reported through AMC over the 2014 calendar year. Of those, 11,372 were sorties utilizing an AR Track or Anchors, which represents 69% of the overall total. Of the remaining 31% of sorties, 1,000 (6% of the total) were Altitude Reservations (ALTRVs) which are ad-hoc AR refueling requests. The remaining 25% of sorties were inside warning areas, MOAs, and ranges.

Of the 11,372 total AR tracks and Anchors, 7,845 missions (69%) used a CONUS AR track compared with a Track over Hawaii or Alaska or an AR Anchor. This data does contain certain inconsistencies, especially as the data from Altus AFB (the home of training for the KC-135 and the C-17) was missing from the database. One of the most startling pieces of data is that the most often used AR Track (777) is not actually part of the published AR track infrastructure, but a locally designed and managed track, thus showing again the antiquated nature of the national structure.

Additionally, the 2014 CONUS AR track utilization found in Appendix A clearly identifies the training nature of the majority of AR tracks. The data does identify that, of 91 specific AR tracks that are part of the CONUS infrastructure, 98% of the refueling operations (training and operational) were conducted on 57 of the tracks. This corresponds to 98% of the refueling activity occurring on 62% of the tracks which indicates significant underutilization of the infrastructure. Their location therefore can be manipulated (to a certain extent) without an adverse impact to operational requirements. However, bases with the tanker and receiver at the same base represent 17% of the overall AR track usage and the optimization equations in the following research do not account for that phenomenon. Additionally, five AR tracks (302, 20, 62,103, and 356) are significantly used for operational requirements (See Appendix A for their utilization totals) and their modification under the auspices of optimization should be offset against their operational necessity. These AR tracks are graphically depicted below in Figure 6.

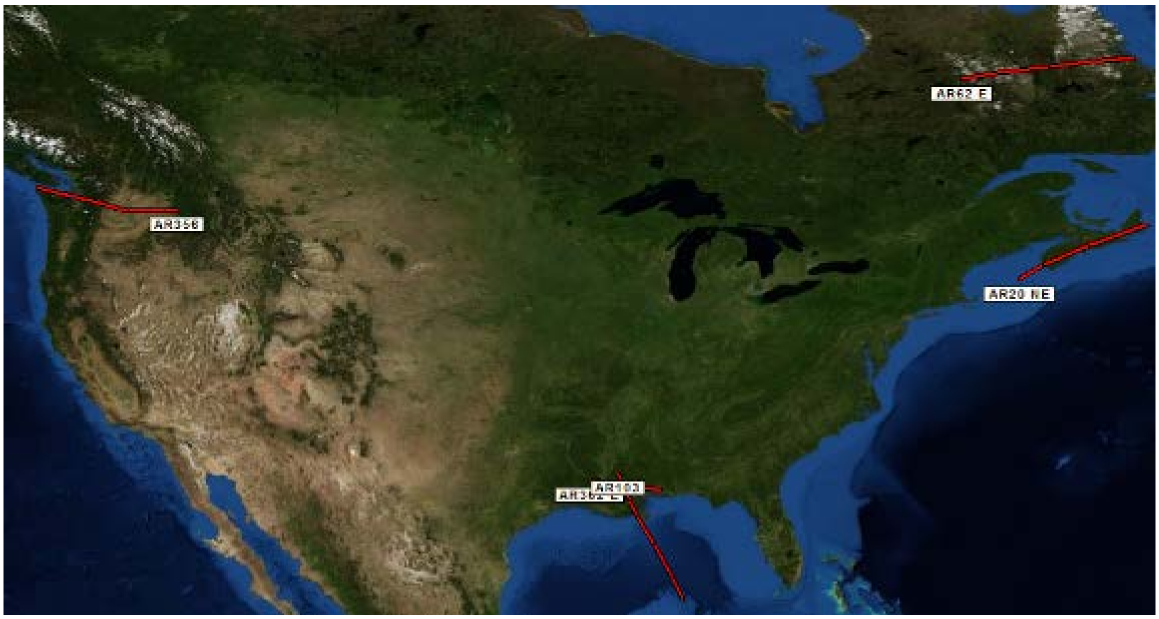

Figure 6: Operationally Used AR tracks

While this study focused on the traditional users of AR tracks, six of the AR tracks identified as having minimal usage are, in fact, low level (i.e. below 10,000 ft) tracks designed and operated by special operations forces (SOF). While these are not specifically VFR AR tracks, their usage is not tracked by AMC due to AFSOC having its own AR assets. Therefore, any analysis or conclusion on their usage cannot be accomplished with the data set analyzed. Additionally, two AR tracks (324 and 332) are owned and operated by the Puerto Rico Air National Guard (PRANG). These appear to be holdovers from the period when the PRANG had refueling C-130s (approximately 16 years ago). Their current force structure does not require holding onto AR tracks as they do not maintain any AR capable aircraft. The AR tracks that do not get utilized more than 2 times per month are graphically depicted below in Figure 7.

Figure 7: Non-Utilized AR tracks

Optimization Analysis (Reference Appendix H)

Seattle and Oakland ARTCCs

In order to optimize the northern portion of this sector, AR 356 (utilized mainly for operational reasons) was eliminated, and the Salt Lake City AGB to McChord AFB was modified to accommodate two factors. First, it was modified to avoid Restricted Area 6714 that extends up to 50,000ft MSL. Then, it was moved to enable the descent of civilian carriers IAW Figure 4. However, the reconfigured AR tracks do conflict with the ideal path for American flights from Miami to Seattle. The Miami to Seattle leg does occur once a day seven days a week and the Salt Lake City AGB to McChord AFB occurs more than twice a month, but AR 356 (which was eliminated – but lies close to the amended track) has an operational necessity of once a month.

In the southern portion of the sector (and overlapping into Oakland airspace) one must consider when Travis AFB is the sources of both the receiver and tanker (which is the second most frequent occurrence over the calendar year) and when Travis AFB receives gas from Fairchild AFB. Considering that these two pairings are responsible for 8% of the total ARs over the year and they occur more than once a day, one optimized track will not be adequate to solve the problem. Therefore, the current tracks will remain in lieu of a more optimized solution.

Denver ARTCC

Similar to Indianapolis, there is only one optimized AR track within the Denver ARTCC, and that track would only be utilized approximately 2 times a month. The optimized solution for Ellsworth AFB and McConnell AFB has the AR track running along the ARTCC border with Kansas City and Minneapolis. In order to alleviate this possible conflict, it was shifted to the west by 50 miles (the original optimization forced a 50 mile offset, so this shift places it in line between the two bases).

Minneapolis ARTCC

The Minneapolis ARTCC was separated into two distinct segments due to the competing nature or the AR tracks and the size of the airspace. The first analysis was done around the Minot AFB region. Due to the frequency of effort, there are three optimized AR tracks that service Minot AFB (from McConnell AFB, Grissom ARB, and Sioux City AGB). None of these three tracks interfered with the idealized American Airlines tracks, but the Grissom and Sioux City tracks were moved due to other reasons. The Grissom track was moved to push it into the CONUS (vs. Canadian) airspace, and also to avoid Restricted Area 4301. The Sioux City AR track was moved to also avoid Canadian Airspace, and was moved south to avoid the other two AR tracks.

The second distinct section of the Minneapolis ARTCC is the southern airspace supporting Offutt AFB. Offutt aircraft completed 638 different ARs over the year paired with 8 different tanker bases. The lion's share of the tanker effort to support Offutt based aircraft came from McConnell AFB and Lincoln AGB, with the smallest contributions coming from Selfridge AGB, Grissom ARB, and Tinker AFB. If the optimized solutions from the three smallest bases are removed from consideration (as their total is less than the sole contribution of McConnell AFB), the picture becomes slightly clearer. The next major obstacle comes from the Sioux City AGB pairing. The optimized Sioux City AGB pairing was Method 1due to a 1,000lb difference in fuel spent. When, the method 2 optimization of Sioux City AGB is analyzed, it conveniently aligns with that of Forbes AGB.

Now that four of the 8 routes have been eliminated, once must also cater the remaining AR tracks in order to eliminate conflicts. The McConnell AFB, Lincoln AGB, and Scott AFB pairings were shortened to 250NM (and as a side note the McConnell AFB optimized route will enable KC-135R/T receiver training originating from McConnell AFB). With the three AR tracks being shortened, the Forbes AGB pairing also had to be shortened in order to accommodate AR track pairings between McConnell AFB and Whiteman AFB and Scott AFB and Tinker AFB.

Kansas City ARTCC

Kansas City ARTCC is the most congested ARTCC in terms of optimized AR tracks due to the receivers located at Tinker AFB and Whiteman AFB. The analysis of Tinker AFB has two major concerns: 1. Tinker is home to both tankers and receivers and 2. 23% of their AR occurrences over the calendar year were for operational, not training purposes. Acknowledging that the most common operational tracks have already been identified, one can eliminate the MacDill AFB and JB McGuire-Dix-Lakehurst optimized pairings, as these were predominantly operational vs. training. At the southern end of the ARTCC, the pairings between Grissom ARB, Scott AFB and McConnell AFB conveniently aligned with each other, and were adjusted to eliminate one and parallel the other two.

The ideal AR track between Lincoln AGB and Whiteman AFB crosses perpendicular to 4 different idealized tracks (due it being optimized via Method 1). While the Method 2 optimization is larger by 3,000lbs, it conveniently aligns with AR tracks between McConnell AFB and Offutt AFB. The Forbes AGB and Whiteman AFB idealized track also crosses multiple idealized AR tracks and is used infrequently compared with the tracks it crosses.

The final two optimized AR tracks to be addressed in the sector are the idealized tracks between Grissom AFB, Scott AFB and Whiteman AFB. While the Grissom AFB pairing is infrequently used, the paring between Scott AFB is executed rather often. Additionally, the Grissom AFB/Whiteman AFB optimized track encroaches on Chicago arrival traffic. The only modification required of the Scott AFB pairing is to shorten it to accommodate for the Forbes AGB/Offutt AFB pairing previously discussed.

Fort Worth ARTCC

Fort Worth, Memphis and Kansas City ARTCCs have the preponderance of AR tracks due to the location of Tankers, Bombers, and Cargo Airlift being largely based in the middle of the CONUS. Barksdale AFB is a large demand on tanker assets with 2 out of the 5 most common AR base pairings (McConnell AFB and Forbes AGB). Memphis ARTCC (discussed later in the research) also deals with this problem. To solve the competing optimizations of McConnell, Forbes, and Tinker AFB and to reduce the conflict with the arrivals corridor to the Dallas Fort Worth metroplex, the AR tracks were consolidated and paralleled. The resulting two (vs. three) AR tracks provide an avenue where the desires of all the air force bases are taken care of, whilst deconflicting with the Dallas arrival structure.

Similar to Barksdale AFB, Kelly Field (part of Joint Base San Antonio) places a great demand on the tanker fleet. When looking at the sector, the idealized AR Track between McConnell AFB and Kelly Field is strikingly similar to the AR Track between Tinker AFB and Kelly Field. Both of these tracks are only utilized two and a half times a month, and utilize the same receiver aircraft (C-5s). Therefore, one can eliminate the Tinker/Kelly track and solely rely on the McConnell/Kelly Track. The McConnell/Kelly Track also avoids restricted area 5601 at Fort Sill, which extends up to 40,000ft MSL. Finally, the optimized AR track does pass in a perpendicular nature to the arrival pathways from the west into Dallas-Fort Worth International Airport. However, the volume of traffic entering the Dallas-Fort Worth Metroplex is believed to be either above (during departure) or below (during arrival) the AR track.

Next, the optimized AR Track between Salt Lake City AGB and Tinker AFB conflicts with the McConnell/Kelly track, the McConnell/Tinker track and also restricted area 5601. In order to eliminate those conflicts, the AR Track will be shortened to 260 NM, which will also assist training at Altus AFB, which is located directly below the AR track exit.

Memphis ARTCC

Memphis ARTCC can be analyzed in two separate segments, the northern portion and the southern portion. The large impact to AR operations in the Memphis sector is the demand from Barksdale AFB. In the original laydown of the optimal tracks between airfield, the AR tracks between Barksdale AFB (as the receiver location) and Scott AFB, Grissom ARB, Key Field ARB, and Birmingham AGB (tanker locations) all conflicted with each other. In order to deconflict these optimized Tracks, while maintaining their training necessity, the Grissom/Barksdale and the McConnell/Barksdale AR tracks were paralleled. Further, these parallel tracks were shortened to place them inside the Memphis and Fort Worth ARTCCs, vs. also inside the Kansas City ARTCC.

Similarly, the Birmingham/Barksdale and the Key Field/Barksdale AR tracks were also paralleled. An additional difficulty with these two AR tracks is that they lay on the same pathway between Dallas- Fort Worth and Atlanta airports. In order to deconflict these tracks from the high traffic between these two hubs, they were offset 10 NM. Fortunately for all four AR tracks, there were no MOA or restricted area conflicts to their proposed or modified locations.

In the southern portion of the Memphis sector, bordering on the Houston ARTCC, the ideal leg between Key Field and Jackson AGB ran perpendicular to the Birmingham/Barksdale and Key Field/Barksdale AR tracks. In order to accommodate all three, the Key Field/Jackson leg was shortened to 250 NM. On the south eastern portion of the Memphis sector crossing into the Jacksonville ARTCC is the ideal AR track between MacDill AFB and Jackson AGB. This optimized AR track conflicts with multiple MOAs and warning areas from the Pensacola and Eglin AFB region and was therefore move to the Northeast by 20 NM to avoid these conflicts. The adjusted route does go through the terminal areas of Tallahassee, Meridian, and Montgomery, but due to the volume of commercial traffic should not hinder air traffic into these airfields.

Finally, the Birmingham AGB and Memphis AGB optimized track does not conflict with any other AR Track nor does it conflict with any MOA or Restricted Area. While it does not appear to conflict with commercial traffic, the limitation of using American Airlines data and not data from an airline using Memphis or Atlanta for their respective hubs negatively impacts the analysis.

Indianapolis ARTCC

The Indianapolis sector is rather simple compared with the other sectors considered in this research. The only optimized AR track completely located in the sector is the track between Grissom ARB and Wright Patterson AFB. This proposed AR Track lies directly over both Cincinnati and Indianapolis airports, but does not affect their arrival and departure legs. Further, consideration, however, should be given to commercial traffic in and out of Chicago. The AR track also avoids the one restricted area that exceeds 18,000 MSL.

New York, Boston, and Cleveland ARTCC

While the eastern seaboard is home to multiple Air Force Bases, the airspace concerns reflect a greater usage and population density. Unlike the Fort Worth and Memphis ARTCCs which balanced a multitude of bases against rather wide open airspace, the New York, Boston and Cleveland ARTCCs must balance a reduced amount of bases against an extremely busy airspace. Due to said congested airspace, two ideal AR tracks are able to be immediately eliminated from consideration due to their conflicts with commercial traffic. The AR track between Joint Base (JB) McGuire-Dix-Lakehurst and Westover AGB transits along the coast between Washington DC and ends over Boston, which conflicts directly with commercial traffic in and out of these major airports and also with any traffic proceeding to and from the North Atlantic. Similarly, the Dover AFB tracks with Andrews AFB and JB McGuire-Dix-Lakehurst conflict with the Washington DC, Patuxent River, and Aberdeen proving ground restricted areas, and the commercial traffic passing through the eastern seaboard.

The ideal AR tracks between Bangor AGB and JB McGuire-Dix-Lakehurst and Pease AGB and Dover AFB fall largely along the same path and these base pairings accounted for 130 AR occurrences in the average calendar year. The Bangor/JB McGuire AR track is most viable as it conflicts least with commercial traffic. The Selfridge AGB and JB McGuire-Dix-Lakehurst also runs perpendicular to the majority of traffic transiting to and from the northeast and its southern end conflicts directly with the arrival and departure corridor into Washington DC. In order to keep the track (which is utilized 39 times a year – not too often), the track must be shortened to 200NM long.

Pittsburg AGB refuels with Dover AFB and JB McGuire-Dix-Lakehurst over 200 times a year, but like the problem previously encountered with the Selfridge/McGuire AR Track, the AR tracks for Pittsburg/Dover and Pittsburg/McGuire must be shortened and adjusted to accommodate commercial traffic in and out of the Washington Metroplex. Luckily, these AR tracks also overlay the ideal track between Grissom ARB and JB McGuire-Dix-Lakehurst, which eliminates the need for duplication for a pairing that occurs less than once a week.

Finally, the most common AR Track and paring used was AR 777, which, as discussed earlier, is a locally designed AR Track and is not part of the current national structure. This AR track does not conflict with any SUAS boundaries or commercial traffic, and remains within the ARTCC boundaries. Due to the lack of conflicts, the amount of usage, and the fact that the preponderance of usage for the track comes from a base where the tanker and receiver are co-located, this track (similar to the situation at Travis AFB) will remain untouched as part of the optimization process.

What started out as nine different idealized tracks and one locally designed track across the most congested airspace in the CONUS can be reduced to four modified tracks and one pre-existing AR Track which can benefit all users of the airspace.

Atlanta & North Jacksonville ARTCC

Similar to the concerns of the Northern Eastern seaboard, the Atlanta sector is compounded by the volume of civilian traffic that transits the two cities of Atlanta and Charlotte. Additionally, the off coast warning areas that constricted the Jacksonville AR (as previously discussed) provide constraints that must be managed. Charleston AFB (being home to a large preponderance of C-17s) is the major user of AR amassing a total of 532 different AR events over the calendar year. Their major partner in AR (MacDill AFB, was analyzed in the specific Jacksonville ARTCC section, but the remaining six major partners were not.

The optimized AR track between Charleston AFB and JB McGuire-Dix-Lakehurst, McGee-Tyson ARB, and Seymour Johnson AFB fall along a relatively similar course and location. Taking into account the volume and location of commercial traffic, and the location of ARTCC boundaries, it is mutually beneficial to consolidate the three ideal routes into one. Although JB McGuire-Dix-Lakehurst is the larger preponderance of usage in this equation, the optimized track between Seymour-Johnson and Charleston eliminates complications with Washington DC traffic and does not “ride the line” of sectors between Atlanta and Jacksonville. The optimized tracks between McGee-Tyson and JB McGuire-Dix-Lakehurst are thereby eliminated.

The remaining three partners with Charleston AFB are Pittsburg AGB, Rickenbacker AGB (Ohio), and Grissom ARB. These three bases represent 27% of the AR usage from Charleston, of which Pittsburg has the largest preponderance. Again, the three proposed AR tracks must be analyzed against the commercial aircraft corridors and the idealized track established in the previous paragraph (between Seymour Johnson AFB and Charleston AFB). Due to this, the idealized AR track requires shortening from 300NM to 250NM. This does place the AR track over three different AR sectors, but this is more a function of the congested airspace rather than any other concern.

The final optimized AR track within the Atlanta ARTCC does not pair with Charleston AFB, but instead between Warner-Robins AFB and Pittsburg AGB. While this does meet the minimum criteria of at least 24 occurrences over the calendar year, its usage is dwarfed by the requirements of Charleston. Additionally, Warner-Robins AFB is already serviced by an idealized AR track between it and MacDill AFB. The AR track between Pittsburg AGB and Charleston AFB will also serve to accommodate any AR between Pittsburg and Warner-Robins.

Jacksonville ARTCC

The Jacksonville sector suffers from extremely congested airspace with vastly competing interests. The optimized AR Track between MacDill AFB and Charleston AFB fall directly within the confines of multiple warning areas off the coast of Jacksonville, and any move west for the track would put it within multiple MOAs and conflict with commercial track. Therefore, it is best for this pairing (utilized 119 times over the annual period) to maintain AR 202 which falls outside the warning area.

The MacDill AFB and Warner-Robins AFB paining must be modified to provide separation from the McGee Tyson AGB-Charleston AFB Track and also Restricted Areas 2903 and 2910 that go up to 23,000ft MSL. Further, the adjustment must avoid the commercial traffic into Savannah, Tampa and Orlando. Therefore the track was shifted to the west and modified for length. The resultant track is 250 miles long vs. the standard 300 miles long, and is slightly offset from the optimized path.

Investigative Questions Answered

Analysis on the historic usage of AR tracks proved suitable to answer the first two investigative questions identified at the beginning of the paper. If one was to eliminate the SOF controlled AR tracks from consideration, 28 AR tracks (31% of the total) remain that did not get utilized more than once a month over the course of the year, which indicates a vast disconnect between the design of the infrastructure and its actual usage. These 28 tracks can be eliminated from the infrastructure purely on the basis of usage. While 6 of those 28 tracks were utilized for operational purposes, their infrequency of utilization precludes the blocking of said airspace and can be overcome by an ALTRV request. If one was to increase the requirement of usage to two times a month, an additional 7 tracks may be eliminated. This number is derived from the 9 additional tracks that were utilized less than 24 times over the calendar year, but subtracting out the 2 tracks that were used exclusively for operational purposes. Thus, 38% of the AR track infrastructure appears to be underutilized.

Table 2: Tracks Proposed for Elimination (in numerical order)

Track	Owning Organization
4	62 OSS, McChord Field
9	120 FW, Great Falls
14	28 OSS, Ellsworth AFB
19	28 OSS, Ellsworth AFB
80	EADS, Rome
81	EADS, Rome
102	2 OSS, Barksdale AFB
107	Alpena CRTC
108	2 OSS, Barksdale AFB
109	55 OSS, Offutt AFB
114	7 OSS, Dyess AFB
121	49 OSS, Holloman AFB
167	149 FG, Kelly AFB
197	97 OSS, Altus AFB
205	305 OSS, McGuire AFB
214	NSAWC, NAS Fallon
217	171 OSS, Pittsburg ANG
218	171 OSS, Pittsburg ANG
219	171 OSS, Pittsburg ANG
233	60 OSS, Travis AFB
318	126 ARW, Illinois ANG
324**	156 AW, Puerto Rico ANG
332**	156 AW, Puerto Rico ANG
355	55 OSS, Offutt AFB
452	366 OSS, Mountain Home AFB
453	55 OSS, Offutt AFB
462	60 OSS, Travis AFB
729	Already Eliminated

The third and fourth investigative questions attempted to identify the optimal solutions for AR tracks between the most common AR base pairings and to then offset those optimized routings against each other and the proposed NAS redesign. The two methods of optimization identified 61 different ideal AR Track locations based on current basing. These 61 were then weighed against each other, SUAS boundaries, the proposed point to point direct flight of commercial carriers, and also (for the 17% of AR activity that originated from the same base) the current existing AR structure.

The most complicated (and manual) part of the solution set was the offset of the proposed optimal solutions to ARTCC boundaries, SUAS boundaries, and the flight schedule of American Airlines.

Summary

The historical analysis identified a bloated AR track infrastructure that can be streamlined. Of the 91 active AR tracks, only 57 were utilized more than twice a month or for operational purposes. Of that 57, 3 were AR tracks that were utilized less than twice a month, but were solely used for operational purposes. 98% of the AR track usage was performed on 62% of the AR track infrastructure.

The analysis of actual AR usage revealed 61 different base pairings that most utilized the AR infrastructure. Those 61 different pairings were then optimized and compared with each other, ARTCC boundaries, SUAS boundaries, and the desired flight tracks of American Airlines under Next Gen air traffic ideals. By offsetting the usage and airspace concerns of the 61 different optimized paths, 42 different AR tracks remain (34 as a result of optimization, 4 due to operational purposes, 4 due to same base originating traffic) that accommodate all the constraints of the complex airspace concerns.

V. Conclusions and Recommendations

Current AR Structure

98% of the AR track usage for 2104 over the CONUS was performed on 62% of the AR track infrastructure. This is an alarming indicator of a bloated infrastructure that has not kept up with actual demand. While critics may argue that the infrastructure exists for contingency operations, the extensive use of ALTRVs (ad-hoc AR refueling requests that composed 6% of the 2014 usage) shows that there are other avenues to maintaining infrastructure. Regardless of the implementation of the optimization model for future usage, the 2014 historical analysis supports the elimination of the 28 tracks that were not used at least 1 time per month over the calendar year. The DoD in conjunction with the FAA may opt to go further and eliminate a further 7 tracks that were not utilized at least 2 times a month over the year. The elimination of these tracks provides multiple benefits as its streamlines the current AR structure, it alleviates the responsibility of the owning organization, and it eliminates the requirement for the owning airspace authority for maintaining it.

Further, the AR track that was utilized the most over the calendar year (AR 777) is not part of the national infrastructure, and this analysis shows that it should be added in order to properly illustrate the AR tracks that exist. Additionally, the track should be added to provide greater visibility to all parties involved. Its absence from the national database prevents commercial partners from planning around it, and non-local users from utilizing the track.

Future AR Structure

The optimized solution for the future of the AR infrastructure utilized 2014 usage data and two mathematical optimization equations. 42 different AR tracks have been consolidated from the original 91, which will sufficiently handle both the operational and training requirements of the MAF, while optimizing the amount of training. It is important to note that the different optimization equations were used for 34 different pairings, and were adjusted based on their impact to commercial traffic, SUAS boundaries, and ARTCC borders. The 4 AR tracks predominantly used for operational purposes were maintained in their geographic locations, and the 4 AR tracks that supported same base originating traffic or provided a non-optimized solution due to other conflicts (out of Joint Base McGuire-Dix-Lakehurst, Travis AFB, and AR 202 which conflicted with the Atlantic Warning areas) were also maintained.

Significance of Research

This analysis and optimization was done in order to streamline airspace operations and increase training effectiveness at a time when airspace across the CONUS is getting more congested and inflight training opportunities are dwindling. The USAF and FAA should come to an agreement via the Policy Board for Federal Aviation, where they can discuss the implementation on the whole study. The USAF stands to gain efficiencies in aircraft training, which can be directly tied to MAF readiness. At a time when hours spent flying overseas in support of the Global War on Terror are dwindling, the utilization of the hours remaining becomes more crucial. Furthermore, the commercial sector stands to save money by eliminating some of the fuel buffer that they currently carry to avoid AR training activities. The amount that the commercial sector can save by this survey cannot be determined by this study, as the fuel carried numbers were not provided due to individual company policy. However, even though oil prices are currently at all-time lows, even reducing the amount of fuel onboard an aircraft by 100lbs across the entire fleet of aircraft will save millions of dollars.

Again it is important to note that the optimization does not result in the elimination of flight hours, but the better utilization of said hours. The shorter amount of time spent getting to the track allows for a greater amount of time spent doing AR training. This greater utilization of flying hours towards the overall training objectives enables the MAF and CAF to achieve higher training levels, and thereby increased overall readiness.

Recommendations for Action

This research supports the following recommendations:

1) Based on the historical analysis:
    a. Eliminate the 28 tracks that were not used at least 1 time per month over the calendar yea
    b. Eliminate a further 7 tracks that were not utilized at least 2 times a month over the year.
    c. Add a data element to GDSS2 to show the departure and arrival airfield of the receiver aircraft. If said data element already exists, it is recommended to add to the business intelligence tool availability for research applicability.

2) Based on the Optimization model:

   a. Eliminate the current AR track infrastructure and replacing it with the proposed optimal solutions from this research. This would eliminate 91 AR tracks, and replace it with 42 tracks, which gives greater flexibility to the FAA and optimizes training ability for USAF aircraft.

Understanding that applying a holistic redesign to the entire CONUS airspace infrastructure with a proof of principle is rather unrealistic, the implementation of the model can be applied incrementally. The methodology of this research analyzes by individual ARTCCs which lends implementation of the model to an incremental approach. The FAA and DoD can begin with the least complex sectors (e.g. Seattle ARTCC) and move forward to each sector incrementally. Furthermore, they can align the AR track redesign with the Metroplex initiative currently underway with the NextGen program. Incremental implementation offers multiple advantages to include the ability to assess the effects of unintentional consequences of the redesign.

Finally, it is also important to ensure that this analysis is done each year following either path taken. The MAFOPs database allows an ease of access for this information, and, if the data element is added to GDSS2 (per the above recommendation), the historical analysis may be accomplished with greater fidelity. Regardless of which path is taken, it is vital to conduct an annual study on the use of resources so that any further adjustments may be initiated. Following the implementation of the elimination of current tracks or the implementation of the full optimization or even changes in the training patterns of the USAF the usage statistics will change, and thus the AR track infrastructure must remain malleable.

Recommendations for Future Research

This research focused on the traditional AR tracks and eliminated from consideration AR Anchors and VFR AR tracks. However, they represent just under half of the AR infrastructure, and a significant impediment to the optimization of the CONUS airspace. A cursory analysis of the AR Anchor infrastructure (utilizing the same database) reveals that 29 of the 62 Anchors are used more than twice a month over the year. Incorporating an optimization model to the Anchors and VFR AR tracks would aid in the implementation of the NextGen infrastructure.

Summary

This study leaves the USAF and the FAA with two ways forward. First, if the decision is made to not make drastic changes to the AR infrastructure, the elimination of either 28 or 35 tracks (from the overall 91) can be made without a significant impact to operations or training. If the decision is made to further optimize the AR infrastructure to fall in line with NextGen updates, the 42 identified tracks will fulfill the USAF operational and training needs, while also offsetting military activity from commercial interests.

Appendix A - Current CONUS AR tracks and Anchors

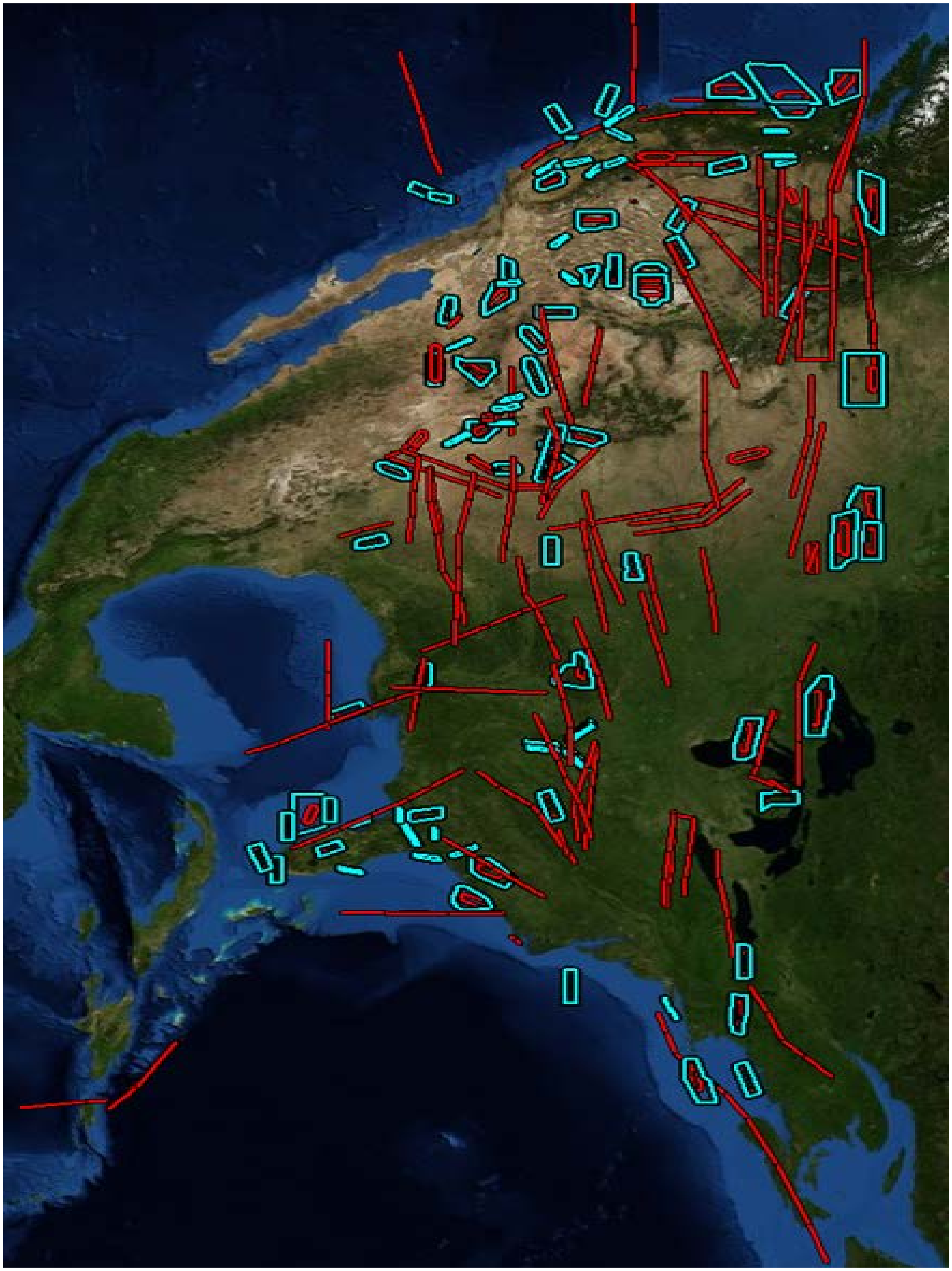

Figure 8: Current CONUS AR tracks and Anchors

Appendix B – CONUS AR Track Utilization

Table 3: CONUS AR Track Utilization

AR TRACK	Operational	Training	Totals	AR TRACK	Operational	Training	Totals
777	3	624	627	314	0	25	25
112	3	429	432	62	24	0	24
7	2	367	369	103	23	0	23
105	1	338	339	312	0	23	23
406	0	331	331	400	0	21	21
110	5	310	315	779	0	20	20
220	0	282	282	2	1	16	17
212	1	265	266	12	0	13	13
302	30	227	257	356	13	0	13
207	0	246	246	3	3	9	12
202	2	241	243	17	0	12	12
204	2	223	225	14	0	9	9
309	7	210	217	107	0	9	9
8	0	207	207	318	0	9	9
330	5	196	201	109	2	6	8
101	7	186	193	219	2	5	7
338	1	186	187	4	0	6	6
216	1	171	172	9	1	4	5
111	4	166	170	19	1	4	5
455	0	164	164	217	1	4	5
328	2	152	154	108	0	4	4
6	8	145	153	218	0	4	4
20	132	5	137	355	3	0	3
313	0	134	134	452	0	3	3
16	3	128	131	114	0	2	2
116	7	118	125	121	0	2	2
206	0	119	119	462	0	2	2
201	2	104	106	80	0	1	1
10	6	94	100	197	0	1	1
315	3	93	96	233	1	0	1
104	0	89	89	729	0	1	1
307	6	83	89	81	0	0	0
337	0	72	72	102	0	0	0
209	7	63	70	115*	0	0	0
200	11	58	69	167	0	0	0
113	3	64	67	205	0	0	0
255	3	54	57	208*	0	0	0
11	2	51	53	214	0	0	0
24	0	49	49	221*	0	0	0
5	15	29	44	222*	0	0	0
106	2	35	37	223*	0	0	0
203	0	36	36	224	0	0	0
13	3	31	34	324**	0	0	0
321	0	34	34	332**	0	0	0
310	8	22	30	453	0	0	0
1	6	21	27				

* Indicates AR tracks owned/operated by SOF Wings
** Indicates AR tracks owned by the Puerto Rico Air National Guard

Appendix C – AR Missions between ICAOs

Table 4: AR Missions between ICAOs

ICAO Pair	# AR Msns	ICAO Pair	# AR Msns	ICAO Pair	# AR Msns	ICAO Pair	# AR Msns
KWRI-KWRI	604	KBHM-KBAD	62	KGSB-KWRI	26	KMTC-KCHS	16
KSUU-KSUU	530	KWRI-KTIK	59	KPIT-KWRB	25	KGSB-KDOV	16
KSKA-KTCM	320	KIAB-KMIB	58	KBHM-KMEM	25	KLCK-KWRI	16
KIAB-KBAD	227	KPSM-KDOV	57	KGUS-KMIB	25	KPIT-KTIK	15
KIAB-KOFF	177	KMEI-KJAN	55	KGUS-KSZL	24	KFOE-KMIB	15
KSKA-KSUU	149	KFOE-KSZL	54	KGUS-KFFO	24	KADW-KWRI	15
KBGR-KWRI	137	KMKE-KOFF	53	KIAB-KTCM	23	KRIV-KSUU	15
KFOE-KBAD	131	KPSM-KWRI	50	KMEI-KSZL	23	KMKE-KTIK	15
KIAB-KSZL	119	KTIK-KTIK	48	KBHM-KTIK	22	KLNK-KMIB	14
KMCF-KCHS	119	KADW-KDOV	47	KIAB-KWRI	22	KWRI-KOFF	14
KPIT-KDOV	117	KMCF-KJAN	45	KIAB-KLSV	22	KMKE-KSZL	14
KWRI-KCHS	115	KMCF-KTIK	43	KTYS-KDOV	22	KMEI-KTIK	14
KPIT-KWRI	115	KGUS-KWRI	42	KTYS-KMEM	21	KPIT-KMRB	14
KIAB-KIAB	107	KGUS-KCHS	40	KSKA-KMIB	20	KRIV-KFFO	14
KLNK-KOFF	107	KGUS-KOFF	39	KPIT-KSWF	20	KBLV-KCHS	14
KIAB-KTIK	105	KMTC-KWRI	39	KWRI-KBAD	19	KSKA-KSWF	14
KBLV-KBAD	94	KLCK-KCHS	38	KMCF-KSZL	19	KSKA-KSZL	13
KGSB-KCHS	89	KSLC-KTCM	32	KBHM-KSZL	19	KWRI-KSZL	13
KBLV-KOFF	89	KGUS-KBAD	32	KTIK-KJAN	19	KBHM-KWRB	13
KRIV-KRIV	88	KTIK-KSZL	32	KMTC-KDOV	19	KPIT-KFFO	13
KSUX-KOFF	74	KMEI-KBAD	31	KMCF-KBAD	18	KBLV-KMIB	13
KBLV-KTIK	73	KTIK-KOFF	31	KBHM-KCHS	18	KGUS-KWRB	13
KPIT-KCHS	70	KMCF-KWRB	30	KMKE-KFFO	18	KBLV-KMEM	13
KSLC-KTIK	68	KIAB-KSKF	30	KPSM-KTIK	17	KPSM-KBAF	13
KFOE-KOFF	68	KSUX-KMIB	28	KADW-KCHS	17	KADW-KSZL	13
KTYS-KCHS	68	KTIK-KSKF	28	KGUS-KDOV	17	KCHS-KCHS	13
KTIK-KBAD	67	KLNK-KSZL	27	KGSB-KWRB	16	KWRI-KTCM	12
KBLV-KSZL	67	KIAB-KRCA	26	KLCK-KWRB	16	KIAB-KJAN	12
KWRI-KDOV	66	KWRI-KCEF	26	KSKF-KSKF	16	KWRI-KWRB	12
KGUS-KTIK	63	KSUU-KTCM	26	KIAB-KLTS	16	KSUU-KTIK	12
KBGR-KDOV	63	KTCM-KTCM	26	KBLV-KRCA	16	KLCK-KDOV	12

- Green Highlight indicates same ICAO base pair (i.e. tanker and receiver from the same base)
- ICAO pairings less than 12 not listed in table
- KTCM pairing due to tankers on business efforts to KTCM from Home Station

Appendix D – Air Route Traffic Control Centers (ARTCCs)

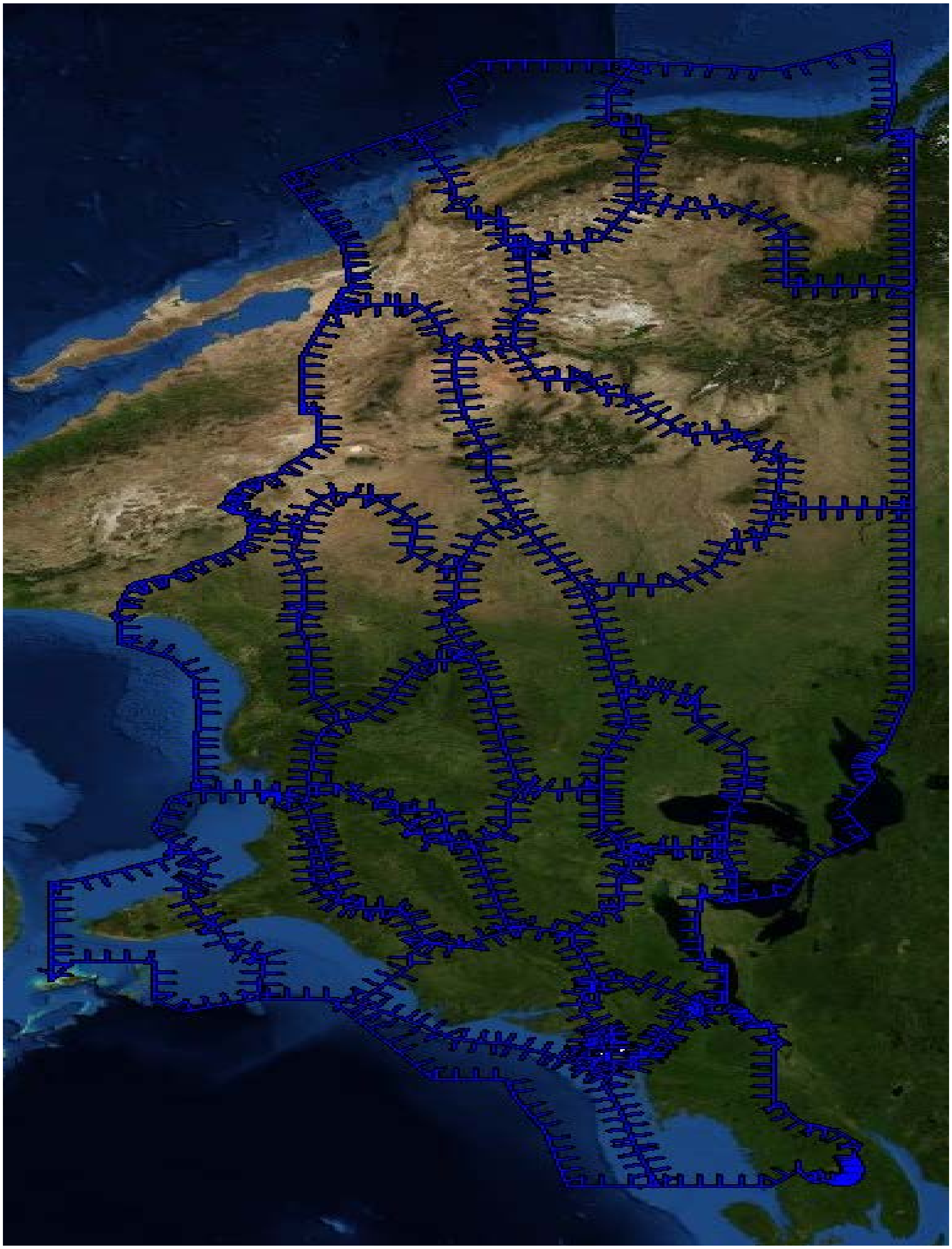

Figure 9: Air Route Traffic Control Centers (ARTCCs)

Appendix E – Special Use Airspace (SUAS)

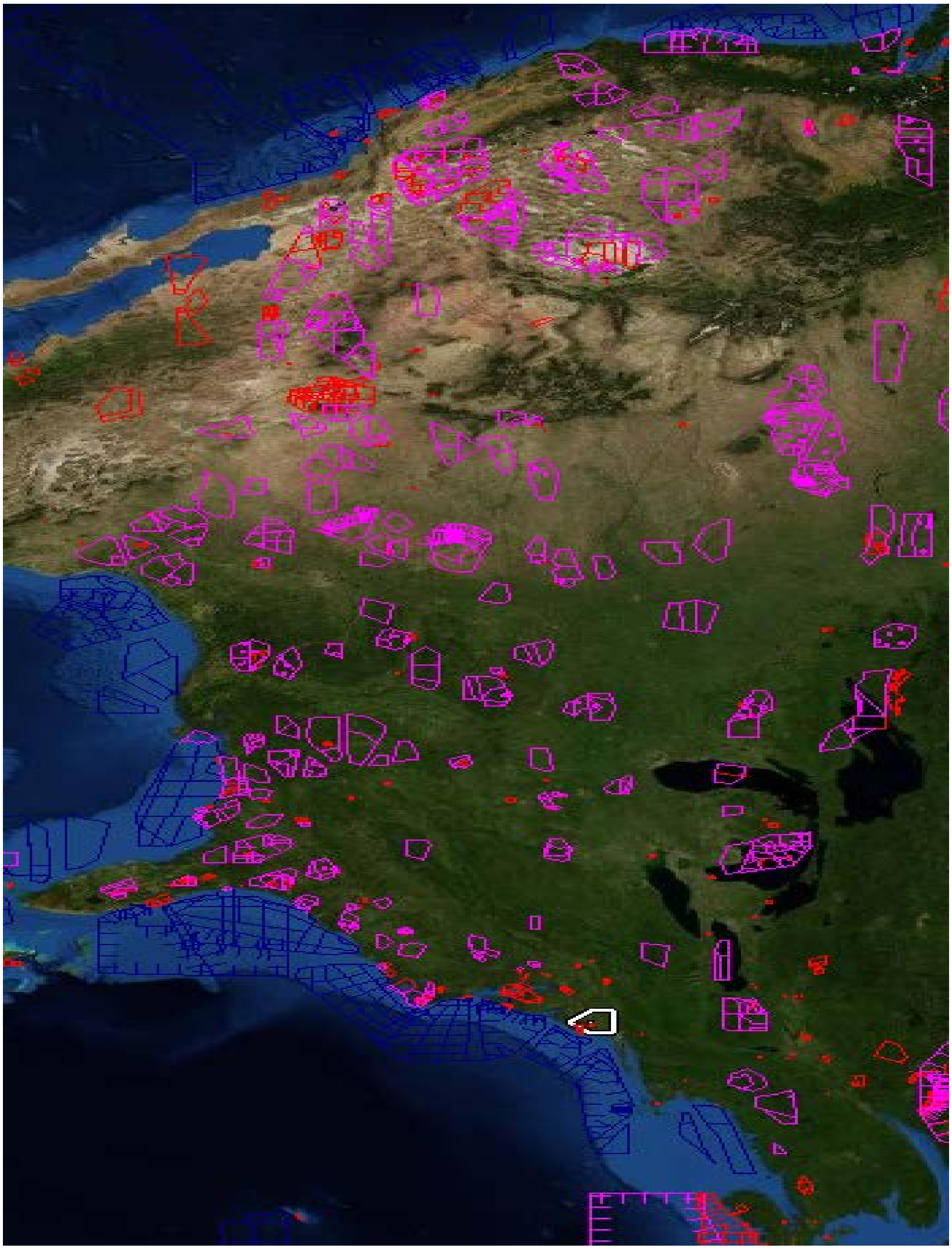

Figure 10: Special Use Airspace (SUAS)

Appendix F – Initial Optimized AR tracks w/o Adjustment

Figure 11: Initial Optimized AR tracks w/o Adjustment

Appendix G – Final Optimized AR tracks w/Adjustments

Figure 12: Final Optimized AR tracks w/Adjustments

Appendix H – Individual ARTCC Optimizations

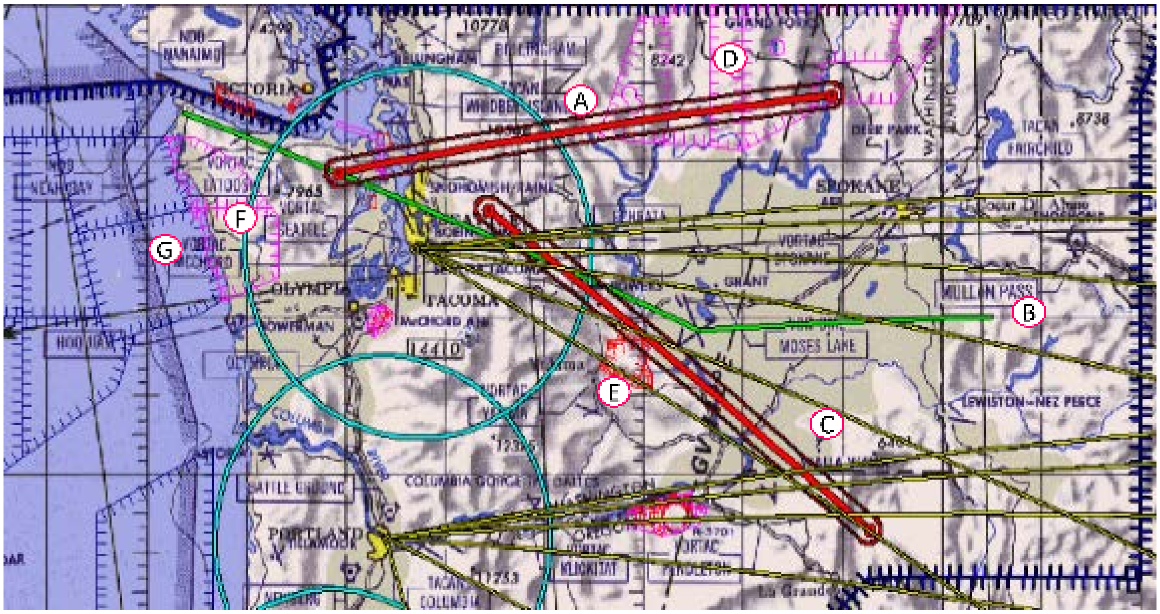

Figure 13: Seattle ARTCC Initial Optimization

Table 5: Seattle ARTCC Points of Interest

A – Ideal KSKA – KTCM (Red)	E – Restricted Area 6714 – Up to 29,000 MSL (Red)
B – AR 356 – Operationally Used (Green)	F – Olympic MOA – Up to 18,000 MSL (Pink)
C – Ideal KSLC – KTCM (Red)	G – Warning Area 237 – Up to 50,000 MSL (Blue)
D– OKANOGAN MOA – Up to 18000 MSL (Pink)	
Light Blue Rings indicate 75NM buffer around airfield for commercial descent	
Yellow lines are commercial traffic (above 30,000 MSL unless landing at airfield with blue ring)	

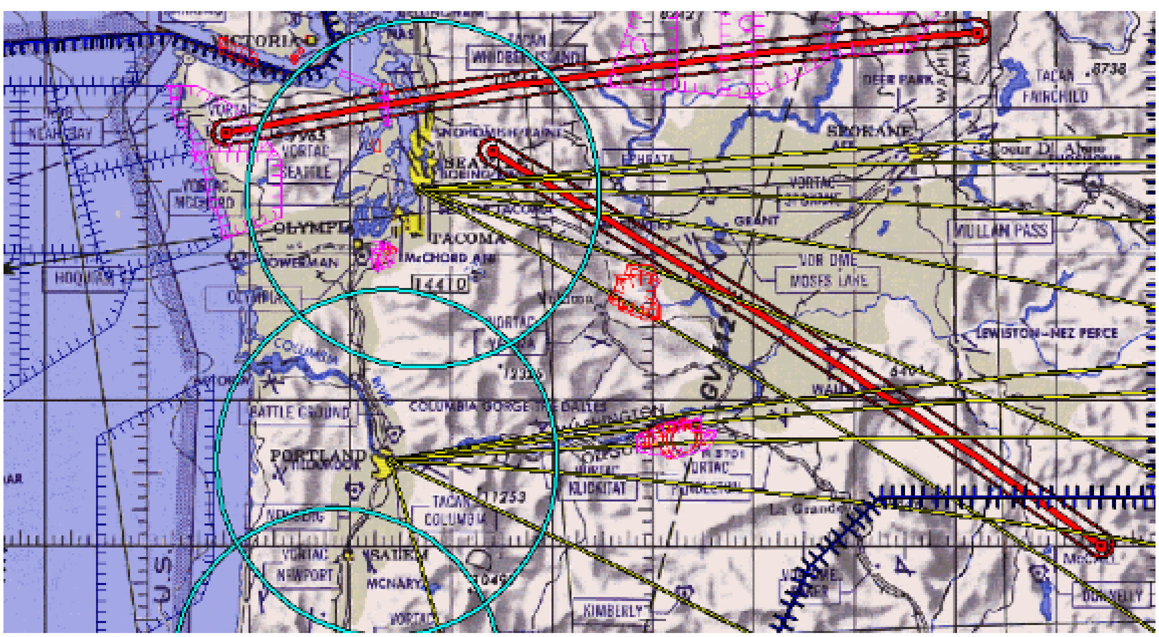

Figure 14: Seattle ARTCC Final Optimization

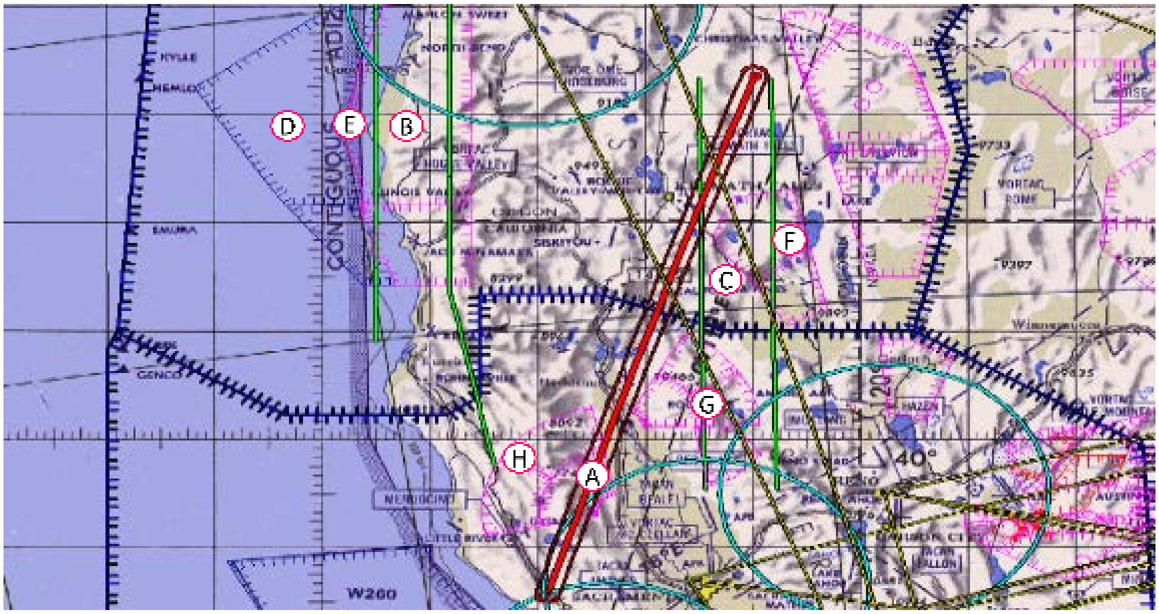

Figure 15: Seattle-Oakland ARTCC Initial Optimization

Table 6: Seattle-Oakland ARTCC Points of Interest

A – Ideal KSKA – KSUU (Red)	E – Dolphin MOA – Up to 18,000 MSL (Pink)
B – AR 8A, 8B (Green)	F – Goose MOA – Up to 18,000 MSL (Pink)
C – AR 7A, 7B (Green)	G – Whitmore MOA – Up to 18,000 MSL (Pink)
D – Warning Area 93 – Up to 50,000 MSL (Blue)	H – Maxwell MOA – Up to 18,000 MSL (Pink)
Light Blue Rings indicate 75NM buffer around airfield for commercial descent	
Yellow lines are commercial traffic (above 30,000 MSL unless landing at airfield with blue ring)	

Figure 16: Seattle-Oakland ARTCC Final Optimization

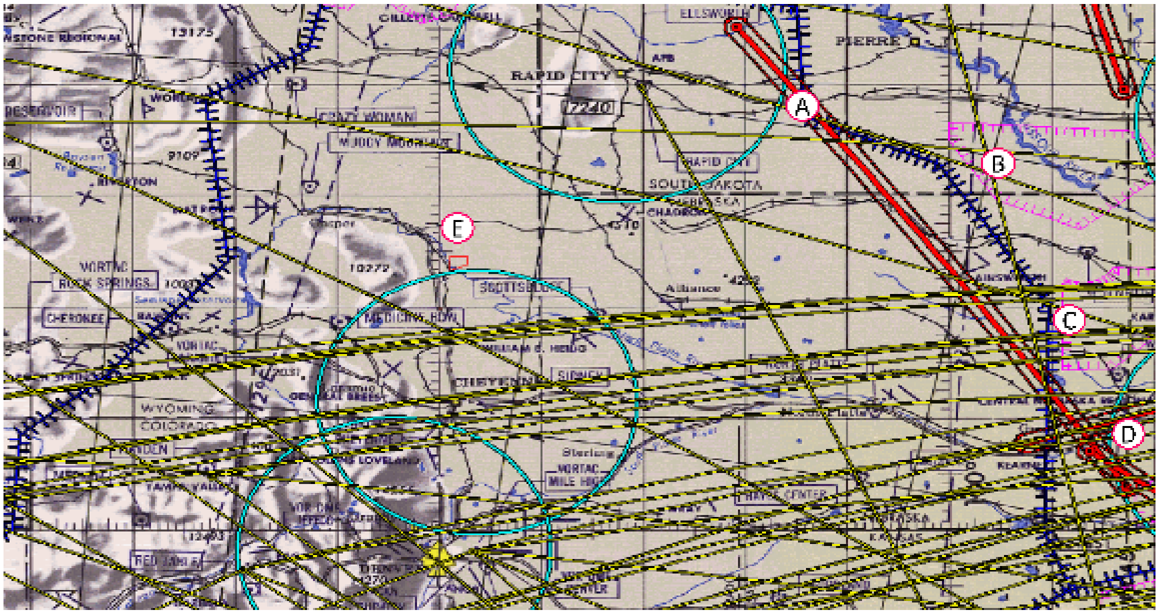

Figure 17: Denver ARTCC Initial Optimization

Table 7: Denver ARTCC Points of Interest

A – Ideal KIAB – KRCA (Red)	E – Restricted Area 7001 – Up to 8,000 MSL (Red)
B – Lake Andes MOA – Up to 18,000 MSL (Pink)	
C – O'neill MOA – Up to 18,000 MSL (Pink)	
D – Lincoln MOA – Up to 18,000 MSL (Pink)	
Light Blue Rings indicate 75NM buffer around airfield for commercial descent	
Yellow lines are commercial traffic (above 30,000 MSL unless landing at airfield with blue ring)	

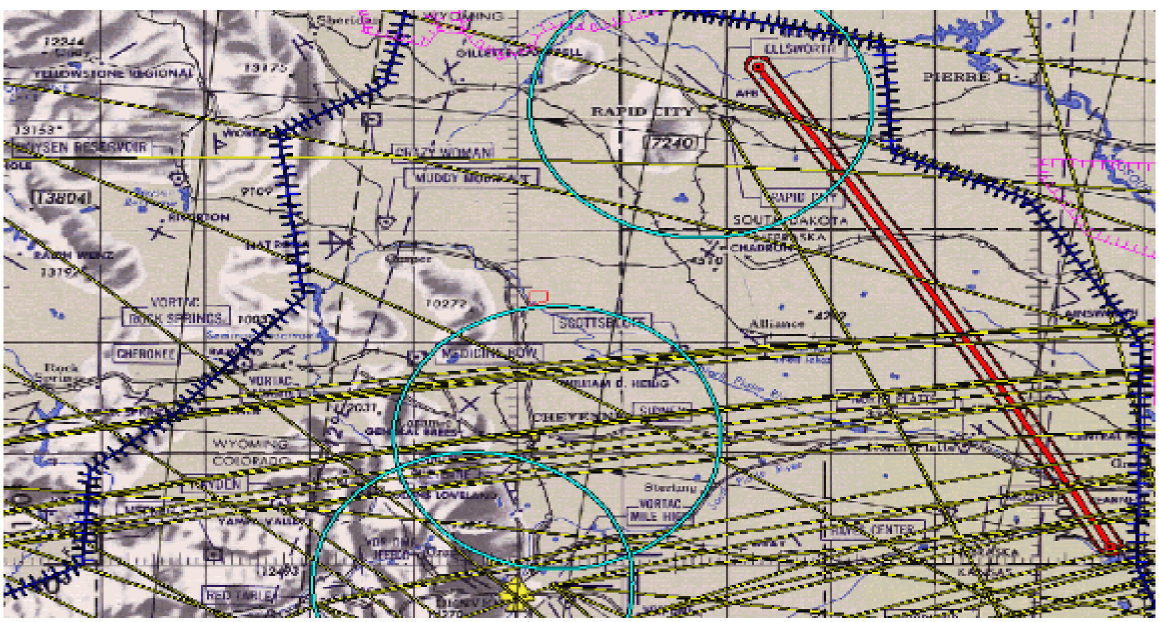

Figure 18: Denver ARTCC Final Optimization

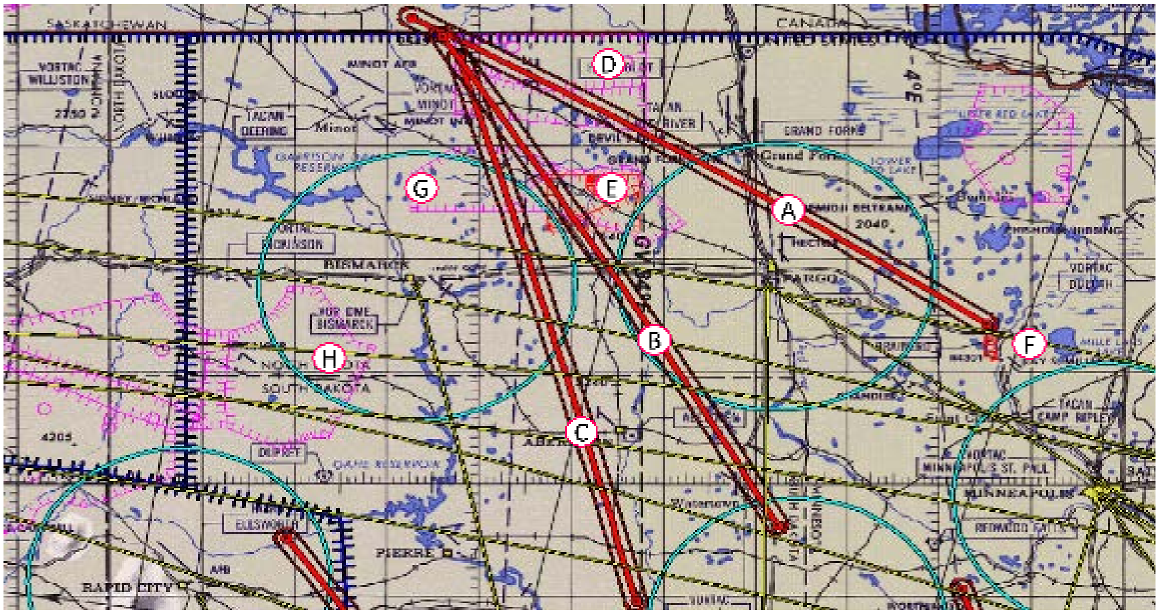

Figure 19: Northern Minneapolis ARTCC Initial Optimization

Table 8: Northern Minneapolis ARTCC Points of Interest

A – Ideal KGUS - KMIB (Red)	E – Restricted Areas 5402,3 – Up to 12,000 MSL (Red)
B – Ideal KSUX - KMIB (Red)	F – Restricted Area 4301 – Up to 27,000 MSL (Red)
C – Ideal KIAB - KMIB (Red)	G – Devils Lake E/W MOA – Up to 18000 MSL (Pink)
D– Tiger North/South MOA – Up to 18000 MSL (Pink)	H – Powder River MOA – Up to 18000 MSL (Pink)
Light Blue Rings indicate 75NM buffer around airfield for commercial descent	
Yellow lines are commercial traffic (above 30,000 MSL unless landing at airfield with blue ring)	

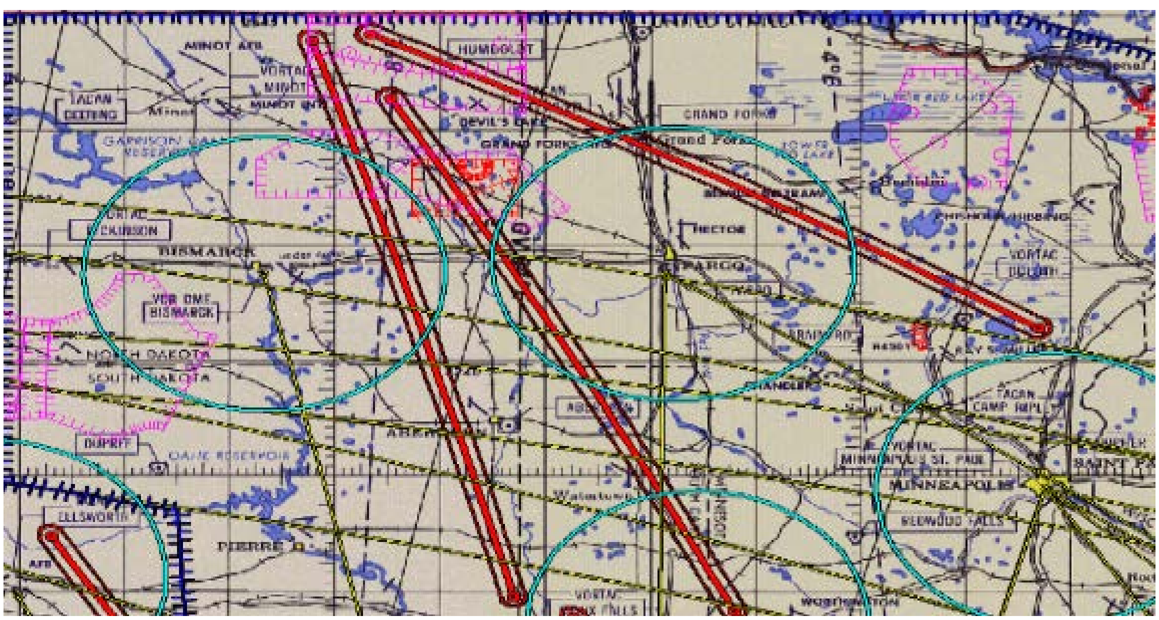

Figure 20: Northern Minneapolis ARTCC Final Optimization

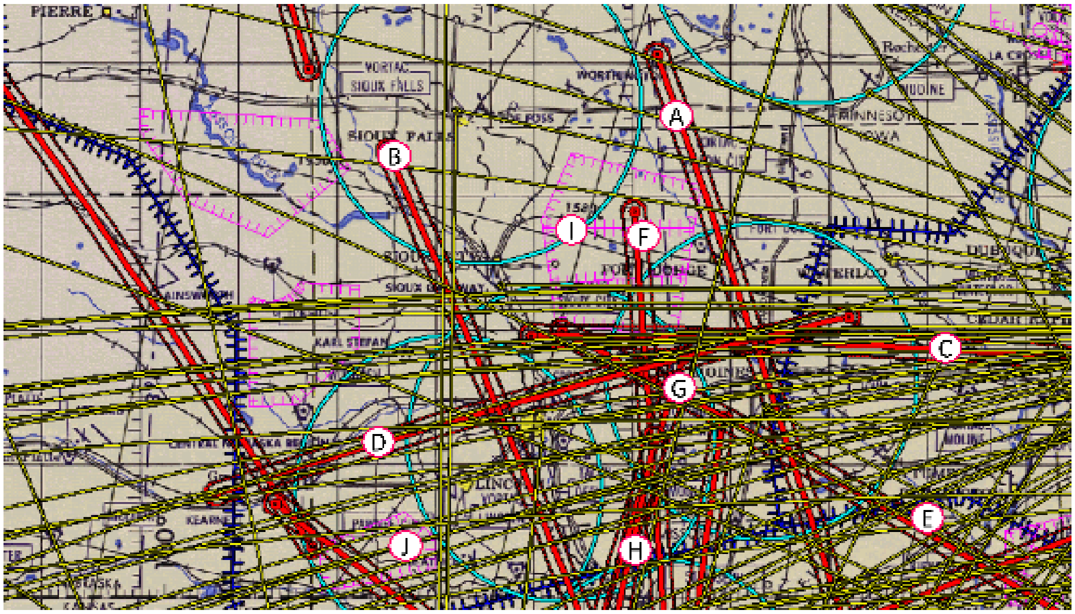

Figure 21: Southern Minneapolis ARTCC Initial Optimization

Table 9: Southern Minneapolis ARTCC Points of Interest

A – Ideal KMKE – KOFF (Red)	F – Ideal KFOE – KOFF (Red)
B – Ideal KLNK – KOFF (Red)	G – Ideal KIAB – KOFF (Red)
C – Ideal KGUS – KOFF (Red)	H – Ideal KTIK – KOFF (Red)
D – Ideal KSUX – KOFF (Red)	I – Crypt MOA – Up to 18000 MSL (Pink)
E – Ideal KBLV – KOFF (Red)	J –Lincoln MOA – Up to 18000 MSL (Pink)
Light Blue Rings indicate 75NM buffer around airfield for commercial descent	
Yellow lines are commercial traffic (above 30,000 MSL unless landing at airfield with blue ring)	

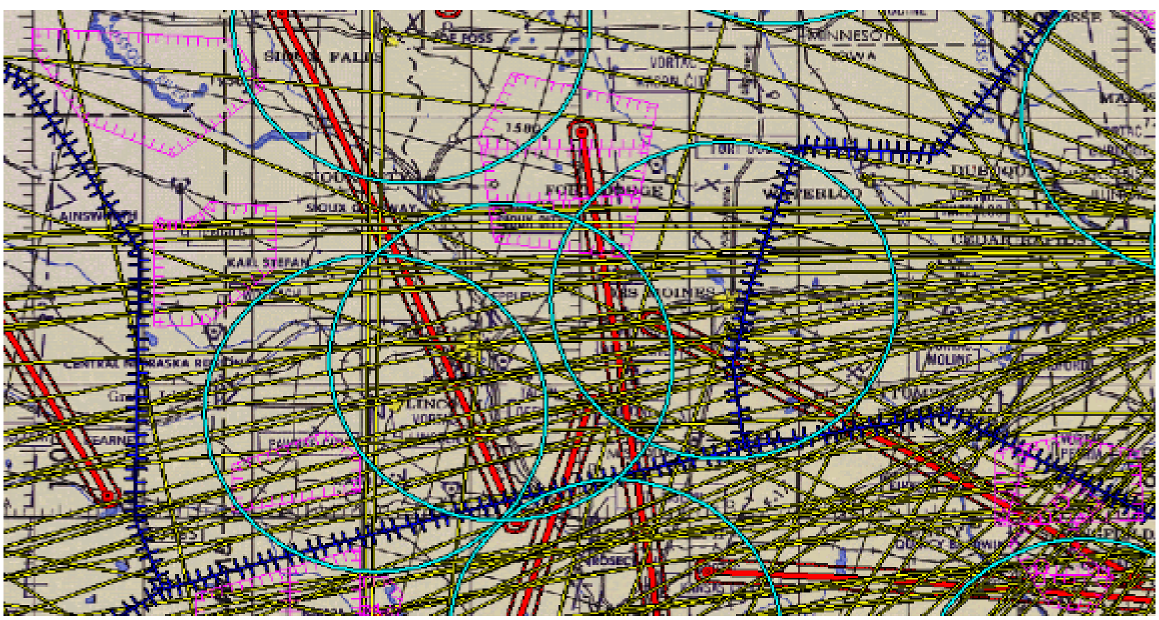

Figure 22: Southern Minneapolis ARTCC Final Optimization

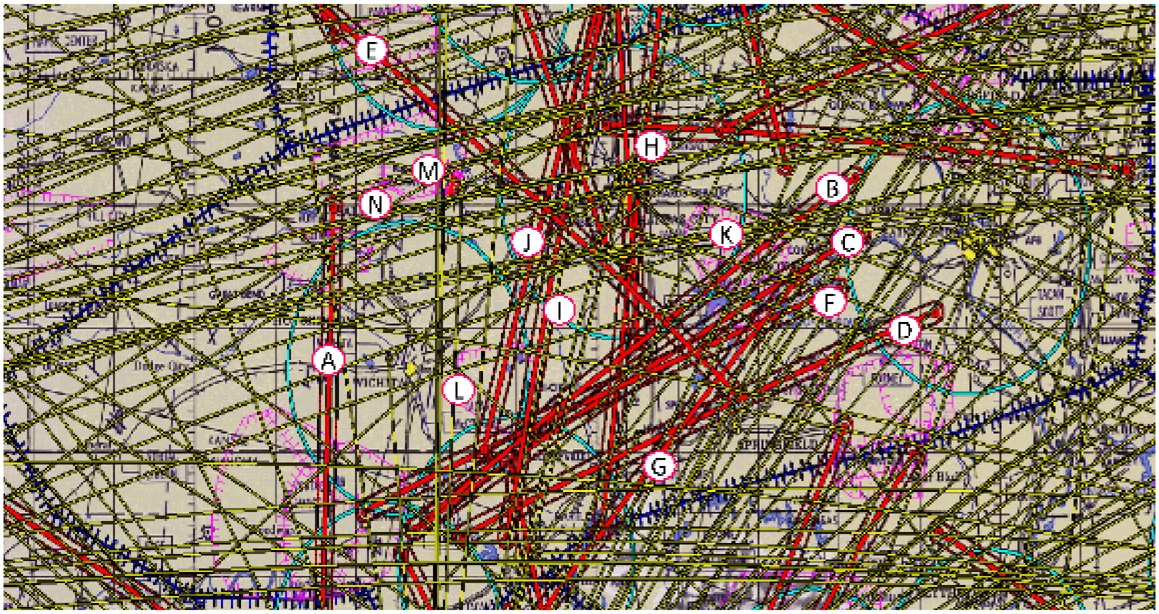

Figure 23: Kansas City ARTCC Initial Optimization

Table 10: Kansas City ARTCC Points of Interest

A – Ideal KIAB – KTIK (Red)	H – Ideal KFOE - KSZL (Red)
B – Ideal KGUS – KTIK (Red)	I – Ideal KTIK – KOFF (Red)
C – Ideal KBLV – KTIK (Red)	J – Ideal KIAB – KOFF (Red)
D – Ideal KWRI – KTIK (Red)	K – Truman MOA – Up to 18,000 MSL (Pink)
E – Ideal KLNK – KSZL (Red)	L – Eureka MOA – Up to 18,000 MSL (Pink)
F – Ideal KIAB – KSZL (Red)	M – Restricted Area 3602 – Up to 29,000 MSL (Red)
G – Ideal KTIK – KSZL (Red)	N – Restricted Area 3601 – Up to 18,000 MSL (Red)
Light Blue Rings indicate 75NM buffer around airfield for commercial descent	
Yellow lines are commercial traffic (above 30,000 MSL unless landing at airfield with blue ring)	

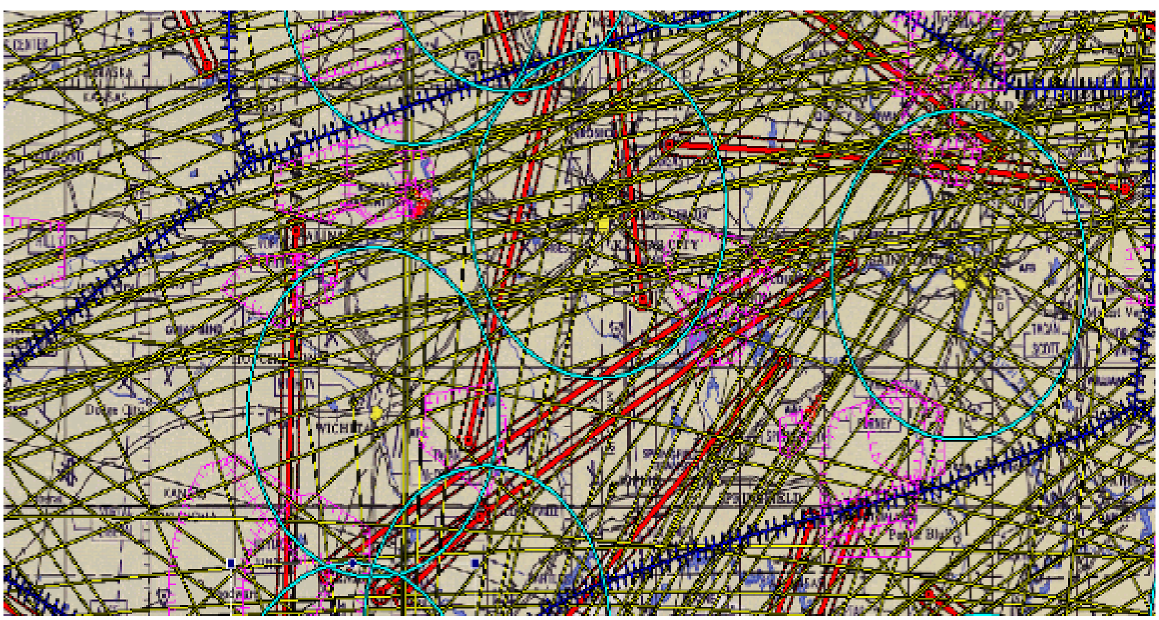

Figure 24: Kansas City ARTCC Final Optimization

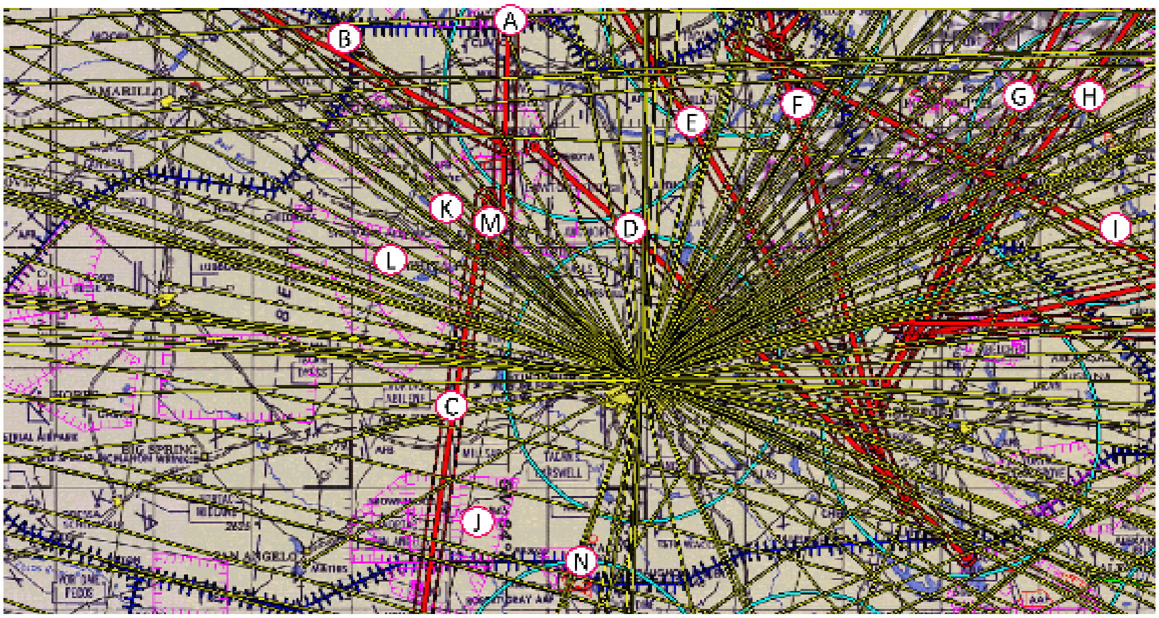

Figure 25: Fort Worth ARTCC Initial Optimization

Table 11: Fort Worth ARTCC Points of Interest

A – Ideal KIAB – KTIK (Red)	H – Ideal KGUS – KBAD (Red)
B – Ideal KSLC – KTIK (Red)	I – Ideal KMCF – KTIK (Red))
C – Ideal KTIK – KSKF (Red)	J – Brownwood/Brad MOA – Up to 18,000 MSL (Pink)
D – Ideal KTIK – KBAD (Red)	K – Sheppard MOA – Up to 18,000 MSL (Pink)
E – Ideal KIAB – KBAD (Red)	L – Westover MOA – Up to 18,000 MSL (Pink)
F – Ideal KFOE – KBAD (Red)	M – Restricted Area 5601 – Up to 40,000 MSL (Red)
G – Ideal KBLV – KBAD (Red)	N – Restricted Area 6302 – Up to 30,000 MSL (Red)
Light Blue Rings indicate 75NM buffer around airfield for commercial descent	
Yellow lines are commercial traffic (above 30,000 MSL unless landing at airfield with blue ring)	

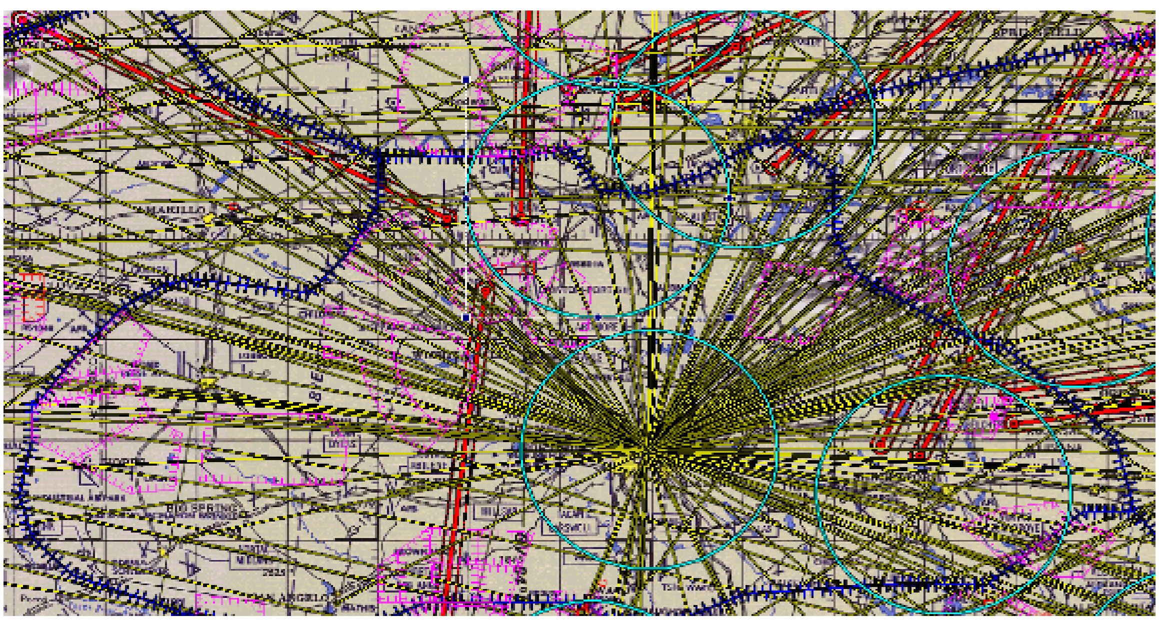

Figure 26: Fort Worth ARTCC Final Optimization

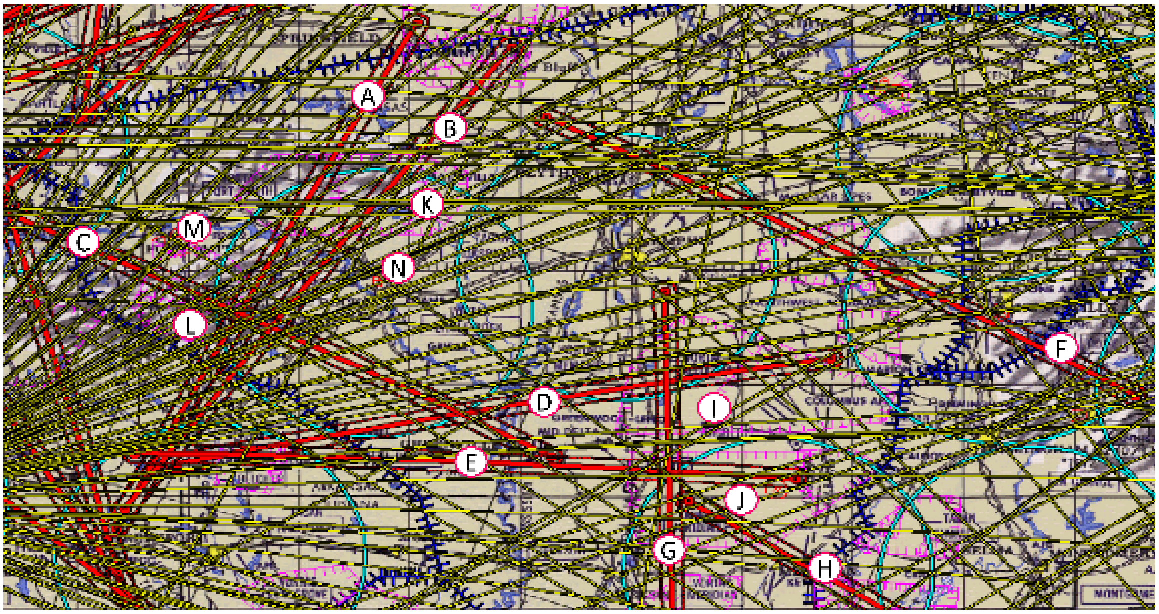

Figure 27: Memphis ARTCC Initial Optimization

Table 12: Memphis ARTCC Points of Interest

A – Ideal KBLV – KBAD (Red)	H – Ideal KMCF – KJAN (Red)
B – Ideal KGUS – KBAD (Red)	I – Columbus MOA – Up to 18,000 MSL (Pink)
C – Ideal KMCF – KTIK (Red))	J – Meridian MOA – Up to 18,000 MSL (Pink)
D – Ideal KBHM – KBAD (Red)	K – Shirley MOA – Up to 18,000 MSL (Pink)
E – Ideal KMEI – KBAD (Red)	L – Hog MOA – Up to 18,000 MSL (Pink)
F – Ideal KBHM – KMEM (Red)	M – Restricted Area 2402 – Up to 30,000 MSL (Red)
G – Ideal KMEI – KJAN (Red)	N – Restricted Area 2403 – Up to 16,000 MSL (Red)
Light Blue Rings indicate 75NM buffer around airfield for commercial descent	
Yellow lines are commercial traffic (above 30,000 MSL unless landing at airfield with blue ring)	

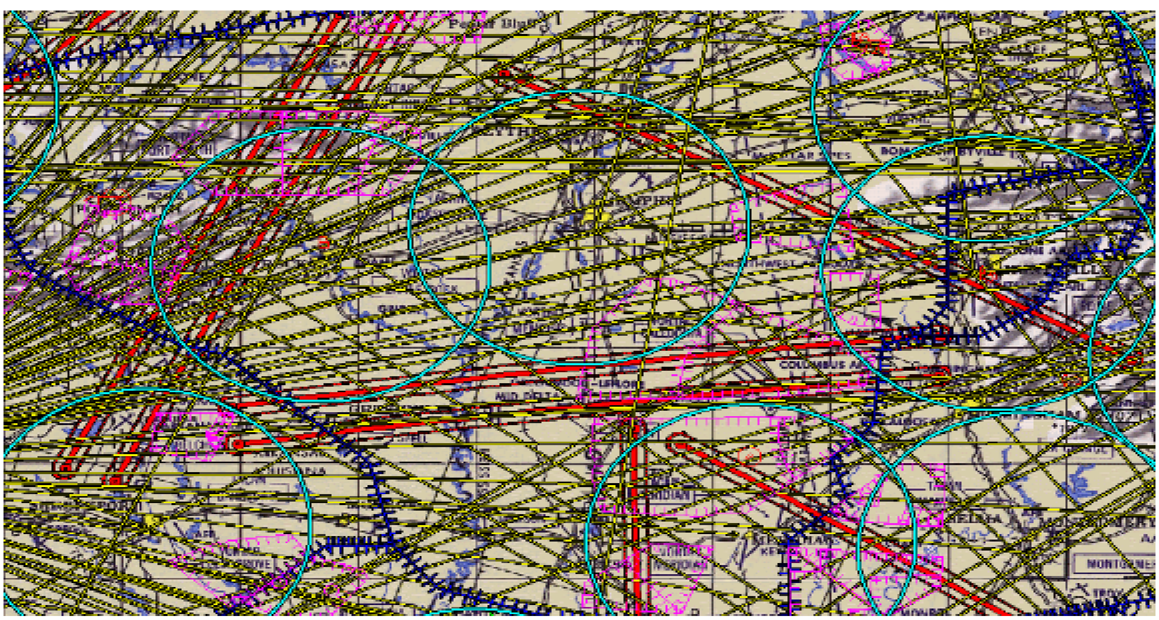

Figure 28: Memphis ARTCC Final Optimization

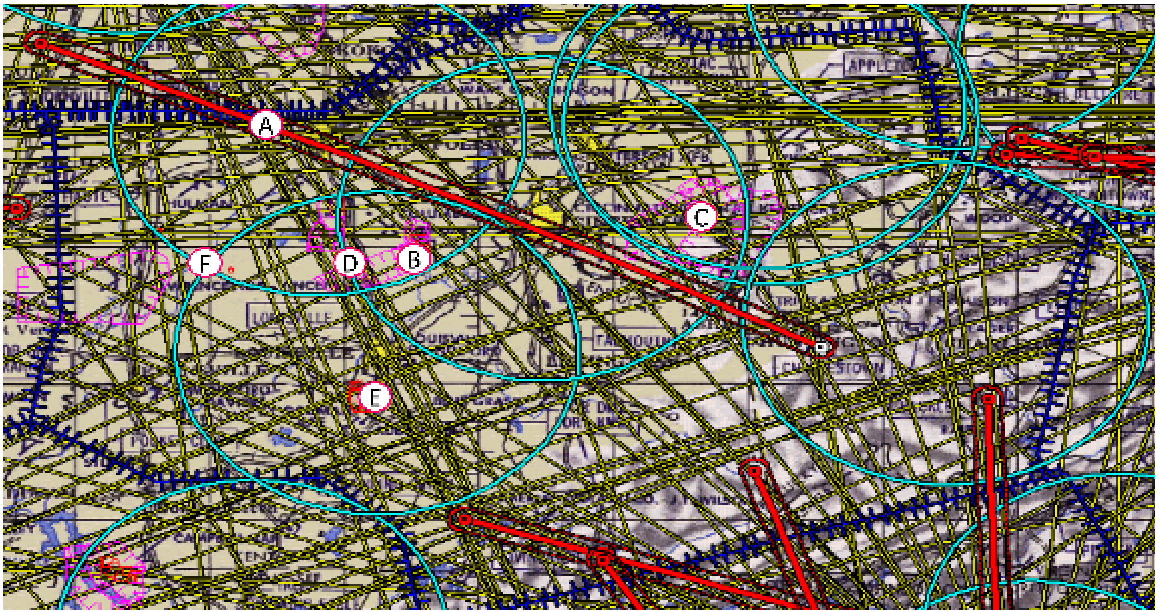

Figure 29: **Indianapolis ARTCC Initial Optimization**

Table 13: Indianapolis ARTCC Points of Interest

A – Ideal KGUS - KFFO (Red)	E– Restricted Area 3704 – Up to 10,000 MSL (Red)
B – Restricted Area 3403 – Up to 43,000 MSL (Red)	F– Restricted Area 3404 – Up to 41,000 MSL (Red)
C – Buckeye/Bush MOA – Up to 18,000 MSL (Pink)	
D – JPG MOA – Up to 5,000 MSL (Pink)	
Light Blue Rings indicate 75NM buffer around airfield for commercial descent	
Yellow lines are commercial traffic (above 30,000 MSL unless landing at airfield with blue ring)	

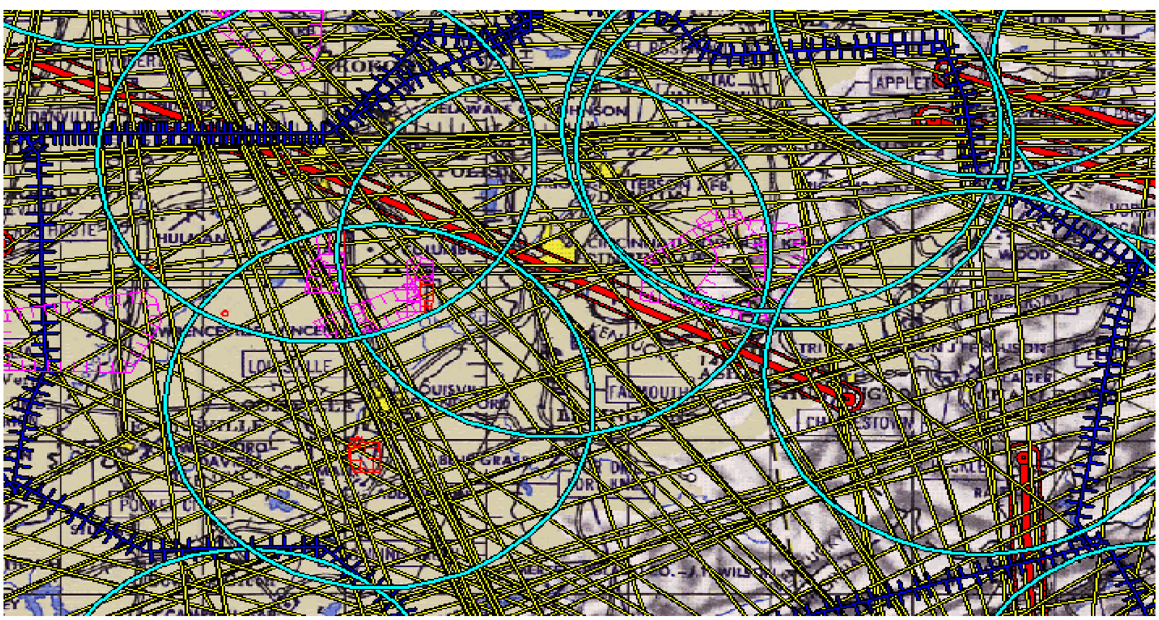

Figure 30: Indianapolis ARTCC Final Optimization

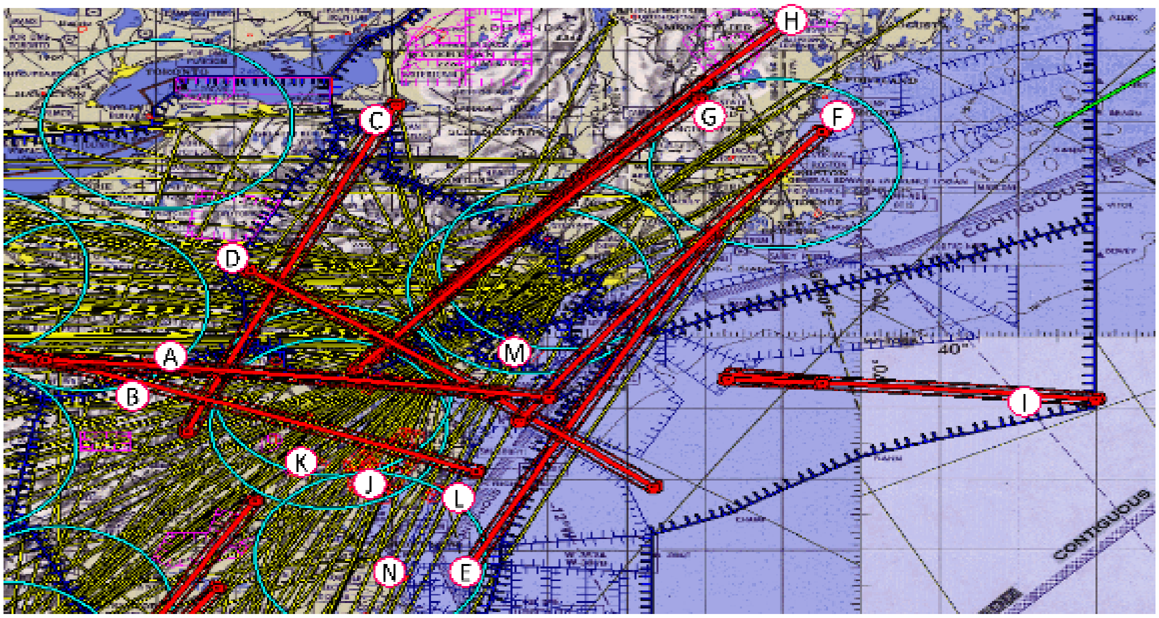

Figure 31: New York, Boston, Cleveland ARTCCs Initial Optimization

Table 14: New York, Boston, Cleveland ARTCCs Points of Interest

A – Ideal KGUS/KPIT – KWRI (Red)	H – Ideal KBGR – KDOV/KWRI (Red)
B – Ideal KPIT – KDOV (Red)	I – AR 777
C – Ideal KMTC – KWRI (Red)	J – Restricted Areas 4005-8 – Up to 85,000 MSL (Red)
D – Ideal KWRI – KDOV (Red)	K – Restricted Areas 6611-3 – Up to 40,000 MSL (Red)
E – Ideal KADW – KDOV (Red)	L – Restricted Area 6604 – Up to UNLTD MSL (Red)
F – Ideal KWRI – KCEF (Red)	M – Restricted Area 5002 – Up to 23,000 MSL (Red)
G – Ideal KPSM – KDOV (Red)	N – Restricted Area 6606 – Up to 51,000 MSL (Red)
Light Blue Rings indicate 75NM buffer around airfield for commercial descent	
Yellow lines are commercial traffic (above 30,000 MSL unless landing at airfield with blue ring)	

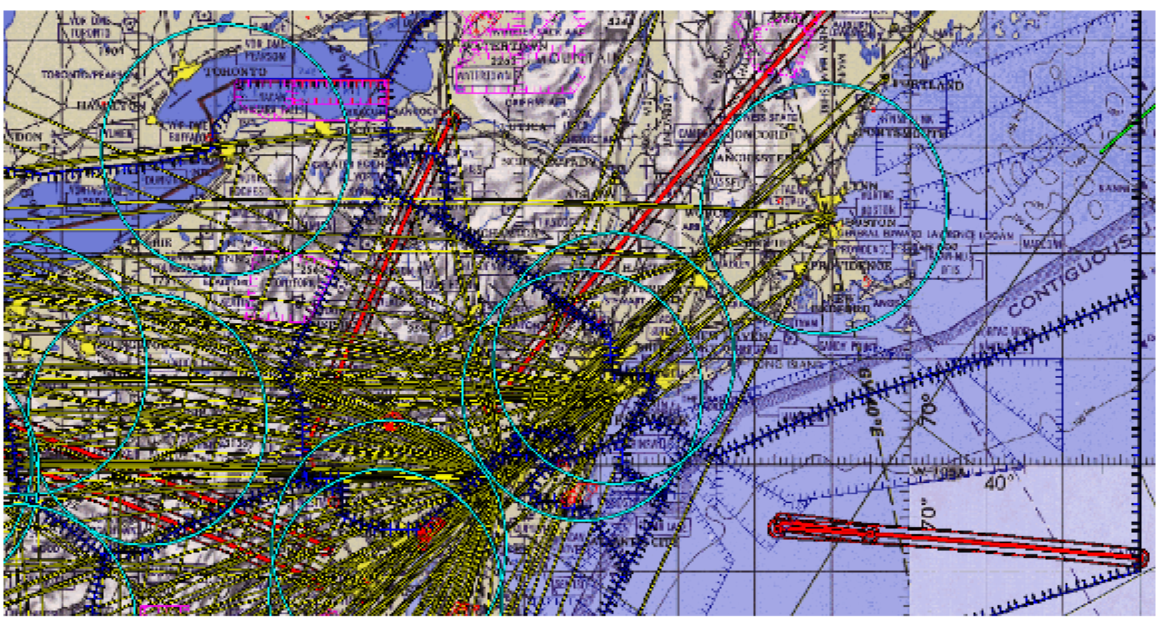

Figure 32: New York, Boston, Cleveland ARTCCs Final Optimization

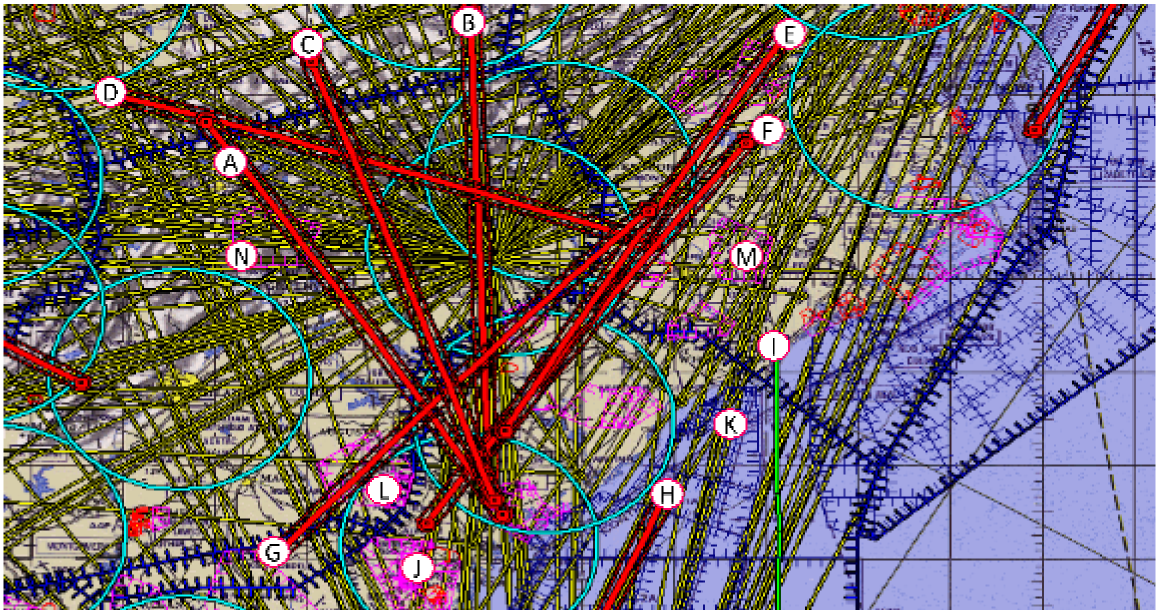

Figure 33: Atlanta and North Jacksonville ARTCCs Initial Optimization

Table 15: Atlanta and North Jacksonville ARTCCs Points of Interest

A – Ideal KGUS – KCHS (Red)	H – Ideal KMCF – KCHS (Red)
B – Ideal KPIT – KCHS (Red)	I – AR 202 (Green)
C – Ideal KLCK – KCHS (Red)	J – Restricted Area 3005– Up to 29,000 MSL (Red)
D – Ideal KPIT – KWRB (Red)	K – Warning Areas 139-177 – Up to UNLTD MSL (Bl)
E – Ideal KWRI – KCHS (Red)	L – Bulldog MOA – Up to 18,000 MSL (Pink)
F – Ideal KGSB – KCHS (Red)	M – KGSB MOA – Up to 18,000 MSL (Pink)
G – Ideal KTYS – KCHS (Red)	N – Snowbird MOA – Up to 18,000 MSL (Pink
Light Blue Rings indicate 75NM buffer around airfield for commercial descent	
Yellow lines are commercial traffic (above 30,000 MSL unless landing at airfield with blue ring)	

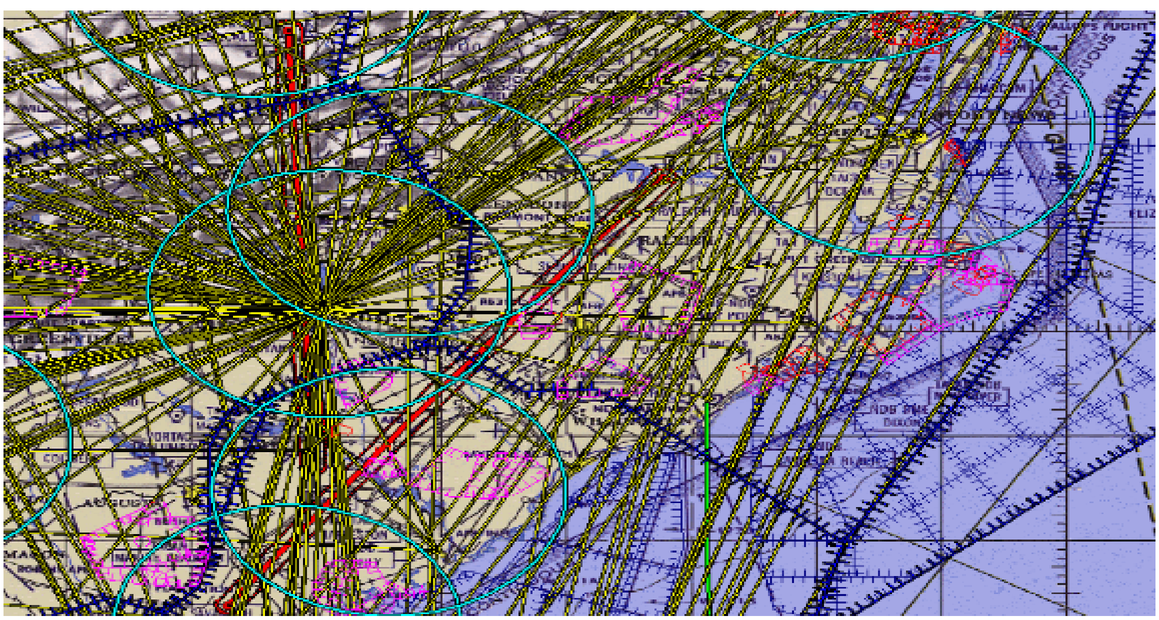

Figure 34: Atlanta and North Jacksonville ARTCCs Final Optimization

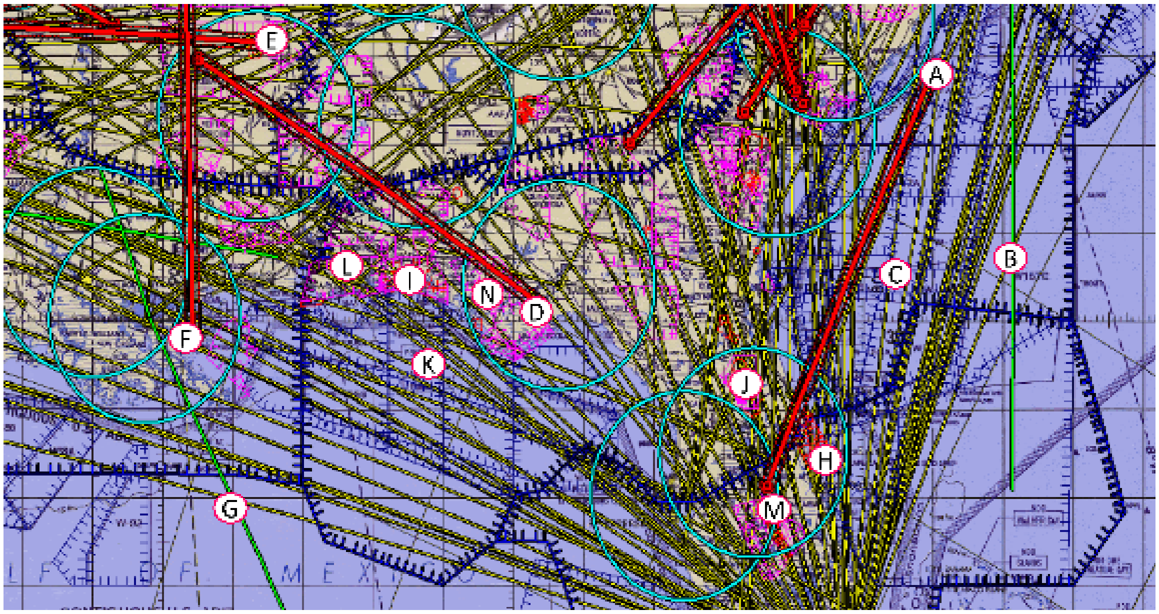

Figure 35: Jacksonville ARTCC Initial Optimization

Table 16: Jacksonville ARTCC Points of Interest

A – Ideal KMCF – KCHS (Red)	H – Restricted Area 2934– Up to UNLTD MSL (Red)
B – AR 202 (Green)	I – Restricted Areas 2914,5– Up to UNLTD MSL (Red)
C – Warning Areas 139-177 – Up to UNLTD MSL (Bl)	J – Restricted Areas 2901-10– Up to 23,000 MSL (Red)
D – Ideal KMCF – KJAN (Red)	K – Warning Areas 151-155 – Up to UNLTD MSL (Bl)
E – Ideal KMEI – KBAD (Red)	L – Pensacola MOA – Up to 18,000 MSL (Pink)
F – Ideal KMEI – KJAN (Red)	M – Restricted Areas 2901 – Up to 23,000 MSL (Red)
G – AR 103 (Green)	N – Tyndall MOA – Up to 18,000 MSL (Pink)
Light Blue Rings indicate 75NM buffer around airfield for commercial descent	
Yellow lines are commercial traffic (above 30,000 MSL unless landing at airfield with blue ring)	

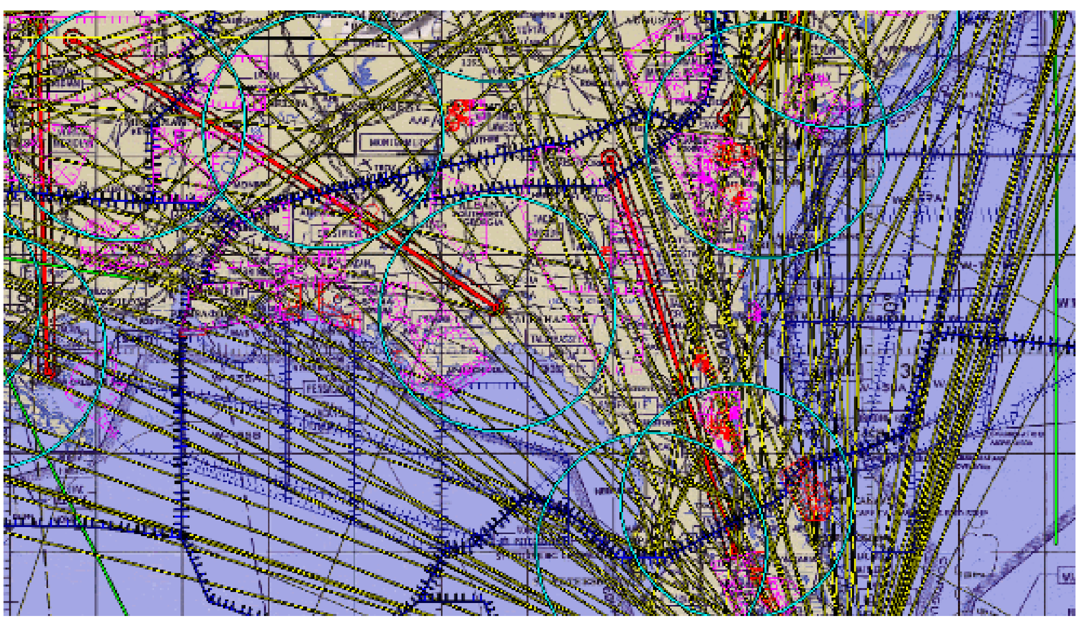

Figure 36: Jacksonville ARTCC Final Optimization

Appendix I – Quad Chart

Optimizing the Continental United States Air Refueling Infrastructure

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Introduction

The current air refueling infrastructure over the continental United States was first created in 1963 and, while having incremental changes through the years, has not been recently analyzed for system utilization and redesigned (if required) based on updated demands, aircraft bed-downs, changing weather patterns, and NextGen concerns.

Research Questions

1: What are the most common tanker/receiver base parings that practice AR over the CONUS?

2: Which current tracks can be eliminated regardless of the conclusions of the redesign?

3: Where are the optimal tracks that can be utilized between tanker and receiver bases?

4: Weighing historical usage and proposed NAS redesign, where can AR tracks be placed to optimize efficiency for the USAF and commercial aviation?

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Analysis and Results

98% of the CONUS AR track usage was performed on only 62% of the current AR track infrastructure and, as a result, proposes the elimination of 35 existing AR tracks. An alternate optimized infrastructure structure will provide standardization and deconfliction with NextGen concerns and other airspace issues enabling greater utilization of flight hours towards training and operational objectives

Methodology

1. Aanalyze the current AR system for utilization.
2. Utilize a multi nonlinear optimization using current and proposed infrastructure to provide proposed AR tracks.
3. Compare the proposed tracks against the projected NextGen airspace to provide a system that is advantageous to all stakeholders (DoD, Commercial Aviation, FAA, DoT).

Implications

Optimizing training and operational value for 36K flights per year. Reducing operational impact to 8 million commercial flights per year.

Recommendations

1. Eliminate 28 AR Tracks from Infrastructure (1 x Month)
2. Eliminate 7 More AR Tracks (2 x Month)
3. Add data Element to G2
4. Incrementally implement holistic change to system to change 91 tracks into 42 optimized tracks

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REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 074-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From – To)*
17-06-2016	GRP	MAY 2015 – JUN 2016

4. TITLE AND SUBTITLE	
Optimizing the Continental United States Air Refueling Infrastructure	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	**5d. PROJECT NUMBER**
Johnston, Taylor J., Major, USAF	**5e. TASK NUMBER**
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S)	**8. PERFORMING ORGANIZATION REPORT NUMBER**
Air Force Institute of Technology Graduate School of Engineering and Management (AFIT/EN) 2950 Hobson Way, Building 640 WPAFB OH 45433-8865	AFIT-ENS-MS-16-J-027
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/MONITOR'S ACRONYM(S)**
Headquarters, Air Force, Directorate of Airspaces, Bases, & Ranges 440 Air Force, Pentagon, VA, 703-697-8489 Steven.pennington11.civ@mail.mil	AF/A3O-J **11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

12. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution Statement A. Approved For Public Release; Distribution Unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The current air refueling infrastructure over the continental United States was first created in 1963 and, while having incremental changes through the years, has not been recently analyzed for system utilization and redesigned (if required) based on updated demands, aircraft bed-downs, and changing weather patterns. Additionally, changes in airspace management brought on by modern aircraft, increasing volume in air traffic, increased on-board navigational performance, and the obsolescence of ground based navigational aids are pushing massive redesigns on overall airspace management. This research analyzes 2014 training and operational data to provide current utilization rates and also proposes a holistically redesigned infrastructure that optimizes the amount of time available for air refueling operations while minimizing the impact to commercial aviation and operational necessity.

15. SUBJECT TERMS
Air Refueling, Optimization, AR tracks, NextGen, PBN

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
					Jeffrey Weir, AFIT/ENS
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(Include area code)*
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