A Modeling and Simulation Approach to the Small Aircraft Transportation System: Assessing Midair Conflict Potential Under the Free Flight Paradigm

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(ABSTRACT)

The Small Aircraft Transportation System, or SATS, is a NASA-led initiative that seeks to revolutionize commercial air travel by increasing accessibility and mobility for the general consumer. The hallmark of SATS is on-demand, point-to-point air transportation from one of the nation's 5,400 public use airports and landing facilities. A second-order benefit is that it may help relieve congestion on the nation's highways and at our mid- to large size airport hubs. In 1999, NASA initiated a five-year, $69 million research program to study the feasibility and viability of SATS including development of the emerging technologies necessary to make SATS a reality. The five-year plan culminated in June 2005 in Danville, VA with a highly publicized flight demonstration and exposition serving as the SATS proof of concept. The "Highways-in-the-Sky" (HITS) premise inherent to SATS is arguably its biggest enabler, and it depends heavily on the idea of *free flight*. HITS will potentially be the first step in moving from traditional cars and other vehicles that travel on the ground to ones that will operate largely, if not entirely, in the air. The notion of "cars" that fly was first introduced by the entertainment industry in movies and television programs decades ago. But if mankind is ever to achieve that vision, we must have a start point. This research focuses not on the economic viability of SATS but rather on the degree of flight safety inherent to a program such as this. One can easily see how the introduction of a large number of autonomous vehicles operating simultaneously in an already dense region such as the National Airspace System might carry some degree of risk. This research introduces a modeling and simulation framework that will have applications to SATS at such time as the program must be evaluated from a safety of flight perspective. That will invariably include a high degree of simulation. This work also represents the first large-scale simulation focused primarily on how SATS will perform in the out-years.

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Chapter 1

Introduction

Due to a steady increase in the size of population centers within the United States, congestion has affected all modes of transportation. Additionally, commerce has increased in these cities and the areas that surround them. The impetus behind many transportation systems engineering projects is to streamline existing transportation networks and to employ emerging technologies to increase efficiency and capacity of such systems. Indeed, the appeal of a mode of transportation that can deliver people directly to their destinations, free from the hassles and inherent delays of traveling into a transportation center, or "hub", is self evident. The demand for such a mode of transportation is especially true when applying this ideal to commercial air travel within the U.S. Of the approximately 5,400 public-use airports in the United States, some 70 airports serve approximately 90 percent of air carrier passengers while an additional 410 airports serve virtually the remaining 10 percent (Bowen, 1999). Over 4,900 public-use airports either do not have or are physically unable to support commercial air carrier operations.

There are many factors that affect an individual's decision of which mode of transportation to use for a given trip. The number of variables that a given person may use to make this decision are as numerous as the prospective destinations. For most people, cost is obviously a critical factor. Arguably, however, the most important of these factors is convenience. Regardless of one's social class, convenience – or the ease by which one can travel to his or her destination – is important. Many, if not most, people who have flown commercial air with any regularity have undoubtedly experienced delays, layovers, or other lost time in the process of flying into or out of a busy hub-and-spoke airport.

A question that has caused many to reevaluate commercial air travel as we know it is this: wouldn't it be desirable for the average person to fly from an airport close to one's home *directly* to one's prospective destination? The alternative to this question entails traveling a potentially great distance to an airport from which one can fly to one's desired destination. Unless the destination is a large city, one may have to fly into multiple large airports enroute to pick up passengers or to board connecting flights. At the destination airport, the need for supplemental transportation exists. This includes rental cars, taxis, airport limousines, buses and trains that can deliver travelers to their final destinations. These modes of transportation will invariably increase the cost of the trip. In the traditional scenario, enroute delays often exist. These can take the form of airport layovers between arrival at an enroute airport and the subsequent departure. Somewhat harder to quantify than delay times and dollar costs is the level of frustration that can result from the inconvenience and stress of flying into a hub. Incidents such as hurrying from one terminal to another to make a connection, having one's luggage not make it on a connecting flight, and waiting in queues for services plus general crowding within large airports may further exacerbate such feelings. Flying directly to one's destination can eliminate most, if not all, of the potential pitfalls that can occur when traveling by commercial air. Why would a rational person subject himself to these circumstances? If one could visit friends or relatives by flying into the closest local airport only miles from their homes as opposed to a regional or international airport 50-100 miles away, wouldn't one do it? If a business traveler could fly into a satellite airport close to a major hub to conduct business and avoid the potential delays and unpleasant aspects of commercial flying, wouldn't he prefer to do so? If "doorstep-to-destination" travel were safe and affordable relative to current commercial air travel, wouldn't people use it? I submit that most rational people would do so. The solution to this transportation dilemma may very well be the Small Aircraft Transportation System (SATS).

Given the current National Airspace System (NAS) structure, several methods can be used to study the overall effectiveness of SATS. Assuming that SATS is deemed economically viable and there is sufficient perceived demand to proceed with this undertaking, a critical question needs to be answered. This question is arguably the most important one surrounding the SATS concept—is SATS inherently *safe*? In order to successfully address this issue, one must first quantify the definition of "safe."

The FAA and the aviation industry at large aspire to achieve a level of zero accidents or in-flight incidents in any given year. According to the Bureau of Transportation Statistics (1997), approximately 25,000 flights currently transport more than 1.6 million passengers and over 30,000 tons of freight throughout the U.S. and its territories each day. But the true number of daily flights is actually much greater, as the figures mentioned above do not account for the large number of international flights, military aircraft, and the vast amount of general aviation traffic that operates in NAS. So no accidents or incidents given the large number of aviation operations involved is unrealistic. Consequently, the FAA has established an acceptable operational surrogate for this ideal zero incident goal by seeking to lower the accident/ incident rate from the previous year.

In-flight conflicts are a direct function of aircraft separation distance. Even when established separation standards are followed, aircraft still occasionally deviate from their assigned courses and encounter other aircraft. These occurrences may result in near-misses or, in the most extreme cases, midair collisions. Flight safety associated with SATS will directly translate from the impact SATS has on the incidence of midair conflicts. This will, in turn, depend on whether or not the current NAS infrastructure can effectively handle the increased level of traffic and whether future procedural changes are adequately developed and effectively implemented.

An initiative as ambitious as SATS introduces numerous challenges to the largely fail-safe aviation structure of today. These can translate to enormous loss of life and destruction of multimillion-dollar aircraft if not accounted for and studied exhaustively. Many of these issues are rather intuitive in nature. First, will the inherent increase in air traffic that will accompany SATS cause the already congested airspace over the U.S. to become unsafely overcrowded? Second, will the reduced role of ATC with respect to controlling SATS aircraft create a condition by which numerous aircraft are flying virtually autonomously? Are the pilots of SATS aircraft flying in instrument meteorological conditions (IMC) expected to detect and resolve conflicts with other aircraft free of positive control and the intervention of (ground-based) controllers? A secondary group of potential problems arises when one considers operations on the ground at SATS airports, as well as in the airspace that surrounds them. Will uncontrolled, or non-towered airports, be able to support the potentially large increase in traffic that comes with SATS? Will the pilots of SATS aircraft be able to handle the deconfliction of ground and air operations at or near SATS airports? These and many other questions need to be addressed.

The focus of this research concerns the introduction of SATS and the resulting incidence of future conflicts as NAS becomes increasingly more crowded. This work will highlight SATS performance in the enroute airspace between SATS-compliant airports. The research question to be addressed in this thesis is:

> *Given the proposal of SATS under the free flight paradigm, what is the projected impact of SATS traffic on the occurrence of midair conflicts that can be expected in conjunction with the current level of commercial, military, and general aviation traffic? Additionally, what is the projected impact on midair conflicts given the anticipated growth of air traffic levels over the next 10 and 15 years? In each case, the overall objective of this study is to determine the order by which midair conflicts increase relative to the volume of air traffic in NAS..*

This question will be investigated using air transportation operations research methods, airspace and airport modeling, and simulation. Additional tools will be utilized to conduct analysis of real-world and projected aggregate transportation data, as well as the examination of current and future forecasted air traffic densities. A simulation framework will be developed that will replicate SATS network performance. This technique will provide insights into how a proposed SATS model performs at the state level in support of regional SATS implementation. The effort is valuable for several reasons. First, it will enumerate the conflicts that airspace managers might expect to see between proximate pairs of aircraft given the number of sorties that the Federal Aviation Administration (FAA) predicts will operate in NAS on a typical day in the years 2010 and 2015. Second, it will help establish functional relationship between simulated air traffic volumes and resultant conflicts under controlled conditions. Finally, it will give policymakers insights into how NAS will perform in the future, what air traffic controller (ATC) workload will be like, and what constraints may be required to keep NAS safe given the inherent load on the system that SATS will induce.

In this research, SATS will be theoretically implemented in the Commonwealth of Virginia and surrounding areas. Data will be generated during simulation runs containing forecasted sorties and SATS surrogate flights. By expressing blind conflicts spatially in terms of conflict severity, current FAA aircraft separation standards may be examined with respect to SATS. This will aid decision-makers in determining overall SATS feasibility, providing experimental results for risk analysis, and informing future policy development and amendments applicable to published FAA aircraft separation standards.

The SATS research project, sponsored by the FAA and NASA Langley Research Center, culminated with a proof-of-concept demonstration in June 2005. The initiation of the specific research covered in this thesis coincided with the start of a five-year public and private initiative aimed at overall feasibility across the domain of relevant functional areas – economics, technologies and capabilities, and integration into the transportation framework. The value of this research is that it represents the first large-scale modeling and simulation effort associated with SATS. At the time the experiment in this research was conducted, only one other SATS simulation was being considered. That experiment attempted to simulate SATS at a single terminal area airport surrounded by Class B airspace.

This study was limited by the lack of existing SATS research. Very few practical studies incorporating SATS had been accomplished and published at the time this project was initiated. A clean set of input data for forecasted air traffic did not exist. However, robust FAA data from various reliable sources were acquired. The simulation constructed was not limited by the software selected. However, the time intensive nature of each simulation run and associated post-processing of data limited the simulation phase to the minimum number of required runs. Applicability of the results herein to future SATS research, assessments, and policy development are limited only insofar as the simulation construct diverges from additional SATS program decisions and future changes in national airspace rules and procedures.

Chapter 2

Literature Review

2.1 Small Aircraft Transportation System (SATS)

The preponderance of aviation operations at nearly 5,000 of the nation's public-use airports consist of general aviation and light commercial traffic. Most of these airports are underutilized when one considers the airspace requirements of the small, light aircraft that use them. SATS is defined as an intermodal, personal, rapid transit air travel system. The SATS program will increase the role of small, general aviation airports in order to effectively triple the current level of aviation system throughput within the next 10 years (Goldin, 1999). The goal of SATS is to achieve improved rates of travel between remote communities and the nation's transportation and commercial centers, as well as to other remote locations, at four times the speed of highways. SATS proposes to accomplish this by direct flight routing between origin and destination. The speed and efficiency of SATS relies heavily on "free flight" – an innovative concept that will improve the efficiency of NAS by allowing pilots operating under instrument flight rules (IFR) to select aircraft course, speed and altitude in real time (Elder, 1997). Program milestones, as expressed by NASA and the FAA, include achieving SATS service for 25 percent of the country's suburban, rural and remote communities by 2009 and more than 90 percent by 2024 (Holmes, 1999). By expanding all-weather access to the airports mentioned above, NAS capacity could be increased by a factor of 10 compared to the annual seat departures produced by the current hub-and-spoke commercial system (Goldin, 1999).

2.1.1 SATS Framework

The two key elements of the Small Aircraft Transportation System are “SATS airports” and “SATS aircraft” (Holmes, 1999). The SATS framework consists of many of the same elements that make up the nation’s air transportation infrastructure as we know it today, including different classes of airports. It also includes various categories and types of aircraft, each with different capacities, weight classifications, capabilities and limitations. Air traffic services (ATS) and an integrated airspace structure are also critical components. The U.S. currently has this under NAS. How NAS will be modified to accommodate SATS is unclear at this time. However, it should be noted that many of the aircraft and airports currently in service, as well as the enroute and terminal airspace with accompanying flight procedures, may remain unchanged. This provides a fairly well-defined template upon which we can overlay and integrate the SATS framework that may evolve into the overall national air transportation strategy of the future.

2.1.2 SATS Airports

If SATS eventually matures to its full capacity, aircraft from approximately 5,000 public-use (general aviation) airports will utilize over 18,000 landing facilities across the country to deliver passengers. A large number of these passengers will be from areas that have airports not currently serviced by commercial air carriers. These airports and landing facilities will be required to undergo substantive overhauls to become SATS-compliant, or bona fide “SATS airports." Among the characteristics required for a given airport to be SATS compliant are the following:

(1) 3,500 - 5,000 foot runway,
(2) Digital two-way communications,
(3) Broadcast flight/traffic information services (FIS/TIS), and
(4) Local broadcast and request/reply destination information services (DIS).

At this point, it is important to highlight that, in the end, not every airport will be designated a SATS airport, due to insufficient demand and other factors (Holmes, 1999). The factors that transportation planners will use to determine whether or not an area would utilize SATS aircraft and facilities if they were available are somewhat vague at this point. However, it is reasonable to assume that unless a given area is assessed as being able to generate enough seat departures to make SATS worthwhile, then it will not see SATS operations in the future.

A SATS airport must provide higher utility and safety in a greater range of weather conditions along with free-flight procedures for expanded NAS capacity and airport utility (Bowen, 1999). This translates to precision approaches to all landing areas and nearly all-weather operational support at uncontrolled airports without radar coverage. A precision approach is a flight procedure executed by a pilot operating IFR. It is designed to allow a controlled approach and landing to a designated point on the active runway. The pilot executes this procedure, maintaining the aircraft on glide path during descent, oriented to published headings that ensure obstacle clearance. This is done by means of verbal ATC descent and heading corrections, in the case of a precision approach radar (PAR) procedure, or by onboard flight instruments in the case of an instrument landing system (ILS) approach. Holmes states that, currently, 22%, or roughly 1,200 public-use airports in the U.S. are equipped with ILS (NASA Aeronautics Enterprise National GA Roadmap 1-36). Therefore, airports without ILS will need to upgrade to this or a next generation precision approach system to support SATS aircraft across the range of possible weather scenarios. To enable the required information services mentioned earlier, SATS airports will need to modernize weather observation, forecasting, and reporting equipment, as well as advanced computer networks. Likewise, many airports may realize the need to revamp operator/passenger facilities and services. Finally, airports should have the infrastructure to fully support the spectrum of SATS' maintenance needs to include the facilities, test equipment, tools, parts, and technicians to service, repair and inspect all resident and transient SATS vehicles.

2.1.3 SATS Aircraft

"SATS aircraft" refers to those aircraft that will employ new avionics, airframe, pilot training and engine technologies derived from current investments in the National General Aviation Roadmap for future air travel. These will also include a new generation of small turbine and piston-powered single or twin-engine business and personal aircraft. There are currently two NASA-led partnerships that are working to develop prototype SATS aircraft. The Advanced General Aviation Transport Experiments (AGATE) and General Aviation Propulsion (GAP) partnerships began work on prototype SATS aircraft in 1998 resulting in critical developments for improved airframe, power plant, and power train systems design. The specifications for SATS aircraft are four- to six-passenger vehicles that are operated by private or hired pilots. These aircraft will have "highway in the sky (HITS)" technologies. The foremost of these will be graphical flight path operating systems providing weather, navigation, traffic, terrain and airspace depictions. These systems will allow the aircraft to, among other things, utilize icing condition avoidance and exit operating procedures (Goldin, 1999).

SATS aircraft power plants will represent a new generation of turbine and compression-ignition engines that burn jet fuel. They will have single-lever power controls and intuitive diagnostics. The major engine and power train components will have longer time before overhaul (TBO) times as well. Piston aircraft will travel in excess of 200 KIAS (knots indicated airspeed). Turbine aircraft will fly in excess of 300 KIAS. The operational ceiling will be approximately 12,000 feet for piston aircraft and 30,000 feet for turbine aircraft (Goldin, 1999). The new SATS aircraft, combined with the capabilities of current aircraft that SATS will employ, should facilitate air travel that will meet the needs of most customers.

2.1.4 Communities Served by SATS

The target population for SATS consists largely of those people who live in suburban, rural and remote communities. These communities or counties lie outside a 50-mile radius (or 60-minute drive, whichever is less) of a current hub-and-spoke airport. The goal for communities served will be to have a SATS-compliant airport or heliport with SATS aircraft available within a 30-mile radius (or 30-minute drive, whichever is less). "Communities" and "counties" are defined as suburbs, ex-urbs, rural villages and remote dwelling locations outside of urban areas and corresponding Class B airspace (Goldin, 1999).

A key element of this initiative is that "SATS aircraft" must be available and affordable to the average consumer. "Availability" connotes being accessible through private or fractional ownership, charter or rental, with both scheduled and non-scheduled service, as required. "Affordability" is defined by the percentage of the population of wage earners rising above the willingness-to-pay threshold for SATS aircraft (Goldin, 1999). Geographically speaking, it is easy to identify the locales that will benefit from SATS. Factors that will drive utilization of SATS services such as availability, affordability and others, are difficult to quantify. It is clear, however, that many communities stand to benefit from the realization of SATS, should the simply stated goal of fast, affordable, convenient air transportation be achieved. In addition to the general public, the operational capabilities of SATS will also enhance the services of small cargo providers, public service aviation, law enforcement agencies and emergency medical services (Bowen, 1999).

2.2 Transportation Demand Problem

Determining the demand for air transportation services is critical in the development of both a comprehensive SATS network and a SATS model. This is especially true in the selection of SATS airports. Teodorovic (1988) stated that the demand for air transportation services is most often a function of the economic development of a given area. Demand is generally greater in an area that exhibits substantial economic growth than in a less prosperous one. He also noted the dependency between the demand for air transportation services and the socio-economic characteristics of the regions linked together by an aviation infrastructure. In its most general classification, there is a simple feedback loop that exists, such that the larger and more prosperous an area or region becomes, the greater the demand for air transportation, which in turn allows the area to become more prosperous as the population grows and commerce expands. This is the basis for "urban sprawl," where the nation's population centers have systematically grown outward over time. Many areas that used to be suburbs or even separate towns have now become a part of the expanding metropolis. Cities and towns that were once separated by distance have grown together in many instances. SATS will lessen the burden on the existing transportation infrastructure resulting from the growth of these areas and the corresponding increase in air travel among them.

Teodorovic described demand estimation models and highlighted the variables that affect them. The dependent variables in many demand estimation models are the number of potential passengers, number of passenger kilometers (or miles) that can be achieved, the expected number of operations – takeoffs and landings, or a percentage share of the number of air passengers out of the total number of passengers (including *all* other forms of available transportation). Other factors, such as the transportation preferences of an area's residents – be it bus, personal automobile, train or other mode – manifest themselves here. The independent variables typically represent certain socio-economic characteristics of the area or region in question, or the characteristics of the transportation system present in that area or region. These include factors such as the number of residents of a given area, volume of trade, average household or per capita income, and number of tourists per year. Even though demand estimation models take into account all modes of transportation available to consumers, it is readily apparent how important all of these variables are to SATS demand estimation. These factors will greatly influence the selection of areas that will receive SATS service. In the context of SATS network development and modeling, this will directly impact SATS airport selection.

The four key steps in forecasting transportation demand are (1) trip generation, (2) trip distribution, (3) modal split, and (4) trip assignment. *Trip generation* is an estimate of the total number of future trips from the region of a certain zone. It produces an aggregate number of trips, reflecting the need or desire of a given area's residents to travel outside their respective region to perform business, leisure and other activities.

Teodorovic used *trip distribution* to establish the number of trips between individual zones. He represented the total number of trips (of all modes), f_{ij} ,between origin i and destination j for (i=1,2,3,…,m; j=1,2,3,…,n). The number of trips generated by zone i is a_i and the number of trips attracted to zone j is b_j, where $a_i = \sum_{j=1}^{n} f_{ij}$ and $b_j = \sum_{i=1}^{m} f_{ij}$.

The *modal split* determines the percentage share of the total number of trips between nodes that will be serviced by the various modes of transportation available to the consumer. It considers the socio-economic characteristics of the population more than the physical characteristics of the area that will generate and draw trips. Depending on the distance between origin and destination, certain modes may be virtually ruled out. Additionally, the cost of a given mode of transportation and time available relative to the consumer affect the distribution of that mode's use. As part of a SATS life cycle study in 2002, McGrath stated ,"On the whole, NASA's premise that when the economic value of time was considered, SATS would be seen as a very economical mode of transportation, received support." In terms of air transportation, the modal split reveals how many flights may occur between various O-D pairs during a particular time period. The number of SATS flights between cities can then be expressed as a percentage of the total air transportation modal share. This percentage varies by geographic location depending upon the projected market penetration of SATS.

Teodorovic stated that *trip assignment* is effectively a routing process whereby all possible routes between paired cities are determined. Given a specific pair of cities and an aircraft as the mode of transportation, trip assignment will generate all possible flight routes between the cities and assign a specific number of trips to each route. At this stage, *all* routes that connect a given O-D pair must be accounted for. It is assumed that all SATS flights will fly wind-optimized profiles direct to their desired destinations. Given this assumption, SATS trip assignment results in simply determining the number of SATS flights that will occur between O-D pairs for the complete set of cities, for a given time period. To complete the trip assignment process, these flights would then be combined with all other forms of air traffic to get an aggregate number of flights and routing assignments.

Papacostas and Prevedouros (1993) presented two widely utilized models for conducting the *trip distribution* process – the gravity and Fratar models. The gravity model is conceptually based on Newton's law of gravitation, which states that the force of attraction, F, between two bodies is directly proportional to the product of the bodies' masses (M_i) and inversely proportional to the square of the distance, r, between them, or

$$F = k\frac{M_1 M_2}{r^2}.$$

Applied to trip distribution, this relationship can be reformulated as

$$Q_{IJ} = k\frac{P_I A_J}{W^c{}_{IJ}},$$

where Q_{IJ} is the interchange volume between trip-producing zone I and trip-attracting zone J, P_I is the magnitude of the trip productions of zone I, A_J is the trip-attractiveness of zone J, and $W^c{}_{IJ}$ is the generalized cost arising from travel between zones I and J. This is known as the travel impedance, or disutility, associated with travel between two specific zones, and it includes out-of-pocket costs, travel time, among other factors.

The trip-production balance constraint states that the sum over all trip-attracting zones, J, of the interchange volumes that share I as the trip-producing zone must equal the total productions of zone I, or

$$P_I = \sum_x Q_{Ix} = kP_I \sum_x \frac{A_x}{W^c{}_{Ix}}.$$

Solving for k yields

$$k = \left[\sum_x \frac{A_x}{W^c{}_{Ix}}\right]^{-1},$$

which insures that the trip balance is satisfied. This leads to the classical expression for the gravity model:

$$Q_{IJ} = P_I \left[\frac{\frac{A_J}{W^c{}_{IJ}}}{\sum_x \frac{A_x}{W^c{}_{Ix}}} \right].$$

Papacostas and Prevedouros present the Fratar model as best employed to estimate *external* trips, or those that are either produced by or attracted to zones that lie outside the boundaries of the region of interest. The characteristics of these external zones may not be known, nor are they explicitly analyzed. The two interchange volumes are Q_{IJ} and Q_{JI}, where $Q_{IJ} = Q_{JI}$. The aggregate trip generation of zone I is the sum of the trip generations that involve zone I, or

$$Q_I = \sum_x Q_{Ix} .$$

$Q_I(t)$, or the target-year trip generation, is estimated by multiplying the base-year trip generation, $Q_I(b)$, by a growth factor, G_I. Therefore, $Q_I(t) = G_I[Q_I(b)]$. The Fratar model estimates the target-year trip distribution, $Q_{IJ}(t)$, which satisfies the trip balance for the year in question. The model is iterative in nature, such that successive target-year interchange volumes are computed based on the expected growth of the producing and attracting zones concerned. The *estimated* target-year trip generation of each zone is then computed and compared to the *expected* target-year trip generation. A set of adjustment factors are then computed according to the relationship

$$R_I = \frac{Q_I(t)}{Q_I(current)}.$$

If the adjustment factors are all sufficiently close to unity, then the trip-balance constraint is satisfied and the process is terminated. If not, then the adjustment factors are used in conjunction with the current estimate of trip distribution, $Q_{IJ}(current)$, to improve the approximation. This process is done until the set of adjustment factors are sufficiently close (to unity). The portion of the target-year generation of zone I that will interchange with zone J is computed by

$$Q_{IJ}(new) = \frac{[Q_{IJ}(current)]R_J}{\sum_x [Q_{Ix}(current)]R_x} Q_I(t) \; .$$

Since the Fratar model employs only one interzonal volume estimate between two zones (i.e. $Q_{IJ} = Q_{JI}$), the two values are averaged at each successive iteration to determine the interchange volume:

$$Q_{IJ}(current) = Q_{JI}(current) = \frac{Q_{IJ}(new) + Q_{JI}(new)}{2} \; .$$

These values are used to calculate the new adjustment factors for the respective iteration, and the process is continued until the termination criterion of unity is achieved.

In terms of trip distribution within the SATS framework, where a limited, or bounded, SATS area of interest (AOI) exists, a combination of both the gravity and Fratar models might be applicable. The gravity model could be employed to determine the trip distribution for flights that both originate *and* terminate within the SATS AOI; the Fratar model could be used to determine the distribution of trips that either depart from or arrive to airports *inside* the SATS AOI, as well as flights that neither depart from nor arrive to airports in the AOI (i.e. overflights). However, in a study where SATS demand is based on a percentage (market share) of the passengers on existing commercial flights, this step may be omitted. Since trip distribution is an embedded step in the commercial air carrier demand forecasting process, surrogate SATS flights subsequently benefit from the trip distribution applied to the commercial flights from which they are derived.

2.3 Air Traffic Collision Risk Modeling

For over thirty years, systems engineers and mathematicians have developed and applied mathematical models to air travel as a means of predicting the number of collisions of aircraft flying in close proximity to one another. Initially, these models were developed to determine safe separation standards for aircraft flying parallel tracks at the same altitude over the North Atlantic Ocean. Once models were established that furnished acceptable separation standards for transoceanic flights, engineers then focused their efforts on domestic air travel. Since SATS aircraft will be limited in their range as compared to most commercial aircraft, SATS flights will generally be restricted to operations over and in close proximity to North America. However, these early modeling efforts can provide insights into how SATS traffic will perform in NAS, as well as what factors should be considered when studying potential midair conflicts in conjunction with SATS implementation.

2.3.1 Early Transatlantic Models

As one of the foremost international authorities on aircraft collision modeling, Machol described the early days of transoceanic flight between North America and Europe as almost "hit and miss" (Effectiveness of the air traffic control system, 113-119). In the early 1960's, nearly 100,000 airplane crossings of the Atlantic Ocean occurred, with a lateral separation standard of 120 NM. There was a call by the commercial airlines and the International Air Transport Association (IATA) to the International Civil Aviation Organization (ICAO) to reduce the lateral separation standard to 90 NM and ultimately 60 NM. The International Federation of Airline Pilots Association (IFALPA) rebuked the 90 NM standard claiming that it was unsafe. IATA cited that very few flights ever exhibited position errors greater than 45 NM. A FAA study from February 1962-September 1963 determined airline performance with respect to flight track deviations in the North Atlantic (NAT) region. The results showed that, out of 1000 flights, 30 flights made errors of 40 NM or more, six were 56 miles or more, and only one flight experienced an error of 72 miles or more. In 1966, there was a call for another study with better radar placement. The separation standard was tentatively returned to 120 NM, pending the results of the new study. The results, with over 14,000 radar observations, showed that on average, transatlantic flights spent approximately 1% of their time more than 40 NM (laterally) off course. Machol used a collision model originally developed by Peter G. Reich, representing each of two aircraft in a proximate pair by rectangular parallelepipeds with dimensions 150×150×40 feet. An equivalent system portraying a collision between an aircraft pair was then represented by a parallelepiped 300×300×80 feet and a point. In accordance with figure 2.1, negligible collision risk exists between aircraft A and B whenever point B – the aircraft characterized as conflict initiator – is outside an enveloping shape, or "proximity shell." Within this shell, aircraft *B* is said to be in proximity to *A*, and the pair is at risk of collision. Using this model, a controller's task would be to insure that the intended position of any other aircraft, *B*, is never inside the inner box. Significant collision risk arises only when *B* is intended to be in a position just outside the inner box or on one of its faces (Reich, 1966).

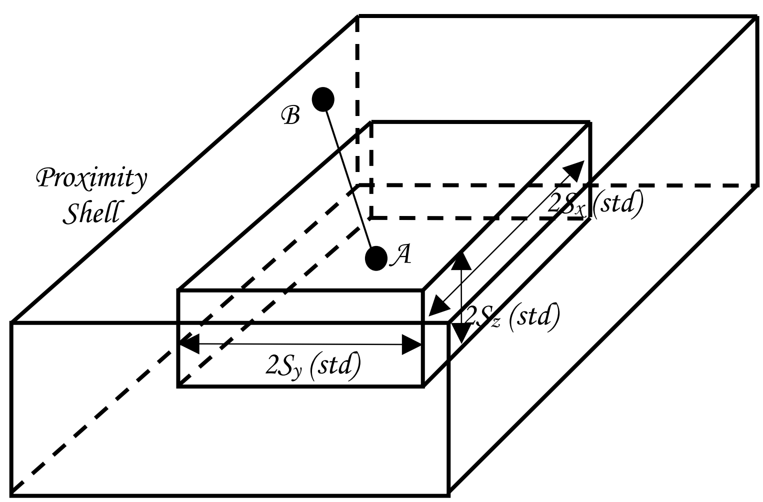


Fig 2.1 Reich's Model

Machol determined the aggregate probability of collision by multiplying the probabilities of collision in each of the three dimensions—namely the probabilities of lateral, longitudinal and vertical overlap. By examining observed data for 2,000 aircraft pairs, Machol determined that the relative errors were greater than the errors of single aircraft by a factor of $(2)^{\frac{1}{2}}$. This data was generally normally distributed with a standard deviation of about 12 NM. He determined that the 143 large errors in the "Accordion" study (i.e. >40 NM), were approximately exponentially distributed. The probability of collision decreased by a factor of approximately $\frac{1}{e}$ per 11 NM for some distance beyond 40 NM, and then slowly thereafter. Machol gave the probability of lateral overlap as follows:

$$P_x(N) = p\left(x' - \frac{1}{40} \le x \le x' + \frac{1}{40}\right) = \int_{x=-\infty}^{\infty} \int_{x'=x-\frac{1}{40}}^{x+\frac{1}{40}} p(x)p(x'+N)dx'dx,$$

where x is the lateral coordinate of the point, x' is the lateral coordinate of the center of the box, $\frac{1}{40}$ is the lateral half-width of the box, N is the nominal separation (NMs), and $p(x) = p(x')$ is the density function of the lateral errors.

It followed that the probability of lateral overlap, P_x, for 90-NM nominal separation was approximately 10^{-6}. Due to excellent station-keeping, or the ability to maintain one's assigned altitude, the probability of vertical overlap, P_z was $\frac{1}{4}$.

For longitudinal separation, he assumed a speed of 480 knots (KTs) and a 25-min separation along flight routes. These *proximate pairs* would be 200 NM apart. Considering a box 300 feet (or $\frac{1}{20}$ of a mile) long, $P_y = \frac{1}{4000}$. The product of these three probabilities was 0.625×10^{-10}.

By relaxing numerous assumptions in the model and refining the parameters to more accurately reflect empirical data, the expected number of lateral collisions was 0.6 per 10^7 flight hours and 0.1 per 10^7 flight hours for 90-NM and 120-NM separation, respectively. Machol determined a "target level of safety" at between 0.45 and 1.2 collisions per 10 million flight hours. He stated that a collision every 10^6 flight hours averaged out to one every other year—clearly not tolerable.

One collision every 10^9 flight hours was much too stringent a target. So the level that they developed was a realistic compromise between these two extreme cases.

A final point that Machol presented concerned the concept of *staggered separation*. In the case of conventional separation, aircraft were spaced 120 NM laterally and 2000 feet vertically. Staggered separation allowed for aircraft to be separated laterally by 60 NM and vertically by 1000 feet. This concept introduced the idea of diagonal collision. However, as mentioned earlier, the incidence of a collision due to vertical (height-keeping) errors is very small compared to lateral deviations. The overall collision probability was reduced because the increase in probability of a lateral collision (0.5 times greater with 60-NM separation) was greatly offset by the decrease in probability of a diagonal collision with a neighbor separated by 60 NM laterally and 1000 feet vertically (2.6 times less likely). Machol's work laid the foundation for the safe scheduling of early transatlantic flights. It also quantified risk and established separation standards and procedures that are still in use today.

2.3.2 Lateral Aircraft Separation Criteria

Beginning in the late 1970's , Brooker (1984) also examined the flow of air traffic between Europe and North America while working for the Civil Aviation Authority (CAA) Chief Scientist's Division in Great Britain. He examined the general traffic flow at peak times of the day, focusing on the lateral and longitudinal separation of aircraft. He noted that in the afternoon (G.M.T.), the general flow of traffic is westbound, with aircraft separated into streams. The separation standard in affect during the time of his work was still 2° of latitude (120 NM) laterally between tracks. Along any given track, aircraft were separated by 2,000 feet vertically, with a 15-minute longitudinal separation. In his work, Brooker identified two subproblems directly affecting viable separation standards. The first was the theoretical issue of estimating flight safety given measured or specified imperfections in navigational performance. The second was deciding what level of safety should be assured by the system design. He compared collision risk theory to the kinetic theory of gases, noting that aircraft are similar to gas molecules in that, rather than traveling in random directions, they travel in well-defined "paths."

He quantified collision risk, N_{ay}, as a function of the product of traffic factors, aircraft parameters and navigational performance of onboard equipment and aircrew members:

$$N_{ay} = 10^7\left[E\left(\frac{u}{2a}+\frac{v}{2b}+\frac{w}{2c}\right)+F\left(\frac{2U}{2a}+\frac{v}{2b}+\frac{w}{2c}\right)\right]P_z(O)\cdot\frac{a}{L}\cdot P_y(S)\,.$$

where a, b and c (a=200 ft, b=200 ft, c=50 ft) represent the length, width or "wing span," and height of an aircraft box, respectively; u=13 KTs is the average along-track speed of two aircraft flying at the same flight level in the same direction; v=47 KTs is the average relative cross-track speed between aircraft which have lost lateral separation; w=1 KT is the average relative vertical speed of aircraft flying at the same altitude; U=480 KTs is the average ground speed of an aircraft; S is the lateral separation value, and $P_z(O)$ =0.25 is the probability of vertical overlap of aircraft nominally flying at the same altitude. $P_y(S)$ is the probability of lateral overlap of aircraft nominally flying on lateral adjacent flight paths; L=120 NM is a parameter used in calculating E and F values, and E=0.5 and F=0.013 are the average number of same-direction and opposite-direction aircraft, respectively, flying on laterally adjacent tracks at the same flight level within segments of length $2L$ centered on the typical aircraft.

This model was tested using a lateral separation standard of 60 NM, which was half the standard in effect at that time. Brooker determined that $P_y(S)$ could be approximated by a probability density function that resembles a two-sided exponential (distribution) with σ equal to 3-4 miles. By utilizing a very lengthy derivation for the convolution integral, he demonstrated that it was possible to get a constraint on the density function for $f(y)$ where $y=S$ by utilizing the target level of safety and estimated values presented in the notation. This constraint came to be known as the minimum navigation performance specification (M.N.P.S.). Three separate M.N.P.S. constraints were developed to cover the full range of navigational data. The first M.N.P.S. constraint measured the percentage of errors that were between 50 and 70 NM. The second measured errors greater than 30 NM, and the third limited the standard deviation of the absolute track deviation to 6.3 NM. He determined that to reduce the lateral separation standard to 60 NM, several procedural changes needed to occur across the spectrum of aviation operations. Over a three-year period, flying procedures, aviation maintenance and ATC communications and procedures all drastically improved. Once the gross error incident rate fell within the target range, the decision was made to implement the 60 NM standard (Brooker, 1984).

Hsu (1982) established a theoretical framework by which Very High Frequency (VHF), Omnidirectional Range (VOR) jet-route systems may be analyzed to determine the nature of lateral position errors exhibited by aircraft by common commercial aircraft. He utilized a second-order differential equation common to the physics of mechanical vibrations:

$$my''(t) = -py(t) - qy'(t), \qquad (p > 0, q > 0).$$

This system normally describes the motion of a spring-mass-dashpot (shock absorber/dampener) system. It consists of a mass with weight, *m*, being placed on top of a spring that has constant stiffness, *p*. The dashpot used to dampen the force generated by the compressed spring, $my''(t)$, has a resistive force, $qy'(t)$. For position error analysis, the equation is interpreted using navigational properties to establish the parameters. First, the model is rewritten as

$$\theta''(t) + \beta\theta'(t) + \gamma\theta(t) = 0.$$

where $\theta(t)$ represents the angular error over time, *t*, where t=0 at the instant the aircraft passes directly over the VOR, β=q/m measures the pilot's promptness in correcting the angular error, and γ=p/m is a constant that is dependent on the period traveling between two adjacent VOR stations. The traveling time between two connected VOR stations, *T*, is determined by

$$\frac{2\pi}{\sqrt{\gamma}} = T.$$

Utilizing data from the Cleveland Air Route Traffic Control Center (ARTCC), He estimated the parameter values of β=0.075903 and γ=0.0012362, validating these results by applying them to VORs in the vicinity of Cleveland and Pittsburgh International Airports. The actual straight-line distance is 190 NM. Using β, γ and the equation above, the period corresponds to a distance of 178.7 NM. This was sufficiently close to validate his results. Hsu (1981) concluded that a time-dependent physics relationship could be reformulated to adequately model lateral position errors along VOR-based, high altitude flight routes.

2.3.3 Vertical Separation and Use of Height Rules

Ford (1982) studied the use of height rules in off-route airspace. The framework he used in his studies consisted of aircraft that were uniform randomly-distributed in the vertical dimension, flying straight-and-level along uniform randomly-distributed tracks. He noted that intrinsic flight safety was degraded significantly when applying the two standard rules that apply to the vertical separation of aircraft, the semicircular and quadrantal rules. The former mandates that aircraft flying magnetic headings of 0-179° must fly at an odd flight level while aircraft that fly 180-359° will fly at an even flight level. The latter splits conventional compass headings into four 90° quarters rather than two 180° spheres. A final rule, the spiral rule, is presented as the ultimate aircraft separation tool because it correlates altitude directly to heading. As an aircraft climbs or descends, its heading will change continuously based on its altitude at any point in time. If a constant of proportionality of 2,000 ft is used, aircraft that change altitude will remain vertically deconflicted with aircraft traveling straight-and-level at assigned flight levels by the 1,000-ft vertical separation standard.

Ford also examined the effect of height-keeping errors on vertical conflict probabilities and on relative velocity. He concluded that, given the inevitable presence of height-keeping error, the semicircular rule does not exhibit marked benefit compared to the other rules at any level of height error. Even when the height-keeping error is large, improvements are marginal at best. He determined that the quadrantal rule performed best with moderate height error. However, the spiral rule performed the best over virtually every level of height-keeping error. Ford verified his results using a computer model for random traffic on straight-line flight paths. He also examined the implications of vertical separation rules on the see-and-avoid principle common in aviation. He found that depending on the rule in use, potential threats were more likely to come from a given direction (e.g. head-on) with respect to one's aircraft. This implies that it could potentially be more beneficial for pilots to anticipate conflicts from one bearing more so than another. He concluded that collision risk using the standard height rules was better than the baseline case of aircraft (randomly distributed in the vertical dimension) flying randomly distributed tracks. This is true unless significant height-keeping errors are introduced.

Nagaoka (1984) of the Electronic Navigation Research Institute in Japan developed an alternative method for estimating the probability of vertical overlap. He introduced the concept of relative vertical distance (RVD), which measured the differences in observed heights of aircraft pairs. His method first derived theoretical probability density functions (p.d.f.'s) of RVD and then verified the resultant functions using Monte Carlo simulation. By assuming that the p.d.f.'s of height-keeping errors were double exponential or double-double exponential distributed, he was able to develop the p.d.f. and parameters of RVD. He concluded that height measurement errors affected the distribution of RVD in two main ways. First, when height measurement errors are negligible, the density of RVD (for comparatively smaller RVD values) becomes smaller than the overlap density. Second, for comparatively large values of RVD, the RVD density dominates, or becomes larger than the overlap density. These results suggested conservative estimates for the probability of vertical overlap, given the standard height separation of 1,000 ft for traffic moving in opposite directions and 2,000 ft for aircraft moving along the same track at adjacent flight levels (234-243).

2.3.4 Collision Risk Probabilities

In the early 1970's, Bellantoni of the U.S. Department of Transportation, Cambridge, Massachusetts, extended the statistical probabilistic method of determining collision risk probabilities from parallel, straight-line flight paths to arbitrary flight paths and vehicle shapes (1971). This research was significant in that it allowed more realistic calculation of collision probabilities, but also because it afforded better, worst-case determinations given more variant flying conditions. Bellantoni began with the simplest form of the probability of collision, where N is the number of collisions between two vehicles in the interval $(t_1\text{-}t_0)$:

$$P[N \geq 1] = P[N = 1] + P[N = 2] + P[N = 3] + ... \, .$$

He subsequently expressed the approximation error as

$$\widetilde{N} - P[N \geq 1] = \sum_{i=1}^{\infty} iP[i] - \sum_{i=1}^{\infty} P[i] = \sum_{i=1}^{\infty}(i-1)P[i] = \sum_{1}^{\infty} iP[i+1] \leq \sum_{1}^{\infty} iP[i]a$$

where $a \geq P[i+1]/P[i]$.

Next, he defined the "collision surface," using V_1 and V_2 to describe the bounded regions of the aircraft. The volume of each region is $\bar{r} = \int v\bar{\rho}dV / \int vdV$. The collision surface, S_c, therefore, is the locus of $\bar{r}_2$ obtained by translating V_2 such that V_1 and V_2 have one or more common boundary points but no other common points. He introduced the relative position vector $\bar{r}(\equiv \bar{r}_2 - \bar{r}_1)$ with origin at the terminus of $\bar{r}_1$. Hence, he further defined a collision occurring whenever $\bar{r}$ enters V_c, the volume that contains S_c due to the relative velocity, $\bar{v}$, when the direction of $\bar{v}$ is such that, if extended from the point of entry, $\bar{v}$ will not reenter V_c. To get the average number of collisions, $\widetilde{N}$, he utilized Rice's method by developing an expression for *dN/dt,* calculating the statistical mean, $d\widetilde{N}/dt$, and simply integrating (with respect to time) to get *N*. Bellantoni applied this approach to the special cases of large relative velocity, nonzero relative velocity, zero relative velocity, and a spherical collision surface. The expressions for average numbers of collisions for these special cases appear below:

$$\widetilde{N} = \int_{t_0}^{t_1} dt\ \bar{v}(t) \cdot \overline{\nabla S_c} W_r(\bar{0}, t) = \int_{\bar{r}(t_0)}^{\bar{r}(t_1)} d\bar{r} \cdot \overline{\nabla S_c} W'_r(-\bar{r}, t) \qquad \text{(Large relative velocity),}$$

$$\widetilde{N} = \int_{t_0}^{t_1} dt \left[\int d(\bar{v}) W_v(\bar{v}, t)\bar{v} \cdot \overline{\nabla S_c}\right] W_r(\bar{0}, t) \qquad \text{(Nonzero relative velocity),}$$

$$\widetilde{N} = (t_1 - t_0)\left[\int d(\bar{v}) W_v(\bar{v})\bar{v} \cdot \overline{\nabla S_c}\right] W_r(\bar{0}) \qquad \text{(Zero relative velocity), and}$$

$$\widetilde{N} = \int_{t_0}^{t_1} dt\ W_r(\bar{0}, t)\widetilde{v}(t)\pi a^2(t) \qquad \text{(Spherical collision surface).}$$

He also applied this method to the case of simultaneous, curvilinear instrument approaches to parallel runways. Through numerous computer runs, he found that the collision risk probability increases dramatically with respect to both *time between touchdowns, T,* and *runway separation* *distance*. In the first case, at T=0, the collision probability is approximately 10^{-38}. As T increases, the theoretical point of passing of the two aircraft moves from the point of touchdown farther up the glide (approach) path. At T=80 seconds, the collision probability worsens to between 10^{-3} and 10^{-4}. Beyond T=100 seconds, the probability drops drastically due to the geometry of the turn (to the final approach course) for vehicle 1. If one introduces the prospect of navigation or piloting errors that are factors in many accidents, this probability increases. The increase is not linear. Standard separation for parallel runways is 5,000 feet. Bellantoni reduced the runway separation by half, modeling an airport with runways separated by 2,500 feet. The results were staggering, but not difficult to believe. He discovered a 6,000-fold increase in the collision risk probability over the baseline case, all other factors being equal (317-339).

Hsu (1981) also studied the evaluation of aircraft collision probabilities at intersecting air routes. Intersecting air routes implies those routes that arbitrarily cross one another at a point other than a waypoint along a given route. Hsu predominately examined air routes over offshore and continental areas. He applied a probability model for use in large-scale navigation systems, a mixture of two double-double exponential (DDE) distributions, to determine collision probabilities at intersection points along air routes. He formally established two entities—the *critical volume of collision* and *critical surface of collision*.

The *critical volume of collision* is defined as "the smallest volume of airspace surrounding the circumcentre (the center of the smallest sphere that completely envelopes the aircraft, or the center of the circumsphere) of an aircraft, outside which the circumcentre of another aircraft under consideration must stay in order to be clear of any potential or actual body contact." The surface of the critical volume of collision is the *critical surface of collision*. In the most basic case, where two aircraft are flying straight-and-level and are assigned flight paths with unspecified headings, the geometry of the critical volume is a right circular cylinder with radius, R, and height, h. In the general case where no specific constraints are imposed on aircraft and no information about flight trajectories or aircraft profiles is given, the critical volume is a sphere with R equal to the sum of the radii of the two respective circumspheres. Hsu partitioned the aircraft collision problem into two subproblems, one in the horizontal plane and one in the vertical. This is applicable for aircraft flying at the same altitude on level flight routes and is valid if the respective components of position error are independent of each other. When a given aircraft reaches an intersection (of two or more air routes), the separation between it and its paired aircraft is known as *nominal separation at the intersection*, S, such that

$$S = u + w \tan\left(\frac{\tau}{2}\right),$$

where τ is the angle of intersection formed by the flight paths of the aircraft in question; u and w represent the longitudinal and lateral separation *minima*, respectively.

Hsu noted that since the probability of observing a collision in time interval of length Δt is very small, the independent binomial variables can be approximated by Poisson random variables. The first-order approximations for lateral and horizontal collisions, as well as the overall probability of collision over (t_0, t_1) are as follows:

$$P\{\text{lateral collision in } (t_0, t_1)\} \approx \int_{t_0}^{t_1} \lambda(t)dt \approx \frac{(t_1 - t_0)P\{\text{lateral overlap}\}}{(2\lambda_y)/(|\tilde{y}|)\text{ at } y = 0},$$

where λ_t is the collision intensity at time t. λ_t equals the $(P\{\text{overlap in } (t, t+\Delta t)\})/\Delta t$; Δt is the average duration of a collision; λ_y is the aircraft wingspan, and $\tilde{y}$ at $y = 0$ is the average relative velocity in the lateral dimension at the instant of collision.

$$P\{\text{horizontal collision in } (t_0, t_1)\} \approx \int_{t_0}^{t_1} \lambda(t)dt$$

$$= \frac{\int_{t_0}^{t_1} (\text{overlap density at } t)(\text{collision area})dt}{\text{expected}\left[\dfrac{\text{length of collision path}}{\text{relative velocity when colliding}}\right]} = 2R\int_{\mathrm{S}_{t_0}}^{\mathrm{S}_{t_1}} C(\mathrm{S}_t)d\mathrm{S}_t,$$

where S_t is a two-element vector indicating the nominal relative position (on the x-y plane) of the aircraft pair at time, t; $C(\mathrm{S}_t)$ is the overlap density evaluated at the relative location S_t.

Overall collision probability over (t_0, t_1)

$$= P\{\text{horizontal collision in } (t_0, t_1)\} \times P\{\text{vertical overlap}\} + P\{\text{vertical collision in } (t_0, t_1)\} \times P\{\text{horizontal overlap}\}$$

$$= \left[2R \int_{S_{t_0}}^{S_{t_1}} C(\mathrm{S}_t) d\mathrm{S}_t \right] \cdot P\{\text{vertical overlap}\} \times \left[1 + \frac{(R\pi)(|\tilde{v}| \text{ at } v = 0)}{4h} \left(\frac{\|d\mathrm{S}_t\|}{dt} \right)^{-1} \right]$$

where $|\tilde{v}| \text{at } v = 0$ is the average vertical relative velocity at the instant of (vertical) collision.

Hsu determined that a combination of two-sided exponential models—one representing expected levels of position error generated under normal conditions and one portraying the abnormal position errors generated by catastrophic failures in the system, would best represent a large navigational system. The resulting double-double exponential (DDE) distribution has a different scale parameter value in each case. In the homogeneous case of individual pilot-facility combinations, the bivariate Gaussian case applies. The p.d.f. of a bivariate Gaussian distribution is

$$f_N(Z|\mu, \Sigma) = (2\pi|\Sigma|^{\frac{1}{2}})^{-1} \exp\{-\frac{1}{2}(Z-\mu)'\Sigma^{-1}(Z-\mu)\}$$

where $Z = \begin{pmatrix} z_1 \\ z_2 \end{pmatrix}$, $\Sigma = \begin{pmatrix} \mathrm{var}(z_1) & \mathrm{cov}(z_1, z_2) \\ \mathrm{cov}(z_1, z_2) & \mathrm{var}(z_2) \end{pmatrix}$, $\mu = \begin{pmatrix} \mu_1 \\ \mu_2 \end{pmatrix}$

and $-\infty < z_1 < \infty$, $-\infty < z_2 < \infty$.

Consider the following system: there is one aircraft pair flying at the same flight level. Aircraft '*A*' is flying east and is positioned at coordinate (0,0) on the conventional *x-y* axis. Aircraft '*B*' is at coordinate (S_x, S_y) and is flying at an angle, τ, toward aircraft '*A*,' measured counter-clockwise from the horizontal (Fig. 2.2).

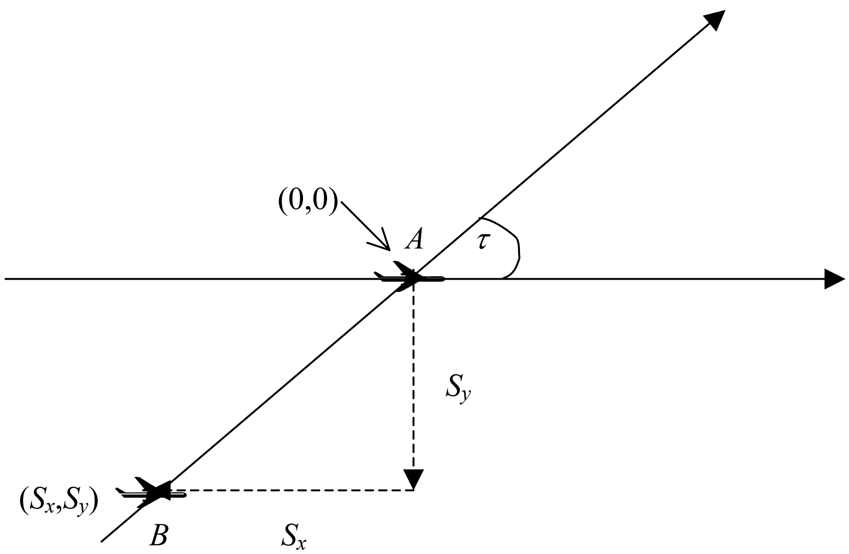


Fig. 2.2: Aircraft Collision Geometry Diagram

Hsu represented the position errors of the aircraft pair with respect to their own tracks by the following model:

$$\begin{pmatrix} x \\ y \end{pmatrix} \sim N_2\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \Sigma^0\right),$$

where $\Sigma^0 = \begin{pmatrix} \sigma_x^{\ 2} & 0 \\ 0 & \sigma_y^{\ 2} \end{pmatrix}$ and x and y represent the *along-track* and *across-track* deviations, respectively.

He represented the distribution of position errors by adjusting for the rotation of the second aircraft by angle, τ:

$$\begin{pmatrix} x^* \\ y^* \end{pmatrix} \sim N_2\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \Sigma^*\right),$$

where $\Sigma^* = \begin{pmatrix} \text{var}(x^*) & \text{cov}(x^*, y^*) \\ \text{cov}(x^*, y^*) & \text{var}(y^*) \end{pmatrix},$

$$\text{var}(x^*) = \sigma_x^{\ 2} \cos^2 \tau + \sigma_y^{\ 2} \sin^2 \tau ,$$

$$\text{var}(y^*) = \sigma_y^{\ 2} \cos^2 \tau + \sigma_x^{\ 2} \sin^2 \tau ,$$

and $\text{cov}(x^*, y^*) = (\sigma_x^{\ 2} - \sigma_y^{\ 2}) \cos\tau \sin\tau .$

It follows that the actual relative positions of the aircraft pair are distributed as follows:

$$\begin{pmatrix} x^* - x \\ y^* - y \end{pmatrix} \sim N_2\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \Sigma^0 + \Sigma^*\right).$$

Therefore, the overlap density of the two aircraft is

$$C_\tau(S_x, S_y) = f_N\left(\begin{pmatrix} S_x \\ S_y \end{pmatrix} \middle| \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \Sigma^0 + \Sigma^*\right).$$

The relative separation position, (S_x, S_y) with respect to time, assuming that the aircraft fly at constant airspeeds (v_a and v_b) and that the separation norm, S is used, is

$$S_x = (\cos\tau)(v_b t - S) - v_a t\,,$$
$$S_y = (\sin\tau)(v_b t - S)\,.$$

The time trace of (S_x, S_y) forms a straight line with slope equal to $(v_b \sin\tau / v_b \cos\tau - v_a)$. With σ_x^2=4 NM, σ_y^2=1 NM, $\tau = 45^{\circ}$, $v_a = v_b$=2 NM/min=120 KTs, and S=10 NM, the overlap density function, $C_\tau(S_x, S_y)$, reaches a maximum of approximately 0.88×10^{-4} over t.

Using the results for $C_\tau(S_x, S_y)$ above, Hsu was able to easily determine the desired horizontal collision probability. At an intersection where aircraft speeds are relatively homogeneous and the minimum nominal straight line separation distance, $D_{\min}$, between an aircraft pair is fairly constant, the collision probability at the intersection can be computed by multiplying the collision probability for a pairwise encounter by the number of encounters over the time period considered. Hsu next applied these methods to parallel flight tracks. He stated that, intuitively, the collision probability of aircraft that fly along intersecting flight routes is smaller than that of aircraft flying alongside each other on parallel routes separated by $D_{\min}$. This is so because, in the case of intersecting flight routes, aircraft are only in close proximity ($< D_{\min}$) as they approach the intersection. Once both aircraft pass the intersection, the distance becomes greater than $D_{\min}$. On parallel flight routes, aircraft travel at a distance greater than or equal to $D_{\min}$ for the duration of a given flight leg. This could be for the majority of the flight in the worst case, and is true as well due to the "dispersed" nature of lateral position errors. He established an upper bound for the collision probability by restraining both the relative orientation and separation distance of the aircraft pair. He determined the length of the time interval during which a given density value is considered is

$$T_c = (2D_{\min} / v_a)\left[(x^2 - 1)/(\mu^2 - 2\mu\cos\tau + 1)\right]^{\frac{1}{2}},$$

where $$\mu = v_b / v_a .$$

Hsu stated that the probability of an aircraft pair colliding at an intersection is no greater than that of the same aircraft pair flying along parallel tracks at a separation distance of $D_{\min}$ for a time period of length T_c. By substituting the product of T_c and the number of pairwise encounters over a desired period for (t_1 - t_0), one can easily determine the upper bound of the collision probability at a given intersection for the desired time period.

2.4 Air Flow Traffic Management Problem

Leal de Matos and Ormerod (2000) discuss the application of operational research techniques to European air traffic flow management (ATFM). There work is based on work carried out by the EUROCONTROL Central Flow Management Unit (CFMU). The airspace over the 36 states that belong to the European Civil Aviation Conference has become excessively crowded in the 1990's. This is primarily due to large volumes of international traffic, as well as vast numbers of intra-European flights. Terminal airspace around Europe's most popular airports is at or near maximum capacity, or saturation point, much of the time. However, the biggest airspace planning challenge exists in the vicinity of Europe's numerous *fixes*, or the points where multiple air routes intersect. IATA forecasted that, between 1993 and 2000, the number of congested fixes would quadruple. There are numerous potential operations research applications in the three critical flight planning phases: strategic, pre-tactical, and tactical.

2.4.1 Strategic Planning

Leal de Matos and Ormerod (2000) present simulation, optimization, and traffic demand forecasting as operational research techniques that can be applied to strategic planning activities. Simulation can be used to assess the impact that airspace control measures have on airspace congestion. Different applications can provide a visual interface, in some cases, that can produce relevant information on bottlenecks, sector traffic loads and levels of ground delays. In the context of European air travel, this is especially critical during the summer months, when recreational air travel increases markedly. In the context of SATS modeling, simulation can provide a visual depiction of the large and varied traffic levels that will exist when SATS flights are combined with existing traffic.

Leal de Matos and Ormerod present optimization techniques in the form of network flow models, integer programming (IP) models and artificial intelligence (AI) tools as helpful in this phase. A network flow model can be adapted to represent the European airspace system. Sources and sinks replicate airports, or sector entry and exit points, nodes take the place of beacons and other navigational points, and arcs represent individual air routes. Traffic capacity for ATC sectors is defined for sets of arcs. IP models can be applied to flow management, since individual flights can be represented by discrete variables. Since strategic planning resolution is low, the requisite level of detail can create IP problems which are fairly easy to solve. AI techniques can be applied to ATC and ATFM issues that contain rules and procedures that are neither easily nor effectively represented in more conventional models. They state that optimization can be effectively combined with either simulation or AI techniques to model different aspects of the AFTM problem. In the U.S., NAS can be modeled using network flow and IP models. However, SATS implementation would create a very complex network model with a multitude of arcs, given the direct flight routing scheme between SATS-compliant airports.

Leal de Matos and Ormerod state that demand can be accurately forecasted using two methods. The first bases traffic on a similar day (called the *reference day*), and the second bases forecasts on air carrier planned flight data. The former does not always adequately capture traffic variability, however flight periodicity can provide a workable estimate of future traffic trends. The latter generally provides a reliable baseline from which air carrier data can be modified. Changes in flights during the pre-tactical and tactical phases are difficult, at best, to capture. Many planners believe that a combination of these two methods can best forecast future traffic demand levels, especially with an improved adjustment factor for flight changes. A SATS model will rely heavily on demand data derived from air carrier inputs. Since SATS flights will be derived as surrogates that capture a percentage of the commercial carrier market share, accurate air carrier data is vital. Development and application of a reference day can be used to forecast demand levels of all flights. In a SATS model, creation of a reference day should accurately replicate general aviation flights, since GA pilots are subject to similar limitations, such as weather conditions. This is especially critical in that most GA aircraft operate at altitudes where SATS aircraft will fly. It should be noted that most GA flights will not be planned months or even days before they occur. Correspondingly, variability of GA flights may tend to be high and challenging to capture.

2.4.2 Pre-tactical Planning

Leal de Matos and Ormerod (2000) cite a "vast and urgent" need for pre-tactical decision support tools. There are three areas where these tools will prove vital: (1) identifying what measures should be taken to prevent overloads—these include negotiation of increases in capacity with flow management position/area control centers, re-routing of flows, and slot allocation regulations, (2) identifying what flows to re-route onto what routes, and (3) selecting where to place slot allocation regulations in order to (a) prevent overloads, (b) minimize overall delay, and (c) have a certain degree of *fairness*. Various regulation plans can be simulated using a simulation tool based on the ATFM Modeling Capability (AMOC) and TACT Automated Command Tool (TACOT) that runs with improved demand forecasts. Since it is recommended that the simulation tool have a strong visual component, the Total Airspace and Airport Modeler (TAAM) might be a good selection for the simulation. Integer optimization, or integer programming (IP), models can be used to re-route traffic flows. The problem can be modeled in such a manner so as to minimize the costs associated with not taking the best route and congestion. Congestion can be represented in two ways—using ground delays, or by using penalties whenever traffic demand exceeds the capacity of a (ATC) sector. IP methods employed at the pre-tactical level have merit in the context of SATS, particularly where congestion is concerned. Given the sheer number of SATS flights in a network that contains large terminal areas (such as New York City, Los Angeles, Chicago, or the Washington, D.C. metro area), both ground delays and ATC sector saturation are distinct possibilities.

2.4.3 Tactical Planning

Leal de Matos and Ormerod (2000) state that the decisions in tactical planning differ from those in pre-tactical and strategic planning "in the level of detail, timescale and volatility: tactical decisions take place a few hours before the flights in a very dynamic environment, where the traffic situation can change in a matter of minutes, whereas pre-tactical and strategic decisions apply to traffic flows and are taken days or months before the flights." Tactical decisions can be characterized by the following questions (1) Given a set of regulations, how should (inherent) ground delays be allocated so that capacity constraints are not broken, delay is minimized and there is equity among flights? (2) How can a foreseeable overload be prevented (e.g. extending/ creating a regulation(s), negotiating increases in capacity, re-routing flights)? (3) How can the heavy delays of regulations be reduced? (4) How can the long delay of (individual) flights be reduced? They also state that TACT Computer Assisted Slot Allocation allocates ground delays automatically on a first planned, first served rule. Other than slot allocation, there is no computer-based support system in the tactical planning phase. At this level, tools "have to be sufficiently fast, detailed and flexible to be used in an operational environment where planning is very close to (the time of) implementation. In terms of re-routing of flights, optimization algorithms and heuristics can be applied to find the *K-shortest* routes between two points. These methods can be combined with other heuristics to quickly identify which flights can be re-routed (in a regulation where delays are building up).

In a SATS environment, effective tactical decisions are especially critical. Even though many SATS flights will be planned in advance—normally in the pre-tactical planning phase—many flights will be requested within 72 hours of the proposed departure time. Depending on the magnitude of the set of SATS flights in a given region for a specific time period, ground delays and sector capacity could potentially reach unacceptable levels quickly. If the planning system cannot make timely corrections, NAS may not be able to safely handle the resulting flights. Conversely, if flight-planning regulations are made more rigid (e.g. SATS flights must be requested no later than 72 hours prior to departure), then much of the flexibility that is a key selling point of SATS may be negated. The tactical planning challenges of SATS are numerous. A tactical question resulting from SATS implementation might be how to re-route SATS flights requested within hours of departure so that both the origination and destination airports meet a given customer's desires. Additionally, if a given SATS flight is re-routed, will the resulting route still resemble "doorstep-to-destination" travel? And will any delays, ground or otherwise, put the departure time of a given SATS flight outside the window that the customer wants to travel? Finally, how is delay allocation and re-routing of flights executed so that commercial air carriers and SATS flight operators experience comparable levels of each? These are just a few of the potential issues that need to be effectively addressed by operations research methods in tactical decision support systems.

The applications discussed above, in addition to some soft OR methods that can be employed in the areas of strategic choice, cognitive mapping, and gaming, represent approaches employed to achieve more efficient use of the limited airspace over Europe. The three phases of flight planning illustrated in the work of Leal de Matos and Ormerod (2000) are also used in the U.S. The operations research techniques they propose, though not tailored to a SATS environment, can be modified and expanded to provide more streamlined use of NAS in the future as SATS is implemented to full maturity.

2.5 Computational Testing

In modeling a real-world system, it is vital to develop a construct that sufficiently represents the system being studied. An accepted methods of accomplishing this is computational testing. Compuational testing is a means by which one can evaluate various facets of the model in question to insure its accuracy and suitability. It is also a means by which inputs and constraints may be varied to test the limits of the model, and to evaluate the quality of its outputs.

Greenberg (1990) presented his ideas on computational testing in a very practical manner, addressing the issues of what testing is, why should one test, how testing is accomplished, and finally, how much testing is required. He stated that the reasons for computational testing are generally to demonstrate (1) correctness of the model or algorithm in question, (2) quality of the solution, (3) speed of computation, and (4) robustness. In terms of correctness, computational outputs can be compared to real world system behaviors as a means of verifying data and hence, validating the model design or algorithm construction. Computational speed is another by-product of testing that can provide useful insights into model and algorithm performance. Speed of computation, generally measured in central processing unit (CPU) time, is very useful in testing entities such as optimization algorithms. Speed can depend on numerous factors, including but not limited to hardware efficiency. But given several algorithms run on the same machine, CPU time then tells the story about how good several competing algorithms are compared to one another. Overall solution quality and model/algorithm robustness can easily be determined through computational testing by verifying model and algorithm results against the real system.

2.5.1 Methods of Testing

Greenberg (1990) highlighted statistical analysis and library analysis as the two primary means of accomplishing computational testing. He stated that statistical analysis presumes random generation over a problem space and collects performance values of replicated trials. Library analysis, on the other hand, uses a fixed library whose properties are either known or reported along with the computational test results. He highlighted experimental design as the single most important factor surrounding the use of statistical analysis. With respect to library analysis, Greenberg stated that a library should reflect a "reality," such as problems or data collected from industry. He pointed out that a major disadvantage of a library is the inability to make rigorous inferences. Controlled randomization of the experiment could possibly overcome this, and must always be included in the experimental design.

Coffin and Saltzman (2000) describe statistical analysis as "a powerful tool to apply when evaluating the performance of computer implementations of algorithms and heuristics (24)." They present theoretical and empirical analysis as two basic approaches to understanding algorithm performance. They state that these two methods are complementary, with the theoretical approach focusing on provable fundamental algorithm characteristics. Empirical analysis consists of implementing the algorithm or heuristic in question in computer code and evaluating performance based on a set of criteria selected by the user. An *algorithm* is a description of a mechanical procedure for executing a computational task. In the context of optimization problems, these are commonly referred to as exact or optimal algorithms, and compute a provably optimal solution. A heuristic algorithm, or simply *heuristic*, is an algorithm that is not guaranteed to produce an optimal solution. Coffin and Saltzman also examine simulation methodology and comparison criteria for competing algorithms. They also reinforce the importance of experimental design when planning data collection. This is especially critical when evaluating head-to-head performance of algorithms or heuristics.

2.5.2 Degree of Testing

Greenberg (1990) considered how much testing was necessary by designing a framework within which one can measure the inherent "need" of the target research effort for the computational results. The levels of "need" are (1) critical, (2) decisive, (3) valuable, and (4) incidental. *Critical* means that the merit of the research contribution depends critically, even entirely, on the empirical evidence provided by the testing. *Decisive* implies that the research merit depends decisively on the computational test results, but there is still merit without it. *Valuable* connotes that the merit of the research is enhanced by the computational test results, but there is sufficient merit without it. *Incidental* implies that the merit of the research is unaffected by the computational test results.

2.6 Impact of SATS

Xu, Trani, Baik, and Cooke (2006) conducted an assessment of airport noise impacts induced by SATS operations. Their work quantified the possible noise contributions of piston-powered SATS aircraft and Very Light Jets (VLJ) weighing less than 7,000 lbs. They conducted five (5) airport noise impact studies of typical SATS-enabled airport – both rural GA and larger, metropolitan airfields. Their sensitivity analysis examined fleet composition and advanced approach procedures, now and in the out-years.

SATS proponents identified early on that noise impacts would be a critical component of the program's widespread acceptance. To fully understand and study noise impacts, the Virginia Tech Air Transportation Systems Laboratory developed the Transportation System Analysis Model (TSAM) jointly with NASA Langley Research Center. TSAM: (1) predicts the number of intercity trips generated based on socio-economic factors; (2) distributes these trips across the country; (3) predicts most likely modes of transportation to execute those trips; (4) predicts flights/ trajectories for trips by air; (5) predicts impacts of the intercity trips on NAS. TSAM has been used to study 3,415 of the nation's 5,000 plus public-use airports. The aircraft modeled in this study consisted of VLJ, as well as advanced Single-Engine (SE) and Multi-Engine (ME) piston-powered aircraft.

Xu, et al (2006) evaluated noise impacts were evaluated at five GA airports: Harry P. Davis Field (HEF) in Manassas, Virginia; Virginia Tech - Montgomery County Regional (BCB); Danville Regional (DAN), Virginia; Teterboro Airport (TEB), New Jersey; and Goodland Municipal Airport - Renner Field (GLD), Kansas. They used the FAA's Integrated Noise Model (INM) in their research to model fixed-wing aircraft noise. Rotorcraft generally use the Heliport Noise Model (HNM) and the Rotorcraft Noise Model (RNM). Sound exposure due to military aircraft noise around bases, Military Training Routes (MTR), Military Operating Areas (MOA) and Special Use Airspace is often modeled using Noisemap.

Using the proposed noise footprints of VLJ and aircraft substitution methods for SATS SE and ME aircraft, airport noise contour maps were derived from the SATS demand function from

TSAM. Wherever possible, the researchers used specific operating procedures at the airports studied. When local information was unavailable, pilot anecdotal experience was used to make assumptions. The General Aviation and Air Taxi Activity (GAATA) report states that 85% of GA flights in the US occur during daylight hours, that is, between the hours of official sunrise and sunset. Likewise, approximately 85% of GA operations are under Visual Flight Rules (VFR) and 15% are Instrument Flight Rules (IFR). For the noise studies, 37.5% of aircraft movements were approaches, another 37.5% were take-offs and 25% were touch-and-go operations. For sensitivity analysis, the researchers used 100% VLJ as well as a 30%-30%-40% mix of SE, ME and VLJ executed approaches of 3-5 degrees of Glide Path Angle (GPA).

Findings were that SATS aircraft may produce comparative little ambient aircraft noise and, hence, a smaller noise footprint compared to current ME aircraft. Varying the GPA had very little effect on the noise exposure around the airfields studied. For the year 2014, SATS operations increased the 65 DNL contours 7% at TEB to less than 0.9% at rural airports like GLD. At a terrain-challenged airport like BCB, noise impacts are estimated at 5%. One of the empirical examples provided for context was at Teterboro, New Jersey; if TEB enacted a stage 2 corporate jet ban, an approximate 11% reduction in 65 DNL is possible.

Xu, et al (2006) highlight that the five airport noise studies conducted present a “pessimistic” view given that additional SATS operations were assumed above and beyond baseline GA traffic levels. Reality is that newer, more efficient, and less noisy aircraft would likely replace a seqment of the older, noisier ones. Noise signatures of VLJs should be continuously validated, and use of actual aircraft noise certification data will help future noise impact studies. Finally, the researchers recommend a comprehensive nationwide analysis aimed at the impacts of SATS aircraft deployment. Typical runway configurations and parametric SATS demand are two of the variables.

Trani, Viken, Dollyhigh, et al (2006) also considered the impact of VLJ traffic in the Next Generation Air Transportation System (NGATS). The researchers describe a methodology to predict on-demand air taxi services using VLJ in NAS. On-demand VLJ air taxi service has been evaluated at 2,300 public-use airports with runways greater than 3000 feet in length with

FAA visibility minima of three-quarters of a mile Runway Visual Range (RVR) or less. Their analysis uses TSAM to estimate the demand function for VLJ air taxi services. It is a multi-mode intercity trip demand model for predicting long distance trips in excess of 100 miles. TSAM employs a nested logit model to assess the likelihood that a passenger will select a given mode of transportation given multi-mode alternatives between origin and destination counties and airports. TSAM predicts annual passenger trip demand values that generate daily demand and accompanying flight schedules. Seasonal effects were studied to adjust the number of travelers in quarterly periods; quarterly demands were converted to daily demands. Travel behavior trends were derived from Enhanced Traffic Management System (ETMS) data. Trani et al (2006) used 2.13 and 3.40 to represent the size of the average business and non-business parties, respectively. They describe the emergence of VLJ technologies and model a generic pressurized six-place, two-pilot, twin turbofan aircraft. Their VLJ has a maximum cruise speed of 365 knots and 1,130 NM range and operational ceiling of 41,000 feet. The researchers ran scenarios with NGATS using socio-economic and demographic forecasts for 2015 and 2025. VLJ performance was randomized for weight distributions and temperature effects to make more realistic flight assignments.

The Joint Program and Development Office (JPDO) planned NGATS with a stated goal of 30% reduction in gate-to-gate travel times, primarily in the areas of passenger processing and airport slack time. A 5% reduction in schedule times may accompany future improvements in direct routing and airspace management. Cost was the primary variable studied. Temporal variations in on-demand VLJ air taxi services were expressed as a function of cost. TSAM produced results for five future one-year periods. Trani et al (2006) used a VLJ production constraint of 750 aircraft per year. Low- and high cost solutions were developed (5,400 VLJ would be required to satisfy the air taxi market at a cost of $1.85 per passenger-mile; 3,400 VLJ can satisy the TSAM demand function in 2025 with NGATS for $2.50 per passenger-mile).

Results showed a high incidence of VLJ flights near populated areas. Average flight distance for VLJ flights was 225 statute miles at a cruise altitude of 24,000 feet. Monte Carlo simulation was employed. Of 2,300 potential airports in the system, only 1,500 or so might be expected to see traffic on any given day. Using the most optimistic deployment schema, some of the nation's

Air Route Traffic Control Centers (ARTCC) might receive 2,000 VLJ flights per day. This is substantial when one considers other traffic forecasts out to the year 2025.

Trani et al (2006) concluded that, though untested, on-demand VLJ air taxi services could have a significant impact on the future NAS. Effect of the low-cost ($1.85 per seat-mile) scenario would be more pronounced than costs of $2.25 and $2.50 per seat-mile. If the 30% reduction in gate-to-gate travel times is achieved, air transportation demand may increase markedly resulting in more VLJ traffic. An 11% increase in commercial air operations might be anticipated. The utilization of on-demand vehicles for air taxi services may climb to 800-1,200 hours per year per aircraft. By 2017, the most optimistic scenario presented by the researchers shows the possibility of 4,100 VLJ aircraft such as those produced by Eclipse, Cessna and Adam operating in NAS. They expect VLJ to affect metropolitan areas more so than rural ones. They cite the key to success of this program is its accessibility to airports near business centers and procedures that do not impede operations at existing airport hubs. Operational Eveolution Plan (OEP) airports do not significantly impact nationwide demand for VLJ; at the regional level, VLJ may see a marked increase in demand due to the attractiveness of a given area. One of the key assumptions presented by the researchers is that, due to capacity constraints, VLJ rarely traveled into large hub airports.

Trani et al recommended that JPDO and the FAA should consider multiple, varied VLJ deployment options in future NAS studies. The researchers state that OEP airports should not receive VLJ traffic to mitigate congestion. Three OEP airports, Chicago-Midway (MDW), Las Vegas' McCarran International Airport (LAS), and Washington's Ronald Reagan National Airport (DCA) are noted to be attractive to VLJ customers. Constraints and delays associated with airport and airspace capacity should be integrated, in a direct fashion, to VLJ demand analysis. With the introduction of VLJ aircraft will come additional congestion and delays, especially below 30,000 feet. High fidelity airspace simulators were cited by the researchers as a necessary tool to be used in future analysis, including refined interaction between VLJ and transport aircraft in NAS.

Chapter 3

Methodology

3.1 The Research Method

A system as innovative and complex as SATS requires a robust research methodology that can accomplish several basic, yet critical, tasks. Since SATS will fundamentally change the nature of air travel for a segment of the population, research associated with it must recognize the necessity of flight safety. This is to say that, without guarantees that a new system such as SATS is seamlessly integrated into NAS and is inherently safe, then one can not reasonably expect the concept to meet widespread acceptance. Computing technologies have evolved greatly over the past several decades. Hence, the modeling, simulation, and analytical tools exist by which to fully study SATS without risk of the loss of human life and destruction of materiel. The research method that is employed to determine the viability of SATS from a safety of flight standpoint is accomplished in three distinct phases. These are sequential in nature and have several embedded steps that comprise each.

Figure 3.1 shows the three phases of the research methodology. These phases support a study of SATS by (1) enabling SATS to be modeled in accordance with the concept described by NASA and the FAA; (2) replicating the model and implementing it in a computer-based simulation to generate experimental outputs; (3) providing data and the means by which to explore SATS flight safety using analytical methods.

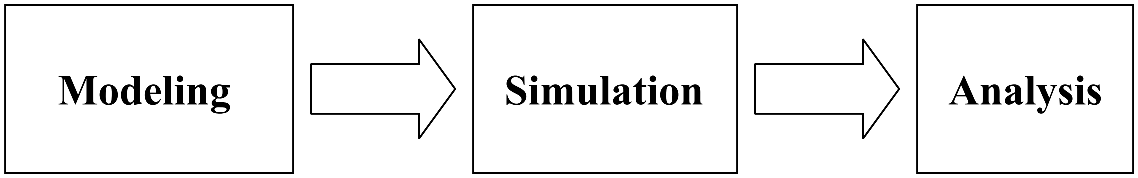


Figure 3.1: Phases of the Research Method

3.2 Phases of the Research Method

The modeling phase consists of several steps, most notably SATS network development – this includes designation of the SATS area of interest (AOI) and pre-processing of flight data. Several factors must be included when constructing the SATS network for a given state or region. Among these are: selection of airports, heliports and landing facilities; development of SATS clusters; placement of SATS aircraft; air traffic generation for the periods to be studied; and flight routing.

From a strategic standpoint, SATS development takes place at three levels. A national level consists of a plan to integrate SATS as a vital part of the National General Aviation Roadmap of the 21st century. This plan lays out the goals and requirements for SATS nationwide. The second level will include developing a SATS infrastructure for individual states, or cooperative efforts between groups of states. These states will identify requirements and supervise upgrades of facilities to comply with overall SATS project guidelines established by the proponent agency. A third level consists of individual SATS facilities—airports and landing areas. Airport managers will be responsible to execute the physical transformation of existing facilities to become SATS-compliant. This research will focus on conflict analysis at the second level, with a specific application to the Commonwealth of Virginia and airports in surrounding states that are closely linked with Virginia commercial centers and points of interest. Figure 3.2 shows the general land area that comprises the SATS test bed, or area of interest (AOI), for this regional SATS study. The AOI consists of the Commonwealth of Virginia, in total, and portions of

Figure 3.2: Map of Commonwealth of Virginia and Bordering States (Magellan, 1994).

bordering states. Suitable criteria were established by which to select communities from within the AOI (that SATS will service) as well as the corresponding SATS facilities. SATS clusters – an entity of great utility developed in this research – were created. Decisions were made on what policies would drive location(s) of SATS aircraft. SATS demand levels were established and used to generate realistic flights that – along with forecasted commercial, military and GA traffic – would later be used as inputs to the simulation model. Flight routing for SATS, commercial, GA and military sorties were established. The simulation phase was next.

The simulation phase was characterized by the accomplishment of several key tasks: physical construction of the SATS network and all project files in the simulation software language; development of the experimental design; conduct of simulation runs in accordance with the experimental design; and collection of desired output data. This phase included collecting all relevant airport data for each SATS facility and other airports in the AOI to which forecasted traffic took off from and/or landed to. These data consisted of airport designation, geographic (lat/long) coordinates, airfield elevation and other technical information critical to correct spatial representation of the airports in the simulation model. Enroute and terminal area waypoints were selected and put into the model. Likewise, flight routes were chosen and constructed from these waypoints. Timetables that would serve as a virtual flight schedule for the simulation were built from those flight data developed during the modeling phase. Input data were screened for accuracy and completeness. Holes and other inconsistencies in those data were repaired, and input files were subsequently generated that conformed to the required TAAM Plus data structure. Metrics to support the analysis phase were developed and output files that would collect the supporting data were identified. Simulation reports were tailored to deliver the desired outputs. Finally, parameters within the TAAM Plus project construct were modified to reflect the desired (controlled) conditions of this SATS simulation. Once the simulation model was completed, each scenario was run and data were collected. The analysis phase followed.

Analyses consisted of screening the simulation output files for midair conflict data. Output reports furnished the total number of midair conflicts in each scenario for specified sectors. The number of midair conflicts that occurred during a given time interval were also shown. This was accomplished by specifying the report interval (e.g. 15 min., 30 min., one hour, etc.). These data were then assembled in such a manner as to give useful insights into potential trends that might be reasonably expected once SATS aircraft are introduced into NAS. Data were presented in several ways to illustrate the important aspects of SATS as a system, and to facilitate analyses. Graphical representations of simulation outputs show the volume of conflicts in each scenario. These are based upon the proximity of aircraft to one another during midair encounters. Conflicts are characterized by the percentage of the required separation distance between aircraft that is violated during the incursion. Sensitivity analysis was accomplished by modifying air traffic densities consistent with proposed SATS market penetration levels. Finally, a functional relationship was developed that illustrates the factor by which the number of midair conflicts grew as the number of aircraft in the system was increased. Figure 3.1 pictorially describes the research method that was employed in this work.

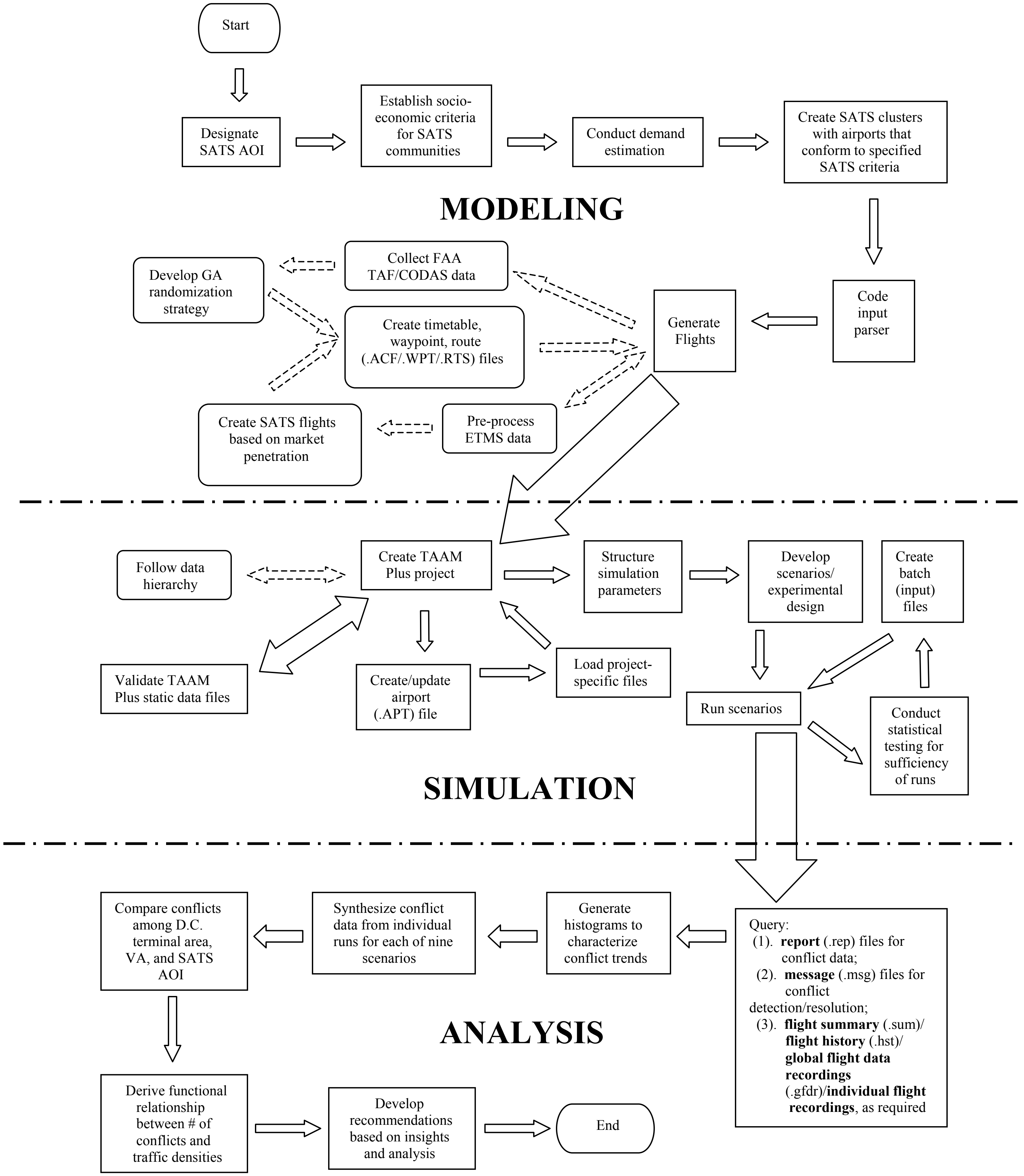


Figure 3.3: Expanded Research Method

Figure 3.3 displays the expanded phases of the research method applied and the various steps inherent to each phase of the work.

3.3 Selection of Airports, Heliports and Landing Facilities

Airports, heliports and landing facilities must be selected such that the resulting model is representative of the desired system. In the year 2000, only four (4) airports in the Commonwealth of Virginia were officially earmarked as future SATS facilities. My Virginia SATS model incorporates these designated airports, as well as others that meet the benchmark criteria laid out in the SATS national strategy. Among these criteria is the desire to have a SATS-compliant airport within a 15-minute drive of communities served. As discussed earlier, there are physical characteristics that SATS airports must exhibit. Additionally, certain assumptions have been made in terms of socio-economic and other criteria that have guided the selection of SATS airports in the Virginia model. It is important to point out that not all airports in Virginia are represented in this model. This assumption is realistic because not *every* airport in the U.S. will become a SATS airport. For example, there are numerous facilities that are designated for private use only. Many of these have short runways, or the runways are not hard-surfaced (e.g. turf, dirt). Also, many facilities exist in areas where there will be insufficient demand to warrant a SATS airport. Private strips that support crop dusters or certain recreational aircraft, such as experimental and ultralight vehicles, are prime examples of this. Generally speaking, traffic originating at such facilities is so infrequent and operates at such low flight levels that including them provides no marked benefit with respect to illustrating likely midair conflicts. Omitting these airports allows the modeling effort to be focused on those areas where SATS facilities will most likely be located in the future.

The general selection policy used to select SATS airports in Virginia is based on
(1) communities (counties or individual cities) with populations greater than 100,000 and
(2) average per capita personal income greater than $20,000. Additional airports were selected in cities and counties that represented "strategic geographical significance." These areas possess individual businesses or institutions that are of great value to the Commonwealth at large.

Hence, we assume that they would benefit markedly from a SATS airport in close proximity. Table 3.1 displays socio-economic data for counties/cities selected for SATS airports. Several airports were selected in areas that fell slightly short of one or both of the stated criteria. These airports service the more remote sections of Virginia, affording greater SATS coverage for

County/City	Population	Avg. Per Capita Personal Income ($)
*Albemarle Co./ Charlottesville	68,040	29,063
Alexandria	111,183	43,676
Arlington Co.	170,936	41,708
Chesapeake	151,976	21,457
Chesterfield Co.	209,274	28,780
Fairfax Co.	818,584	39,951
*Frederick Co./ Winchester	45,723	23,030
*Hampton	133,793	19,973
*Lynchburg	66,049	22,169
*Montgomery Co./ Radford	73,913	17,676
Newport News	170,045	20,258
Norfolk	261,229	20,221
*Pittsylvania Co./ Danville	55,655	19,126
Prince William Co./ Manassas	215,686	24,483
Richmond	203,056	31,207
*Roanoke	96,397	25,169
*Rockingham Co./ Harrisonburg	57,482	20,580
Virginia Beach	393,069	24,425
Washington, D.C.	609,909	35,704

'*' denotes areas of "strategic geographical significance."

Table 3.1: Socio-economic Characteristics of SATS Areas (Old Dominion University, 1993).

the Commonwealth. SATS airports were selected in cities that represent the commercial center for that area. In large transportation centers, locations for SATS airports were selected based upon their proximity to the city center and on the complexity of the overlying airspace.

3.4 SATS Clusters

The *SATS cluster* is introduced in this research as the fundamental building block of the SATS network in Virginia. SATS clusters are groups of airports that are linked together due to their geographical proximity to one another. The cluster generally contains between two and five airports. It is conceivable, though rare, that a SATS cluster would have more than ten airports, however. These clusters contain one or more large airports, surrounded by smaller SATS airports. The larger airports that serve as the focal point of the cluster may vary from smaller regional facilities to one or more international airports. In terms of the real world system, if local authorities choose to pool SATS aircraft at one facility and service the others on a request basis, they may select one airport as the *SATS hub*. This airport would serve as the home station airport for SATS aircraft in the vicinity of that cluster. An operational decision to designate the SATS cluster hub would have to be made, as central pooling of SATS aircraft would occur at that airport. Various criteria, developed by the stakeholders in the local SATS operation, would be applied. Among these might be SATS aircraft supportability, centralized location relative to the preponderance of SATS consumers, and less congested terminal airspace.

In the context of this model and simulation, the SATS cluster has created a very convenient framework within which to generate SATS traffic and to randomize the pairing of origin-destination (O-D) airports. The O-D pairs for SATS flights were generated randomly in accordance with forecasted O-D distribution percentages. In the model, 10% of SATS flights take place between the original O-D (paired) airports from Enhanced Traffic Management System (ETMS) data; 15% of SATS aircraft depart from a smaller SATS airport around the ETMS departure airport and fly to the original destination; 15% depart from the original ETMS airport and fly into a smaller SATS facility. Finally, 60% of SATS flights depart from and arrive to smaller SATS airports in the vicinity of the original ETMS airports. The smaller SATS airports mentioned above are chosen at random. This distribution of SATS flight profiles was chosen for several reasons. The first and most critical is that it represents the entire spectrum of possible pairings between generalized airport types. This is the basis for the algorithm which, when coded, creates surrogate SATS flights for the simulation. The specific percentages applied to each profile were selected such that they are representative of the strategic vision for SATS. That is, the majority of SATS flights will avoid current major airport hubs to maximize passenger throughput in accordance with demand and to minimize enroute delays. The simulation is somewhat sensitive to the breakdown of SATS sorties by percentage of flights that will depart from and arrive to SATS and conventional (non-SATS) airports. However, given that individual airports in a SATS cluster are generally located outside a 10-mile radius of one another, the resultant effect on the incidence of midair conflict is reasonably assumed to be nominal. Further, flight departures and arrivals would realistically wait until they could safely take-off or enter arrival airport traffic patterns. So this would also reduce the probability of a midair conflict between aircraft in close proximity to a departure or arrival airfield.

If an individual airport is chosen as the SATS hub, several factors are critical to select the best location to base SATS aircraft. *Supportability* and *serviceability* should be considered first and foremost. Supportability implies that the home station airport will have the robust support structure required to maintain SATS aircraft. Serviceability means that the location will enhance the ability of SATS aircraft to service the target population. This implies an airport that is sufficiently large and developed enough to require minimal upgrades, and is centrally located to maximize flexibility. Regional and smaller international airports with accompanying class C (terminal radar services) or D (operational control tower) airspace would be the best choices to serve as home station SATS hubs. Most of these airports have solid infrastructures in place that can support these aircraft. Additionally, the airspace is not overly busy. Therefore response time for flights would not be degraded. These airports are most often centrally located to service a given area of the state, thus travel time to outlying SATS airports would not be exorbitant.

The SATS cluster concept is also applicable within large terminal areas, such as metropolitan or international airports with class B (terminal control area) airspace. A fine example of the SATS cluster application in the Virginia SATS AOI would be Dulles International Airport in

Washington, D.C. It is wise to avoid selecting a home station airport that lies close to the center of the 30-NM ring that surrounds the class B airspace. Both the larger home station airports and individual SATS airports should be close enough to the city center to allow ease of travel once SATS aircraft arrive with their passengers. However, the airports should be strategically located whereby they do not become significantly constrained by the volume of traffic taking off and landing at large metropolitan airports. This drives selection of airports that lie outside the 5-NM ring around the class B airport that extends from the surface upward to the base of the overlying airspace. Airports that are situated between the 5-NM and 10-NM rings, and 10-NM and 20-NM rings, have a "step-down altitude," as do those that lie inside the 30-NM radar service area. These step-down altitudes vary depending on the airport. In these areas, aircraft may depart and land without requiring clearance from approach controllers to enter the terminal area. Also, they are generally not required to deviate or accept radar vectors for sequencing and separation purposes. This is contingent on the fact that aircraft do not penetrate the bounds of the class B airspace. Again, the goal is to maximize flexibility, which translates into greater serviceability for the customer. As stated earlier, the SATS cluster concept provides a vehicle by which the SATS network can be effectively constructed. It has been defined such that it meets the requirements imposed by the SATS program vision, yet provides maximum flexibility to support the customer.

The SATS cluster is especially suited to Virginia because of the diversity of the airspace in the Commonwealth and surrounding areas. Though only developed in concept, SATS clusters would facilitate flight operations in the heavily constrained airspace around Washington, D.C., as well as the sparsely populated areas in the west, southwest, and south side of Virginia. The SATS cluster would also allow airport managers and SATS aircraft owners to most efficiently base and operate their aircraft. The only downside to utilizing SATS clusters in the Virginia SATS model would be an increase in the number of short haul trips. Specifically, the increased number of trips to and from the SATS home station hub increases traffic around SATS airports and the potential for midair conflicts. It also complicates flight routing within the SATS cluster. This is another justification for providing SATS aircraft to all SATS airports. However, this model can effectively simulate either case. The only change is in the makeup of SATS flight routes. In the case of (SATS) aircraft based solely at SATS hubs, aircraft would depart the

SATS (home station) hub and fly to the intermediate SATS airport for passenger pickup. Upon returning with the original passenger or termination of passenger services for a given flight, the SATS aircraft would return to the SATS hub. In the case of trips that span several days, SATS aircraft might be required to make empty return trips to their home stations or sit idle until the original passenger was ready to make the return trip. The decision on where to base SATS aircraft and the scheduling of said aircraft is beyond the scope of this research. These are but a few of the reasons why the decision to base (SATS) aircraft at all airports in this SATS model was made. However, both options have positive and negative aspects in terms of practical application. Table 3.2 displays the SATS clusters developed for this simulation, as well as the airports that comprise each cluster in the proposed SATS network for Virginia.

Cluster	ICAO ID	Name	Location
1	**DCA**	Ronald Reagan Washington National Airport	Washington, D.C.
	GAI	Montgomery County Airpark	Gaithersburg, MD
	W32	Washington Executive Airport/Hyde Field	Clinton, MD
	IAD	Dulles International Airport	Washington, D.C.
	JYO	Leesburg Executive Airport/Godfrey Field	Leesburg, VA
	HEF	Manassas Regional/Harry P. Davis Field	Manassas, VA
2	**BWI**	Baltimore-Washington International Airport	Baltimore, MD
	FDK	Frederick Municipal Airport	Frederick, MD
	MTN	Martin State Airport	Baltimore, MD
	W54	Carroll County Regional/Jack B. Poage Field	Westminster, MD
3	HGR	Hagerstown Regional/Richard A. Henson Field	Hagerstown, MD
	MRB	Eastern West Virginia Regional/Shepherd Field	Martinsburg, WV
	OKV	Winchester Regional Airport	Winchester, VA
4	FCI	Chesterfield County Airport	Richmond, VA
	OFP	Hanover County Municipal Airport	Ashland (Richmond), VA
	PTB	Dinwiddie County Airport	Petersburg, VA
	RIC	Richmond International Airport	Richmond, VA
5	BCB	Virginia Tech Airport	Blacksburg, VA
	PSK	New River Valley Airport	Dublin, VA
	ROA	Roanoke Regional Airport/Woodrum Field	Roanoke, VA
6	FVX	Farmville Regional Airport	Farmville, VA
	LYH	Lynchburg Regional Airport/Preston Glenn Field	Lynchburg, VA
7	CPK	Chesapeake Regional Airport	Chesapeake (Norfolk), VA
	ORF	Norfolk International Airport	Norfolk, VA
	PHF	Newport News/Williamsburg International	Newport News, VA
	PVG	Hampton Roads Executive Airport	Norfolk, VA
8	0A9	Elizabethton Municipal Airport	Elizabethton, TN
	TRI	Tri-Cities Regional Airport	Bristol/Kingsport, TN
	VJI	Virginia Highlands Airport	Abingdon, VA
9	BUY	Burlington-Alamance Regional Airport	Burlington, NC
	DAN	Danville Regional Airport	Danville, VA
	GSO	Piedmont Triad International Airport	Greensboro, NC
	INT	Smith Reynolds Airport	Winston Salem, NC
	MTV	Blue Ridge Airport	Martinsville, VA
10	**CHO**	Charlottesville-Albemarle Airport	Charlottesville, VA
	SHD	Shenandoah Valley Regional Airport	Harrisonburg/Staunton, VA
11	BKW	Raleigh County Memorial Airport	Beckley, WV
	BLF	Mercer County Airport	Bluefield, WV
	HSP	Ingalls Field	Hot Springs, VA
	LWB	Greenbrier Valley Airport	Lewisburg, WV
12	2N9	Franklin County Airport	Louisburg, NC
	AVC	Mecklenburg-Brunswick Regional Airport	South Hill, VA
	HNZ	Henderson-Oxford Airport	Oxford, NC
	RDU	Raleigh-Durham International Airport	Raleigh/Durham, NC
	TDF	Person County Airport	Roxboro, NC

NOTE: Bold ICAO indicates SATS Hub

Table 3.2: SATS (Airport) Clusters

Figures 3.3 thru 3.7 show the actual SATS clusters used in this research and the accompanying simulation, superimposed on a World Aeronautical Chart from the National Aeronautical Charting Office (2001).

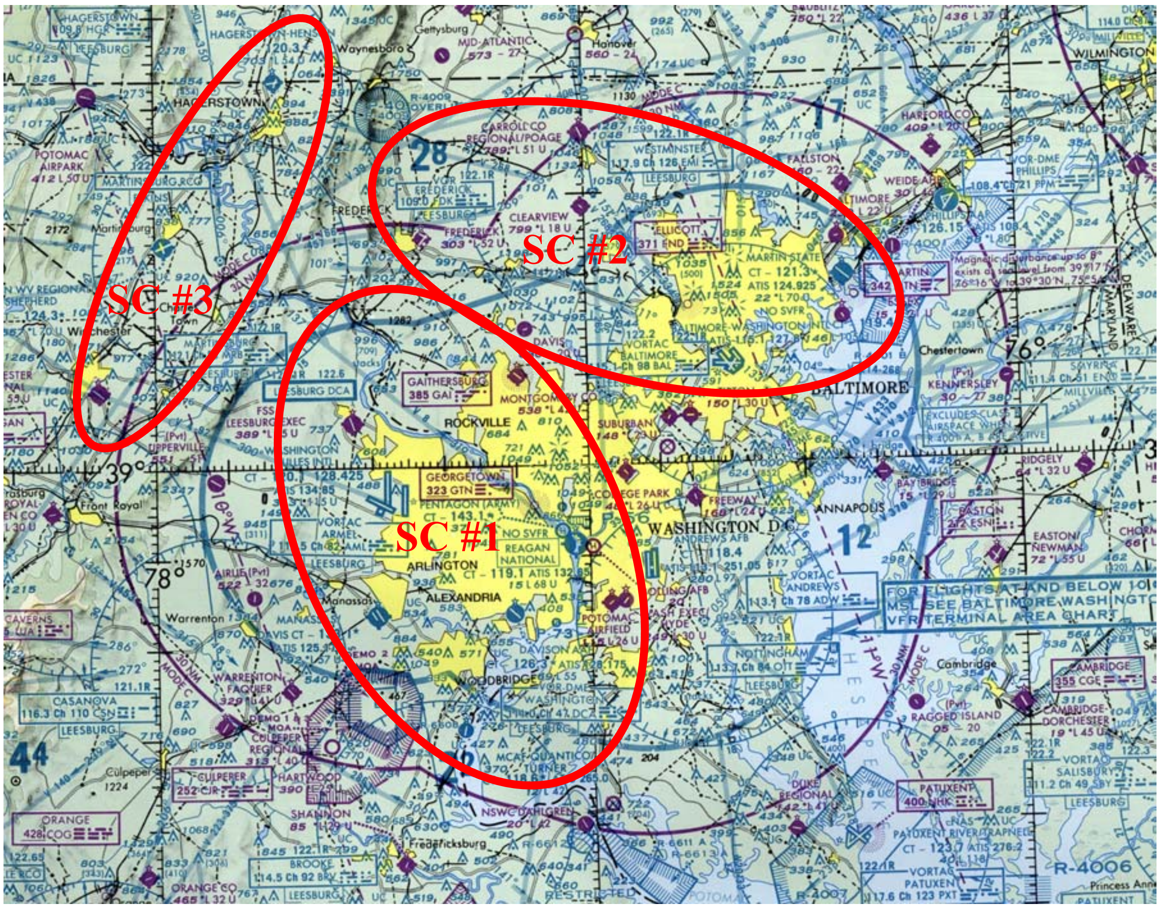


Figure 3.4: Washington, D.C. Class B Terminal Area Airspace; SATS Clusters 1, 2, & 3

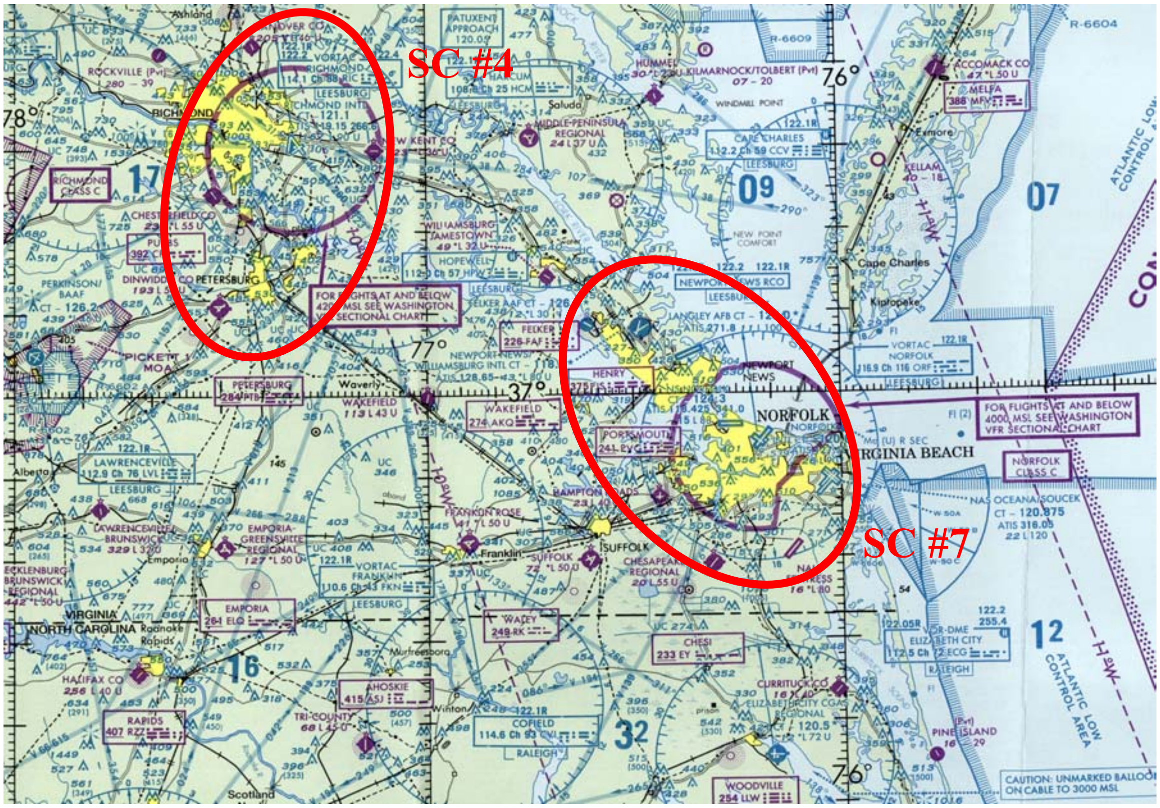


Figure 3.5: Richmond and Norfolk, Virginia Class C Terminal Area Airspace;
SATS Clusters 4 & 7

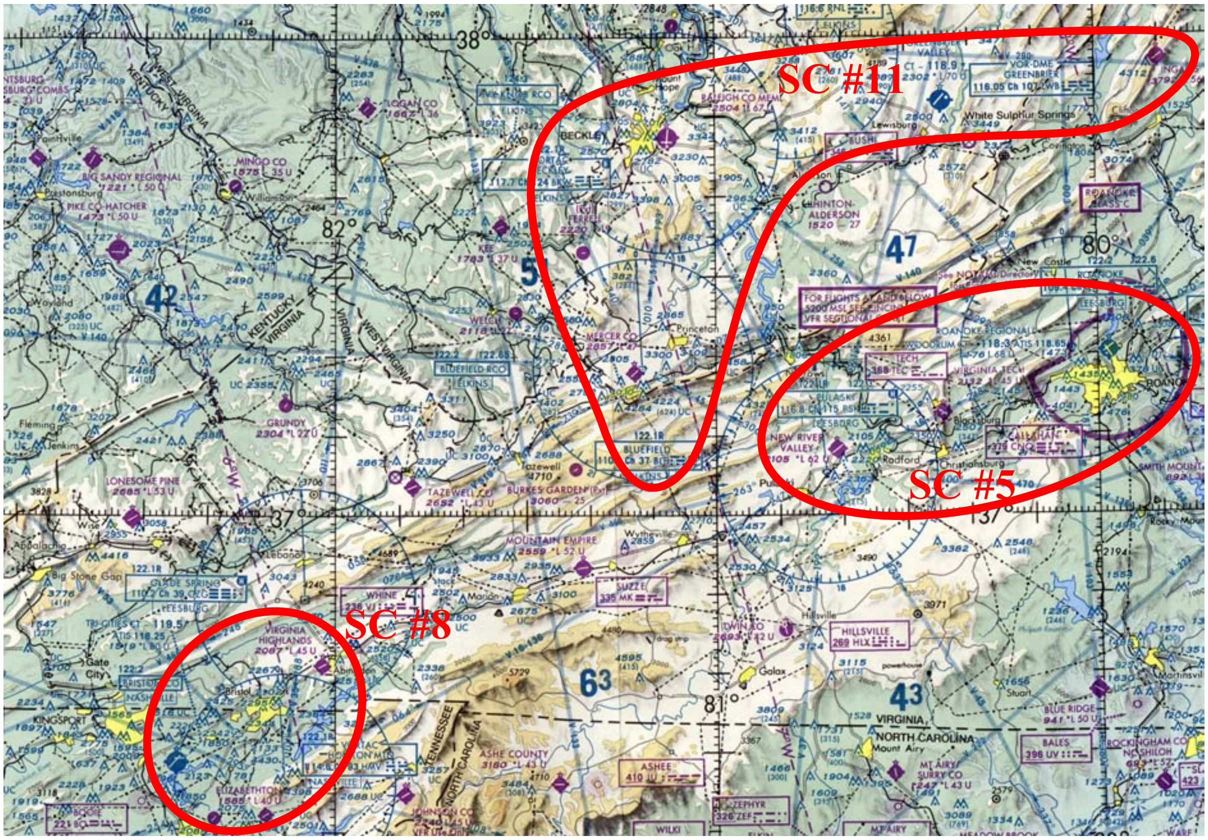


Figure 3.6: Roanoke, Virginia Class C Terminal Area Airspace; Lewisburg, Virginia and Tri-Cities, Tennessee Class D Airspace; SATS Clusters, 5, 8, & 11

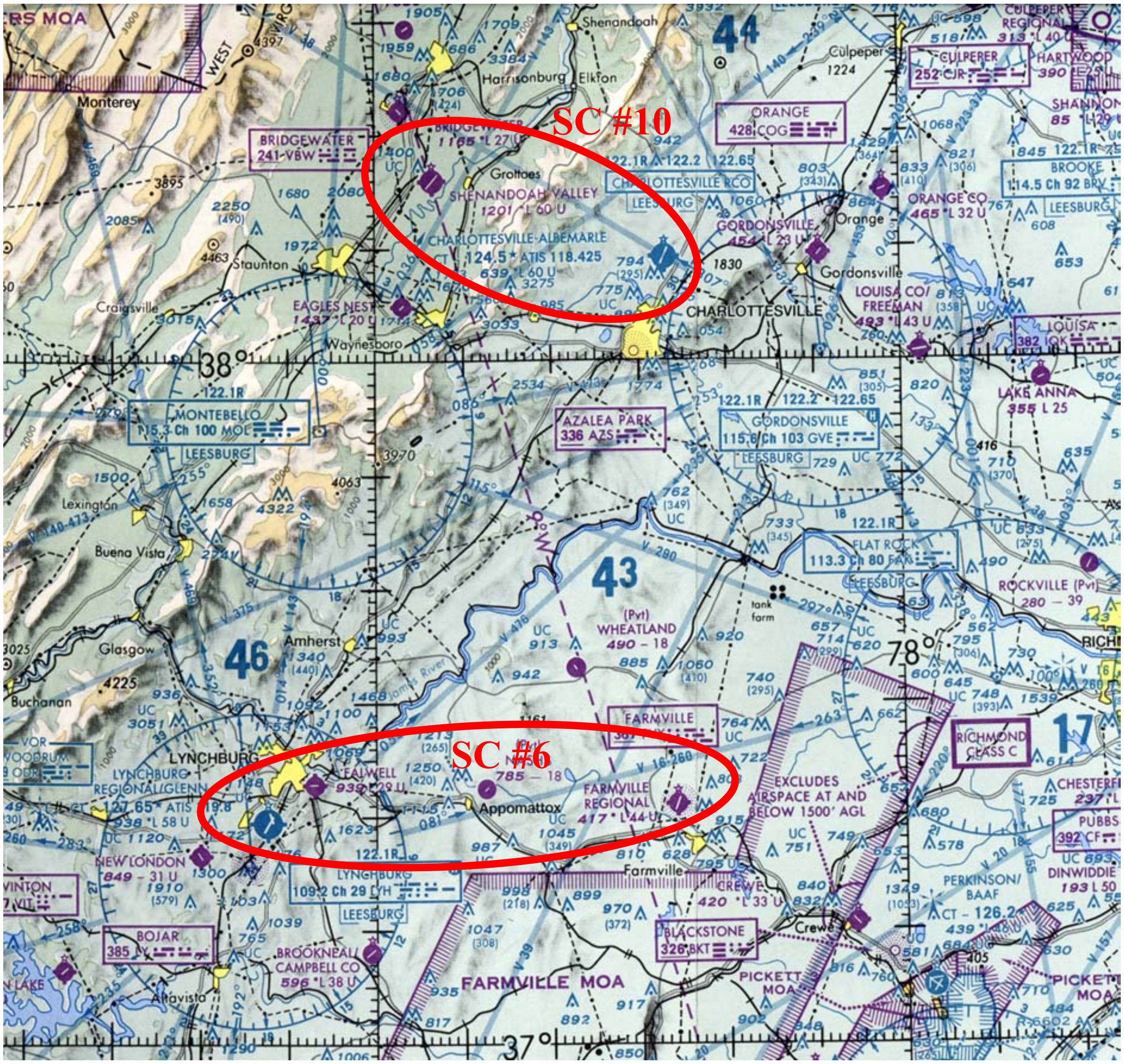


Figure 3.7: Charlottesville-Albemarle County and Lynchburg, Virginia Class D Airspace; SATS Clusters 6 & 10

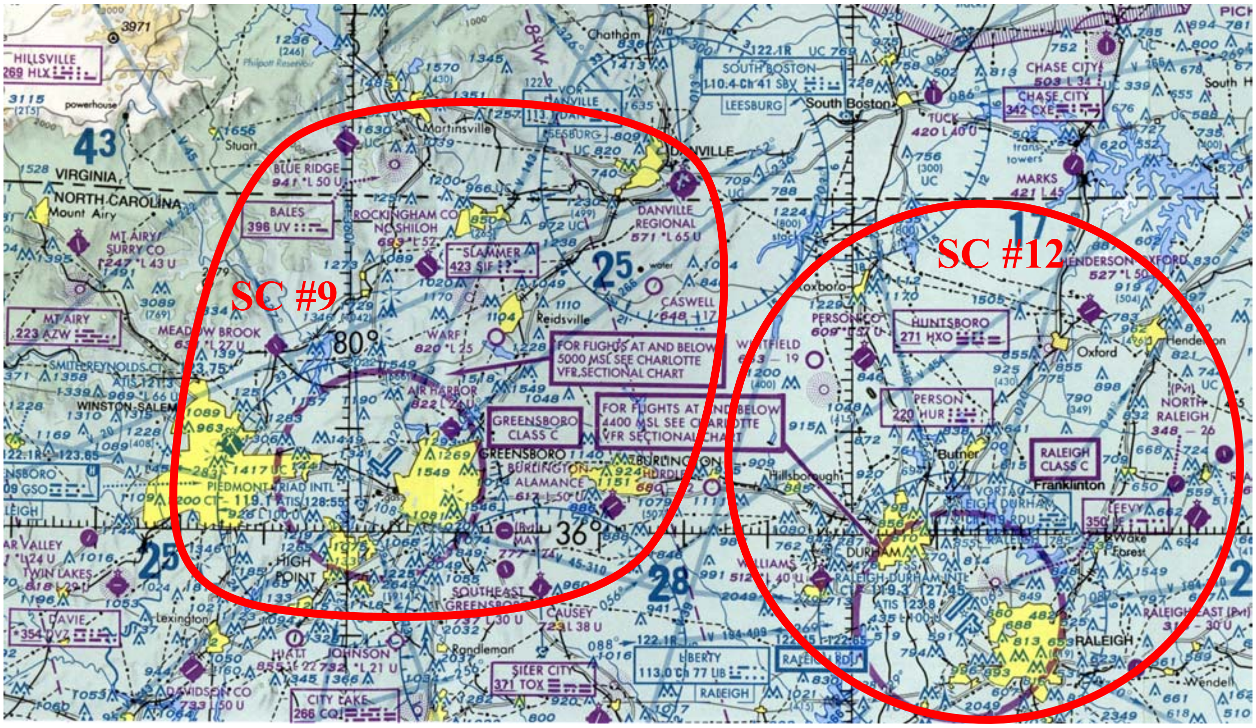


Figure 3.8: Greensboro and Raleigh-Durham, North Carolina Class C Terminal Area Airspace; SATS Clusters 9 & 12

3.5 Placement of SATS Aircraft

In this model, it is assumed that *all* airports represented in the input data set have sufficient numbers of SATS aircraft available to meet demand levels. Given that little information is presently available concerning the socio-economic outlook for SATS at the individual city, town, or airport facility levels, this is a valid assumption. Just as it is likely that bordering states will cooperate to build SATS programs at the regional level, it is also likely that neighboring cities and towns will cooperate (e.g. aircraft owner partnerships) in their efforts to bring SATS to their respective localities.

3.6 Traffic Generation

In order to generate flights – SATS flights, as well as commercial and general aviation traffic – current and forecasted air traffic densities were used. The FAA has an extensive database, CODAS, of actual (recorded) air traffic operations and terminal area forecasts for operations at many public-use airports in the U.S. Such data were available for the airports of interest in this network for the time periods simulated. It includes *local* operations, or general aviation traffic operating at or in close proximity to a given airport. It also contains *itinerant* flights, or transient aircraft that arrive from or depart to other locations. These data provided a means of generating SATS flight demand for rural airport locations. For commercial traffic, recent and forecasted commercial air carrier data were utilized to replicate both high-altitude flights and lower-flying commuter aircraft. Flights resembled actual traffic in both origin-destination (O-D) pairings and trip frequency. It was necessary to simulate aircraft that arrive from and depart to airports that lie outside the proposed SATS network and the corresponding volume of airspace. Existing data were used to forecast airport trends for arrivals and departures.

ETMS data provide flight information such as flight numbers, waypoints with corresponding altitudes for individual trip legs, and flight times (FAA, 1996). Data have been compiled for the approximately 48,000 daily flights within the United States that occurred in CY 1996. These data reflect flights that occurred on three dates – January 4, February 28 and November 12. The FAA has determined that these dates contain traffic levels that represent a valid cross-section of flights that occur on any given day each year. CY 1996 data reflect cruise climb trajectories with reduced vertical separation minima (RVSM). The FAA has also forecasted the flight schedules for the same three days in CY 2010 and CY 2015. No forecasted commercial flight data were available for the years 2000 and 2005. However, CODAS data were used to establish the baseline case for the year 2000. These files contain flight data for approximately 60,000 and 61,000 daily flights, respectively. Flights for these years contain baseline flight trajectories and cruise climb trajectories. The baseline trajectories were developed using the Future Demand Generator for the flight routes filed by commercial carriers (FAA, 1997). Cruise climb trajectories were developed using the Optimal Trajectory Generator (OPGEN), a program that develops wind-optimized profiles based on forecasted winds aloft (FAA, 1997). These trajectories were then fed into the Future Demand Generator to create the flights.

To gain a realistic picture of the impact SATS will have on NAS, the appropriate volume of SATS traffic consistent with forecasted demand must be generated. These flights should occur between city pairs with realistic frequency, in accordance with schedules reflecting times that customers would use.

In the Virginia model, SATS demand was based on real flight data between city (O-D) pairs. By screening existing ETMS, Consolidated Operations and Delay Analysis System (CODAS) and Terminal Area Forecast (TAF) data for the years 1996, 2010 and 2015, specific flight information was accumulated (FAA, 1997). In the case of commercial flights, specific flight profiles to include spatial trajectories – the entire flight path with waypoint location, altitude, and time of flight – were given. It is these commercial flights upon which the SATS sorties were based. For GA, military and air taxi/ charter operations not included in ETMS, specific traffic volumes were available for the forecasted years to be studied. In the case of air taxi/ charter, flights, a proportional share of year 2000, 2010 and 2015 flights were distributed throughout the forecast day, 12 November, in each of those years consistent with air travel trends exhibited by consumers as reflected in ETMS. As both a GA pilot and military aviator, I was able to apply first-hand knowledge and experience to replicate realistic sorties for those respective populations, factoring in predominant historic weather trends at various major surrounding airports to develop flights to the stated forecast levels in CODAS (FAA, 1997). To reiterate, ETMS dictated the estimated time of departure and time of flight for commercial aircraft sorties. And this drove itineraries for SATS surrogate flights. Air Taxi/ charter flights followed similar daily surge trends. GA and military flight schedules were based on times generated by the researcher.

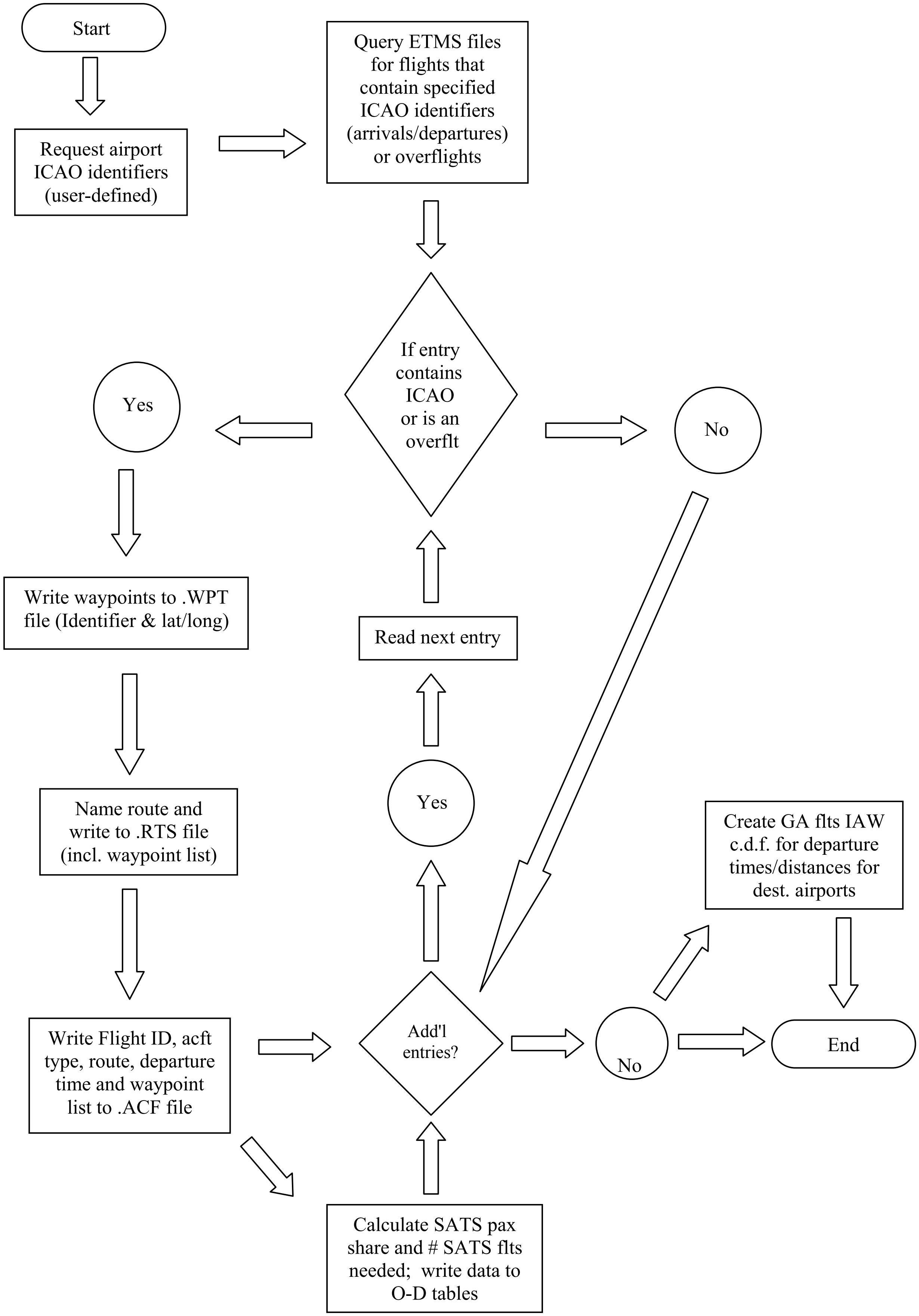
3.7 Flight Pre-processing

In order to develop the aggregate flight schedules for commercial traffic that would operate in the SATS network, a pre-processing program was written to extract flight data from FAA ETMS files. The pre-processor reads ETMS data, identifies and extracts flights that arrive from/depart to the airports of interest or transition the airspace of the SATS AOI (overflight), and reconstructs flights in the TAAM Plus input file format. This includes construction of Waypoint, Routing, and Airport input data files. Additionally, the parser creates O-D tables upon which SATS demand and subsequent SATS flight generation is based. These tables are sparse mxn matrices, where $m = n$, the number of SATS airports in the twelve SATS clusters. Table 3.3 is a characteristic O-D table for GA sorties associated with SATS clusters #5 thru #10 on November 12, 2015.

	BCB	PSK	ROA	FVX	LYH	CPK	ORF	PHF	PVG	0A9	TRI	VJI	BUY	DAN	GSO	INT	MTV	CHO	SHD
BCB	6	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0
PSK	1	2	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
ROA	2	1	14	0	2	0	1	0	0	0	1	1	0	1	2	1	1	1	1
FVX	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LYH	1	1	2	1	13	0	1	1	0	0	1	1	0	1	1	1	1	0	1
CPK	0	0	0	0	1	3	1	1	1	1	0	0	0	0	0	0	0	0	0
ORF	2	0	3	0	1	1	15	2	2	1	1	0	1	1	1	0	0	1	0
PHF	1	0	2	0	2	1	4	11	1	1	0	0	0	0	1	1	0	1	1
PVG	1	0	1	1	2	1	1	2	12	0	0	0	1	0	0	0	0	1	1
0A9	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
TRI	1	2	2	1	2	1	4	3	0	0	19	1	1	1	2	1	1	0	0
VJI	1	1	1	1	1	0	0	0	0	0	1	2	0	0	0	0	0	0	0
BUY	0	0	1	0	1	0	1	2	0	0	0	1	6	0	0	1	1	0	0
DAN	1	0	1	1	0	1	1	0	0	0	1	0	0	4	1	0	0	0	0
GSO	3	1	2	1	1	0	1	1	1	1	2	0	0	6	24	2	1	1	2
INT	1	1	2	1	2	1	3	1	0	0	2	1	1	0	2	18	1	0	0
MTV	0	0	1	1	1	0	0	0	0	0	1	0	0	0	1	0	3	0	0
CHO	2	0	4	0	3	0	0	1	0	0	0	0	0	0	4	0	0	19	5
SHD	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	1	1	3

Table 3.3: Origin-Destination Table for General Aviation Flights (SATS Clusters 5-10 in 2010)

All flights were introduced into the simulation model by activating the above files in the SATS project file protocol. The flights would then originate and terminate in accordance with specified flight information and synchronized with the computer simulation clock. The flowchart in Figure 3.8 lays displays the steps executed by the preprocessing algorithm.


Start
Request airport ICAO identifiers (user-defined)
Query ETMS files for flights that contain specified ICAO identifiers (arrivals/departures) or overflights
If entry contains ICAO or is an overflt
Yes
No
Write waypoints to .WPT file (Identifier & lat/long)
Read next entry
Name route and write to .RTS file (incl. waypoint list)
Yes
Create GA flts IAW c.d.f. for departure times/distances for dest. airports
Write Flight ID, acft type, route, departure time and waypoint list to .ACF file
Add'l entries?
No
End
Calculate SATS pax share and # SATS flts needed; write data to O-D tables

Commercial and other flights found in the ETMS data were executed exactly as they were presented. The number of GA flights in the SATS simulation was based on the most recent three years of GA flights that actually occurred at the airports in the area of interest. Percentages of GA flights on the simulated day were based on three-year averages of CODAS data of the SATS airports in the simulation. These percentages, which depend on the airport's respective daily traffic history, may be more or less than a $\frac{1}{365}$ share of total TAF data, was then applied to the GA departures for the same day in the years 2000, 2010, and 2015. This method of establishing GA traffic accounts for real-world phenomena, such as weather and peak times flown by GA pilots, among others. Since GA traffic is generally dependent on the factors mentioned above, among others, using empirical data to determine trends for extrapolation was a useful method.

3.7.1 SATS Flight Development

SATS demand was based on a percent market share of the total commercial air travel market. At 0% (baseline), 5% and 10% levels of market penetration, the total number of SATS passengers that would result from each ETMS flight was determined by applying a 70% load factor to the product of each aircraft's passenger capacity, C, and the SATS market share, M, for the given scenario, such that

$$M_i \, C_j \, (0.7) = P_{ij} \, ,$$

where $i = 1, .. ,3$ (for each of three percentage market shares), and
$j = 1, ..., n$ (for each of n "parent" commercial aircraft in a given simulation run).

Two assumptions are critical. First, the parent ETMS flights will still occur (without losing the SATS passengers). This is virtually transparent in our model, given that the passenger-carrying capacity of aircraft represented in ETMS data is useful only for forecasting. It would be extremely difficult and not very useful for one to speculate on aircraft or flight rescheduling activities. In other words, given the reduction in passengers on a certain flight due to SATS demand, at what level would a given aircraft be replaced by another – likely smaller – aircraft?

Generally speaking, taking away even 10% of the passengers on a given commercial flight would likely not cause an airline to modify its aircraft scheduling. The second assumption deals with determining what ETMS flights will generate SATS demand. ETMS data contains commercial air carrier, commuter, charter, freight, military, as well as some IFR general aviation traffic. For those aircraft types that were clearly military, freight, or general aviation, zero SATS demand was achieved by listing the pax capacity of these aircraft as "0" in the pre-processor. These flights would probably occur anyway, with or without SATS. However, it is important to minimize the amount of error in traffic generation in order to gain the clearest picture of SATS impact on NAS. It is realistic to state that even given SATS aircraft and SATS-compliant airports, some travelers will still want to include large regional, metropolitan or international airports in their itinerary. However, the bulk of SATS flights will go between two suburban or rural SATS airports.

SATS flights were grouped into one of four categories: (1) flights originating at a large hub airport and terminating at another large hub airport, (2) flights originating at a (smaller) SATS airport in the vicinity of a large metropolitan city and terminating at a large hub airport, (3) flights originating at a large hub airport and terminating at a SATS airport in the vicinity of a large city, and (4) flights originating and terminating at SATS airports in the vicinity of large metropolitan areas. A subset of this final category includes those flights that occur between SATS airports in less busy areas.

3.7.2 SATS Flight Distances

SATS surrogate flight generation was accomplished using a policy developed by the researcher and approved by his advisor. Experience in air transportation systems development and thorough application of all potential SATS mission profiles were used in this process. It is a policy based on a percentage distribution of SATS flights: given a certain O-D pair from the commercial (ETMS) data, 10% of the SATS flights were of the first category – namely between two busy, existing airport hubs; 15% represented demand for each of cases 2 and 3 –

that is, between a hub airport and a SATS airport. The remaining 60% were between two SATS airports. These proportion were determined to be consistent with the intent of SATS and a possible strategy for SATS implementation. This policy is very sound because it accounts for the various different types of flights that can occur once SATS comes online; it assumes appropriate weights in light of SATS' foundation principles, namely avoiding travel to large airports potentially far away from one's home and the inherent delays that often go with large hubs; it maximizes use of otherwise underutilized airports and landing facilities close to one's home; incorporates SATS into the preponderance of aircraft movements in the simulation. In this case, 90% of the SATS flights will depart and/or arrive to a rural, suburban, or metropolitan airport that is not a hub. The overarching criterion for SATS and GA flights, however, was the distance between O-D pairs. If two cities were greater than 1,000 nautical miles apart, commercial aircraft were considered to be the only viable means of air transportation for that O-D pair. This assumption is somewhat realistic, since the time and expense of both SATS and GA flights at this range would be too great by reasonable standards. For long-range flights, it is also very difficult to beat commercial fares especially with numerous low-cost, Tier 2 airlines dominating the market.

For SATS flights, the distances between O-D pairs for all ETMS flights were calculated using a subroutine in Appendix B. If the distance was less than 1000 NMs, then SATS demand resulted. SATS flights were then created using random selection among the three aircraft that were substituted as a means of replicating SATS aircraft – the Cirrus SR-20/21, Lancair Columbia 300, and the Eclipse 500 light business jet. O-D pairs in close proximity to the departure and arrival points of the original ETMS flights were established prior to pre-processing. Both in-region and out-of-region flights generated SATS demand, provided that the parent flight had origin and destinations that were within 1,000 NM of each other. Random variates used to determine which of the three SATS aircraft types would be used for a given flight, as well as the O-D pairs for the SATS surrogates, were chosen using a $U(0, 1)$ distribution.

3.7.3 General Aviation Flight Development

The simulation schema for GA flights was developed pursuant to an examination of travel trends within Virginia, coupled with informed assumptions and generalizations made about general aviation flight.

To determine the number of GA flights arriving and departing to a given airport, historical data were used to develop a realistic level of flight operations for the day to be simulated, November 12. CODAS data for the seven largest airports in the SATS area of interest – BWI, DCA, GSO, IAD, ORF, RDU and RIC – were collected. As previously mentioned in section 3.4, the FAA's CODAS data were available. So CODAS data for November 12 in the years 1997, 1998 and 1999 were used to establish the average level of GA traffic at airports in the SATS area of interest for the year 2000, the baseline. Commercial air carrier, air taxi/ commuter, military, as well as GA flights were aggregated and expressed as a percentage of the entire year's operations at each of the seven airports. Annual flight operations data used in these calculations were gathered from terminal area forecasts for these seven airports, as well as the other 38 proposed SATS-compliant airports. For SATS clusters that contained one or more of these seven large airports, the percentage of GA operations for the large airport – or SATS hub – was applied to the smaller airports in that cluster. Given that the preponderance of GA operations are conducted in Visual Meteorlogical Conditions (VMC), weather is a key factor affecting the number of flight operations. VMC establishes the minimum weather criteria required to fly using Visual Flight Rules (VFR), or without the use of instruments as the primary means of navigation. VMC is generally associated with a minimum cloud ceiling of 1,000 feet above sea level (ASL) and three (3) statute miles of visibility.

It was assumed that the predominant weather conditions in the area of the SATS hub would be largely consistent with conditions at the other airports in the cluster, thereby making the extrapolation of GA flight trends to the other nearby SATS airports reasonable. In the cases where SATS clusters did not contain one of the seven airports mentioned in this section, weather for a *hybrid hub* was applied. The hybrid hub was developed using GA data for November 12, 1997, 1998, and 1999 for the seven major airports (BWI, DCA, GSO, IAD, ORF, RDU and RIC) in the SATS testbed. Intent was to capture the impact of broad weather trends for the entire modeled region rather than simply localized ones at a given airport. Since weather can be very localized, it is quite possible that conditions at two of these seven airports were somewhat different on November 12. It is also possible that the weather at a small SATS airport that is closer in distance to Washington, DC than Greensboro, NC may have weather that mirros the predominant conditions at Greensboro than in the DC area. So the hybrid hub concept accounted for this. Appendix D contains the CODAS data and calculations discussed above, as well as the tables that display the approximate numbers of arriving and departing flights, of all types, that could be expected to occur on November 12 in the years 2000, 2010 and 2015.

In terms of arriving and departing GA flights, a single-constrained method was developed and employed. Given this method, the number of GA departures was strictly limited. The preprocessing algorithm created GA flight departures to the exact level determined above. The number of arrivals to any given airport was unconstrained and solely dependent on the random assignment of O-D pairs for GA aircraft. Generally speaking, terminal area forecast data for GA flights does not change markedly from year-to-year. It is largely a function of the number of GA aircraft based at each individual airport and the average annual flight hours executed per each airframe. Table 3.4 displays the number of GA departures determined to be typical for November 12th and were generated/executed for that date in CYs 2000, 2010, and 2015. These GA traffic levels were based on one of two trends: (1) recent historical data for the specific airport listed, or (2) those data developed for the generalized (model) airport using recent traffic trends and actual flight operations. The latter data were extrapolated to cover airports in the

Cluster	ICAO Identifier	Number of Daily GA Departures 2000/2010/2015	Cluster	ICAO Identifier	Number of GA Departures 2000/2010/2015
1	**DCA** GAI W32 **IAD** JYO HEF	88/88/88 58/58/58 1/1/1 54/57/58 5/6/7 78/90/95	7	CPK **ORF** **PHF** PVG	8/8/8 28/32/34 24/27/29 24/24/24
2	**BWI** FDK MTN W54	48/58/62 58/58/58 111/111/111 39/39/39	8	0A9 **TRI** VJI	2/2/2 37/42/45 8/8/8
3	HGR **MRB** OKV	34/34/34 16/16/16 27/30/32	9	BUY DAN **GSO** INT MTV	14/14/14 11/11/11 47/50/52 37/37/37 8
4	FCI OFP PTB **RIC**	12/12/12 17/17/17 9/9/9 47/44/43	10	**CHO** SHD	34/38/40 8/8/8
5	BCB PSK **ROA**	9/11/12 4/4/4 29/29/29	11	BKW BLF HSP **LWB**	5/5/5 10/10/10 5/5/5 16/18/20
6	FVX **LYH**	3/3/3 24/27/28	12	2N9 AVC HNZ **RDU** TDF	13/13/13 1/1/1 8/8/8 58/63/66 15/15/15

Table 3.4: GA Departures at SATS-compliant Airports on November 12

SATS test bed for which historical flight data were not available. Table 3.5 contains the general range between origin and prospective destination airports, accompanied by the percentage of GA flights that are presumed to occur between airports at that range. Careful consideration was given to typical GA flight profiles, the constraints/ limitations of single-engine and small, twin-engine aircraft – cruise airspeed, range, and duration – and other factors. The percentage distribution of GA flights displayed in Table 3.5 was deemed a reasonable representation of GA

Range	Percentage of GA Flights Occurring at this Range (%)
0-50 NMs	0.50
50-100 NMs	1.55
100-200 NMs	10.00
200-300 NMs	25.00
300-400 NMs	30.00
400-500 NMs	15.50
500-600 NMs	15.00
600-700 NMs	2.00
700-800 NMs	0.30
800-900 NMs	0.10
900-1000 NMs	0.05

Table 3.5: General Aviation (GA) Distance and Percentage Data

flights, with respect to distances traveled, for this simulation. The ranges and corresponding percentages of GA flights operating at those ranges were used to generate the probability mass function (pmf) below and the graphical representation in Figure 3.9.

$$f_X(x) = \begin{cases} 0.005, 0 < x < 50 \\ 0.0155, 50 \le x < 100 \\ 0.1, 100 \le x < 200 \\ 0.25, 200 \le x < 300 \\ 0.3, 300 \le x < 400 \\ 0.155, 400 \le x < 500 \\ 0.15, 500 \le x < 600 \\ 0.02, 600 \le x < 700 \\ 0.003, 700 \le x < 800 \\ 0.001, 800 \le x < 900 \\ 0.0005, 900 \le x \le 1{,}000 \\ 0, x = 0 \end{cases} \text{ for } x = [0,..,1000].$$

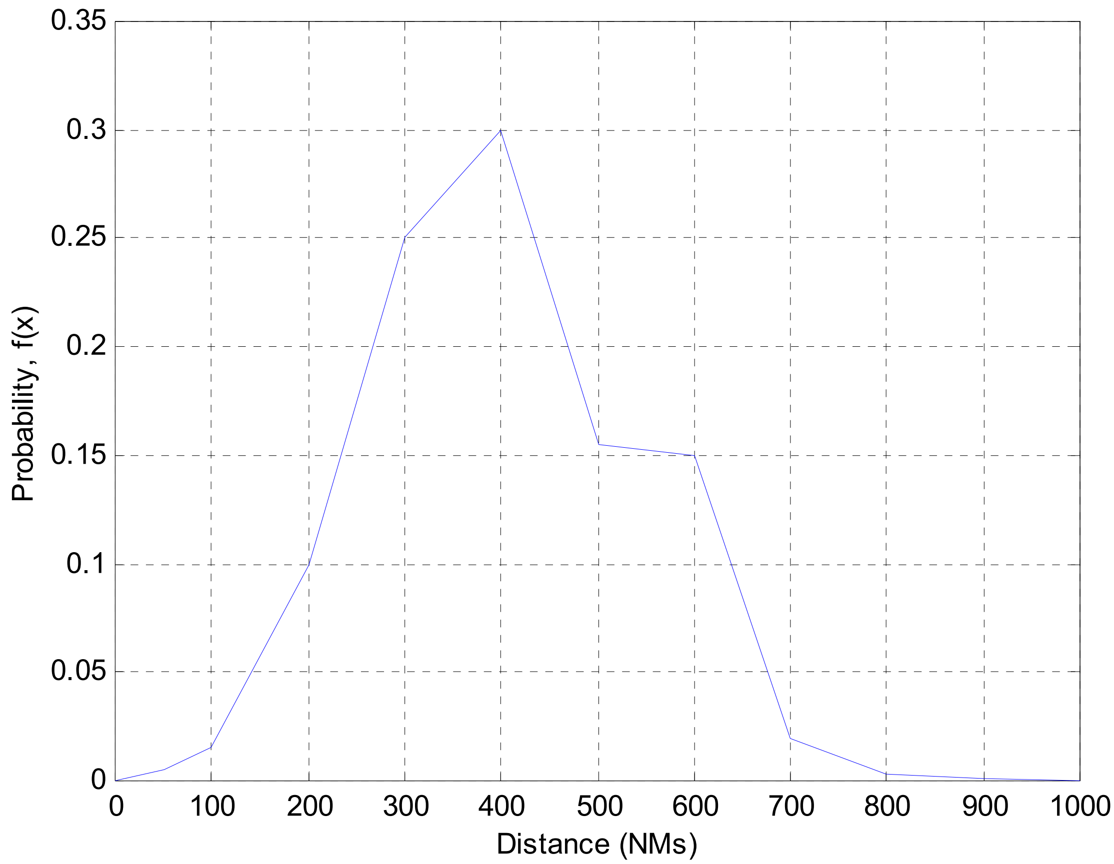


Figure 3.10: Probability Mass Function (pmf) for General Aviation (GA) Flight Distances

The pmf in Figure 3.9 and corresponding piecewise linear Cumualtive Distribution Function (cdf) in Figure 3.10 were determined empirically consistent with the GA flight distances for the set of all airports of origin launching GA aircraft out to a distance of 1,000 NMs from the respective airfields. It was generated using the percentage value from each of ten 100-NM

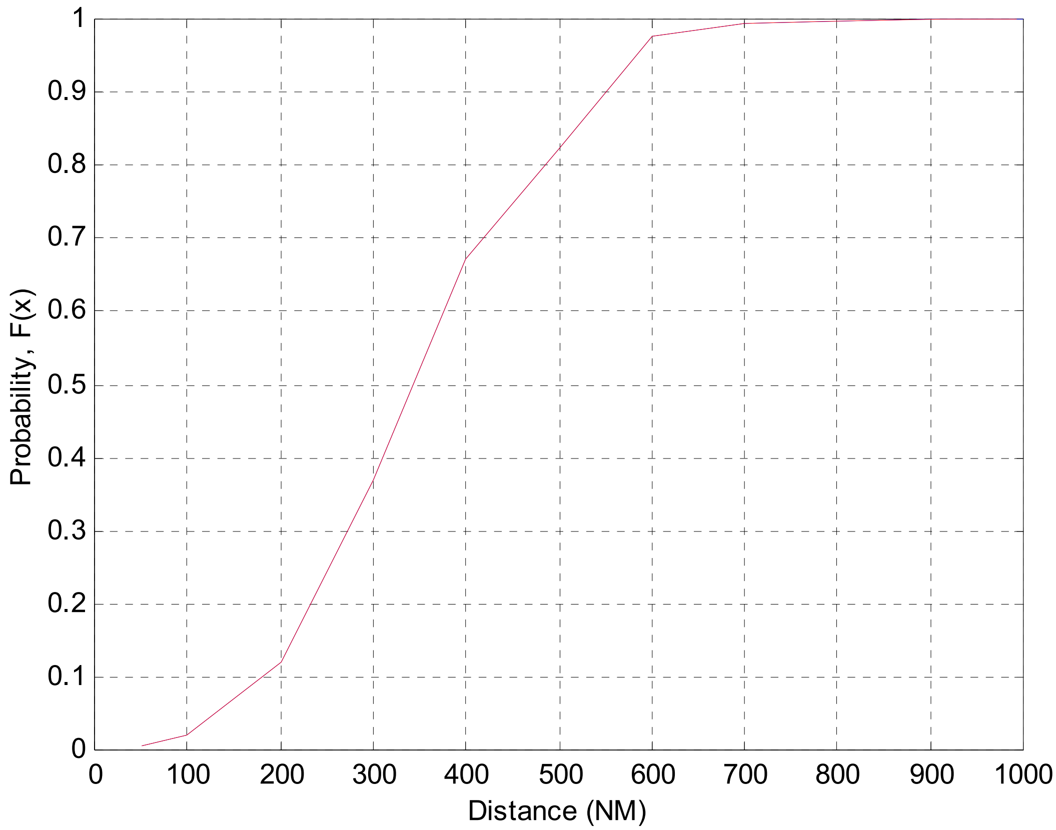


Figure 3.11: Cumulative Distribution Function (cdf) for GA Flight Distances

intervals of subsequent flight distances that different classes of SATS aircraft will operate from their respective home station airfields and/or destination airport selection by potential SATS customers.

During pre-processing, a $U(0,1)$ random number was generated by Matlab's linear congruential generator (LCG). By substituting this value into $\Phi^{-1}(p) = \Phi^{-1}(f(x))$, a distance, x, was returned for each GA flight. This distance then became the radius about each airport of origin within which a corresponding destination would be assigned. O-D pair assignment for GA airports was also done as part of input data pre-processing. Another $U(0,1)$ random variate was generated by the LCG. This subsequent random number was used to assign a destination airport from the reduced set of airports within the radius given by the pmf in Figure 3.9 for each GA sortie that would launch on the day studied. A GA flight execution plan was produced as sorties were decremented, one-by-one, from each airport of origin in the simulation. When all GA sorties at each originating airport were decremented to zero, then the trip assignment process for all GA aircraft in a particular SATS scenario was completed.

For GA flights, several assumptions were made with respect to departure times. Comparatively little GA flying occurs between the hours of 10 p.m. and 6 a.m. This is consistent with the sleep cycle of the average person. The same can be said for commercial aviation. Air carrier operations decrease to virtually nothing as the evening progresses, and they ramp up again the following morning. Additionally, flight during hours of limited visibility inherently has more associated risks. So many recreational GA pilots tend to fly more during the day, and they fly at night for training and evaluation flights or when otherwise necessary. For pilots who have non-flying jobs during the week, their flying often occurs after work, on weekends, holidays or days off. That is why, on a sunny Saturday, one can often hear the drone of numerous piston-engine aircraft aloft throughout the day. Table 3.6 contains the percentage of GA departures per hour over the course of a 24-hour day. This percentage can be likened to the probability that a GA

Departure Times for GA Aircraft	Percentage of GA Flights Departing During this Time Block (%)
2400 ≤ t_{Dep} < 0100	0.2579
0100 ≤ t_{Dep} < 0200	0.1433
0200 ≤ t_{Dep} < 0300	0.0860
0300 ≤ t_{Dep} < 0400	0.1146
0400 ≤ t_{Dep} < 0500	0.0573
0500 ≤ t_{Dep} < 0600	0.3483
0600 ≤ t_{Dep} < 0700	6.5043
0700 ≤ t_{Dep} < 0800	7.8223
0800 ≤ t_{Dep} < 0900	5.3582
0900 ≤ t_{Dep} < 1000	7.1060
1000 ≤ t_{Dep} < 1100	6.1891
1100 ≤ t_{Dep} < 1200	4.5559
1200 ≤ t_{Dep} < 1300	5.5587
1300 ≤ t_{Dep} < 1400	5.0430
1400 ≤ t_{Dep} < 1500	5.7020
1500 ≤ t_{Dep} < 1600	5.7593
1600 ≤ t_{Dep} < 1700	5.3009
1700 ≤ t_{Dep} < 1800	8.7679
1800 ≤ t_{Dep} < 1900	7.5358
1900 ≤ t_{Dep} < 2000	6.4183
2000 ≤ t_{Dep} < 2100	5.7020
2100 ≤ t_{Dep} < 2200	3.2951
2200 ≤ t_{Dep} < 2300	1.4900
2300 ≤ t_{Dep} < 2400	0.8838

Table 3.6: Departure Times with Associated Percentages of GA Flights

pilot will fly during a given time block. These data were used to generate the probability density function for GA departure times found in Figure 3.11. The data in Table 3.6 were summed to

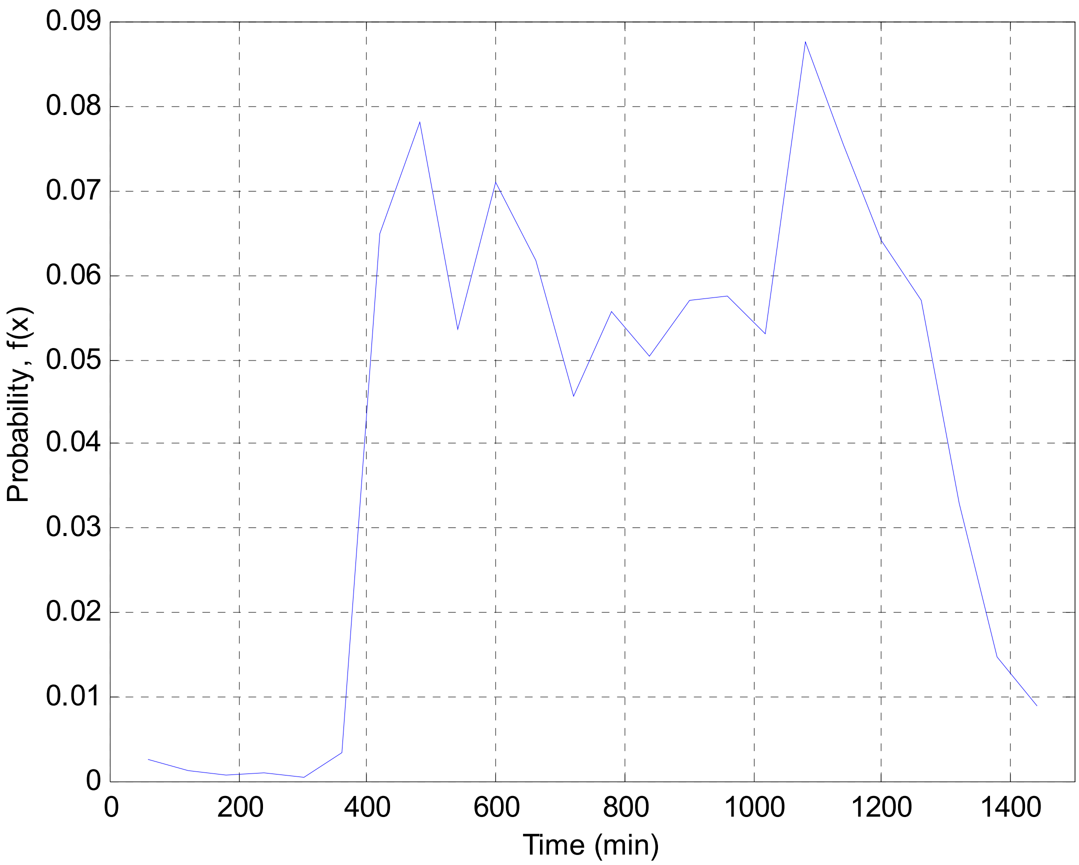


Figure 3.12: Probability Density Function (pdf) for GA Departure Times

create the corresponding cumulative distribution function (cdf) in Figure 3.12. A process similar to the one used for developing actual O-D pairs for GA sorties was also used to determine departure times for those flights. Another series of *U*(0,1) random variates was generated by Matlab's LCG. By substituting these into $\Phi^{-1}(p) = \Phi^{-1}(f(x))$, departure time, *t*, falling between midnight on Day 1 to 23:59 hours later that evening was returned for each GA flight. This created realistic GA traffic volumes extrapolated for the years 2000, 2010, and 2015. Of the three dates for which 2010 and 2015 forecasted ETMS flight data was generated by the FAA, November 12 was chosen by the researcher. GA flights for the baseline case were generated –

consistent with (actual) historical CODAS data for November 12 of the preceding three (3) calendar years prior to the simulation – 1997, 1998, and 1999.

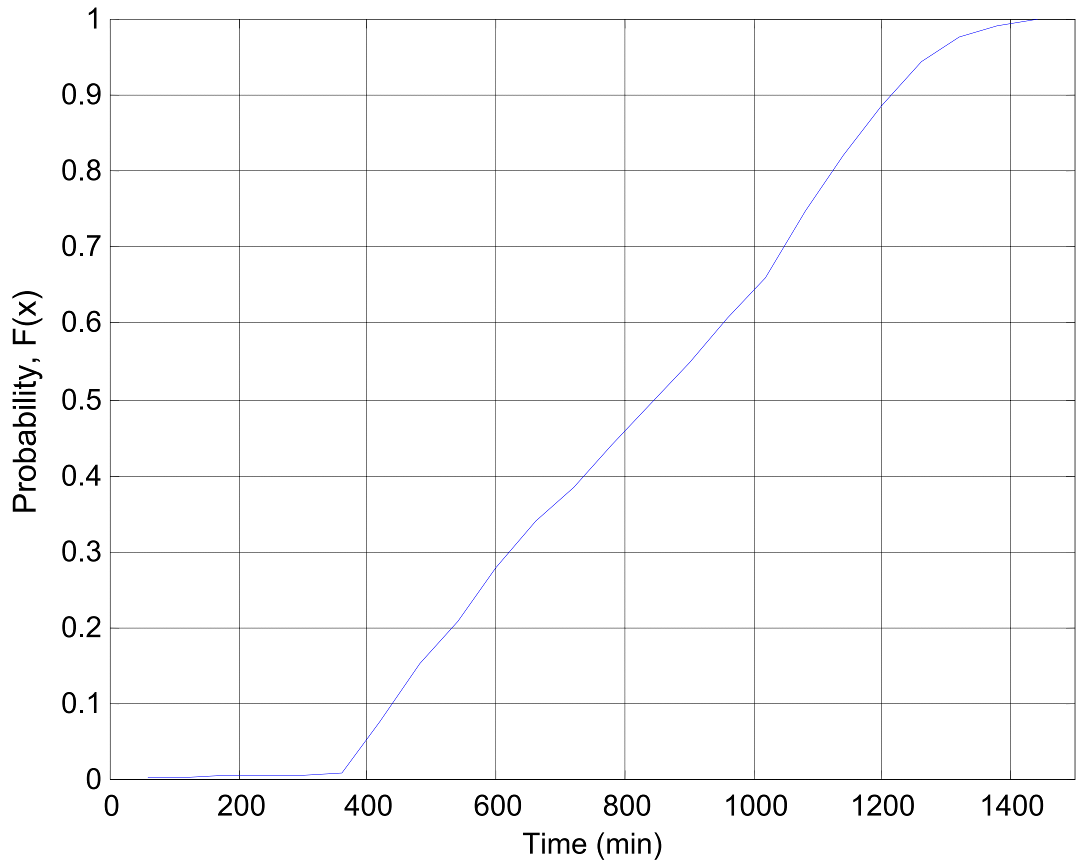


Figure 3.13: Cumulative Distribution Function (cdf) for GA Departure Times

The cdf in Figure 3.12 was used to generate realistic GA traffic at SATS airports in the test bed for various times during the continuous 24-hour period of interest studied. The resultant set of GA aircraft exhibit flight profiles consistent with the habits of GA pilots and flight instruction operations at airports in Virginia and the surrounding area. There is a mix of both transient operations, as well as those GA flights that depart from and arrive to the same airport after flying no longer than the duration provided by one tank of aviation gas.

3.7.4 Flight Routing

The SATS network model contains all flight routes that originate, terminate or are wholly contained within the SATS AOI. This connotes all IFR and VFR flight routes that are at or below the service ceiling of SATS aircraft. It includes those routes that will service mid- and high-altitude commercial traffic transitioning to cruise altitude after takeoff or for landing at large terminal area airports. It also includes those routes that will service *overflights* above the SATS AOI enroute to other destinations. Additionally, direct flight routes for SATS and GA traffic were created. The network includes waypoints and NAVAIDS that are inherent to flight routing in a given geographical area. As NAS moves into the 21st Century, both commercial and SATS traffic will be less dependent on ground-based NAVAIDs and will execute waypoints that correspond to wind-optimized trajectories between origin and destination airports. In the context of the Virginia SATS model and simulation, flight routes were established for each O-D pair. This includes airports outside the defined area of interest. For example, there will be commercial flights between Washington-Dulles International Airport (IAD) and Los Angeles International (LAX). Because of the great distance between these airports, there will be no SATS demand and, correspondingly, no SATS flights servicing passenger within this O-D pair. In the real-world system, any midair conflict is a bona fide concern. However, for the purposes of this study, we only care about conflicts and delays that take place in the airspace above the Virginia SATS network. Therefore, conflict data that were generated in the airspace or in the vicinity of facilities outside the defined area of interest were disregarded, though in reality they would be very important as a matter of flight safety.

Flight routes were generated and waypoints were sequentially numbered. Commercial flight routes and waypoints came directly from ETMS data. SATS flight routes resulted directly from the assigned O-D pairs. SATS flights were surrogates of ETMS (commercial) flights; therefore, the O-D pairs for SATS flights were closely related to the O-D pairs of the parent commercial flights. The waypoints for SATS flight routes in this simulation were assumed to be the origin and destination airports. For commercial flights, ETMS data were parsed and the respective flight route and waypoint files were created. For the former, the origin and destination ICAO identifiers were linked together to form the route name. Waypoints were numbered sequentially and listed along with their respective latitude/longitude coordinates. Waypoints were accessed from the .WPT files once a given flight route was selected. This occurred as the simulation was running. Commercial aircraft from ETMS have waypoints and routes that take these aircraft from an altitude of zero (0) feet at takeoff and to an altitude of zero (0) feet upon landing. The aircraft execute published IFR procedures, to include procedure turns, holding at a fix, and IFR approaches. Many of these points are actually published Standard Instrument Departures (SID) and Standard Arrival Routes (STAR). They are important to an accurate portrayal of commercial flights in the SATS simulation.

In order to gain a realistic distribution of both SATS and GA flights with respect to departure times, a reasonable policy was adopted. GA traffic was simulated to occur most frequently during hours of daylight and, in particular, during the hours of 9 a.m. and 6 p.m. SATS surrogates departed their respective airports within 30 minutes either side of the scheduled departure time of the original ETMS flights. Within this one-hour window, some SATS flights departed at virtually the same time as the commercial flight from which they were generated. However, 30 minutes either side of the departure time was determined to be reasonable since it would allow sufficient time to space aircraft departures. Spacing by time allows wake turbulence produced on the active runway by arriving and departing aircraft to dissipate, a valid concern when large commercial jets take off or arrive just before SATS or GA aircraft. This is due to the huge differences in thrust, gross weight, lift area, and rotation speed – the speed at which the pilot adjusts aircraft attitude upward, breaks ground and begins to climb. However, the one-hour window doesn't require customers to markedly change their travel habits; in this case, they don't have to show up at the departure airport unduly early yet can still take-off on time or very close. In this simulation, departure and arrival airports were modeled as *sources* and *sinks*. Some insights were garnered from SATS network performance in the terminal airspace. However, in order to achieve optimal SATS network performance, more detailed studies should be focused on the nation's busiest airports individually.

3.8 SATS Simulation

A successful simulation effort depends upon many things. Among these are (1) a well-modeled system (2) sufficient inputs; (3) the simulation itself; (4) means by which to collect output data. Item 3, the simulation should represent the model as closely as possible to the specifications of the researcher. A simulation doesn't need to be a computer implementation of the model. However, with technological advances in computer hardware and software, it is arguably the fastest and best way to execute multiple runs and generate outputs. The decision was made to use the Total Airspace and Airport Modeler (TAAM) because of its availability and reputation as being a very realistic aviation simulation used by the FAA, EuroControl and major US airports and airlines.

3.8.1 Simulation with Total Airspace & Airport Modeler (TAAM)

The Total Airspace and Airport Modeler (TAAM) Plus, Version 1.1 was used to construct a detailed simulation environment within which the Virginia SATS model could be evaluated. TAAM Plus is a software package that permits joint discrete and continuous event simulation. The package is designed to facilitate gate-to-gate modeling of airport and airspace architectures developed by the user. The simulation can be run for predefined time intervals with data tracking at distinct points in time. However, the simulation can be run for extended periods consistent with the generated flights as input to gain insight into long-term network performance. Entities in a given scenario depend on a combination of preset logic embedded in TAAM Plus data files and user-specified logic. TAAM Plus provides intricate modeling capabilities with respect to airport terminal areas and facilities. It has computer-aided design (CAD) capabilities that allow graphic construction of airport facilities and airspace control measures with a high level of detail. Individual flights are generated and appear at any desired point in the system, generally at the airport terminal. These flights act just as real flights would – they obey commands that represent ATC instructions for ground taxi, departure, enroute flight, as well as approach, landing and flight termination. All parameters are defined by the user and executed explicitly by TAAM Plus. Individual flights are constructed by selecting an aircraft type and identification (e.g. B747/UAL799). A detailed aircraft data file maintains aircraft shapes and performance characteristics. Airport files contain the location and some facility characteristics for many public-use airports in the United States and worldwide. Those entities and procedures that don't exist can be created and modified as desired. Inputs and parameter settings are chosen and included in the simulation protocol prior to initiating runs. The user recalls applicable data files and activates other project-specific files so that the simulation has all necessary information with which to generate flights, and to track and report desired outputs. The scenario runs on a continuous clock once the simulation is initiated.

TAAM Plus has numerous useful features that aid in modeling real-world or contrived airspace systems. These features allow the user to create integrated airspace models and to modify inputs, change the simulation midstream, and to tailor outputs as desired. The user can create individual projects and project directories to group all relevant models. TAAM has a very useful "Project Details" window that permits viewing and modification of project settings. This feature is used to select display settings, processing parameters and reporting requirements. TAAM Plus *static data files* include information such as aircraft types and characteristics, wake turbulence data, separation standards, randomization of flights, runway-crossing times of aircraft, and wind and weather data. TAAM also allows graphic development of the terrain—mountains, coastlines, bodies of water, as well as cities and other built-up areas can be depicted. The airspace in the scenario can also be broken down into sectors that can be represented graphically, which also facilitates conflict reporting.

The simulation model includes all of the entities presented previously -- airports, waypoints, flight routes, as well as individual aircraft executing predefined flight trajectories. TAAM Plus allows easy modification of data inputs to test the effectiveness of SATS.

3.8.2 Data Dependencies

Model entities within TAAM Plus are highly dependent on each other and conform to a well-defined hierarchy developed by D. Carl (2000). This is also true when one considers these entities in a real-world airspace system. To understand these dependencies, it is best to start with the most basic entities and work upward. Waypoints and airports are the most basic entities, as they stand alone and represent individual physical locations in the model. These two entities (files) are generally not dependent on each other. Flight routes consist of a series of waypoints that an aircraft will pass over to travel between a given origin-destination (O-D) pair. Therefore, flight routes depend on waypoints and O-D airports. Timetables contain all information pertinent to the execution of a given flight. Therefore, it is intuitive that the timetable is dependent on all files that support a given flight (i.e. O-D airports and applicable SIDs/STARs, flight routes utilized and the waypoints that comprise them). Figure 3.13 shows the input data hierarchy. Once Airport (.APT), Waypoint (.WPT), and Flight Route (.RTS) files were created,

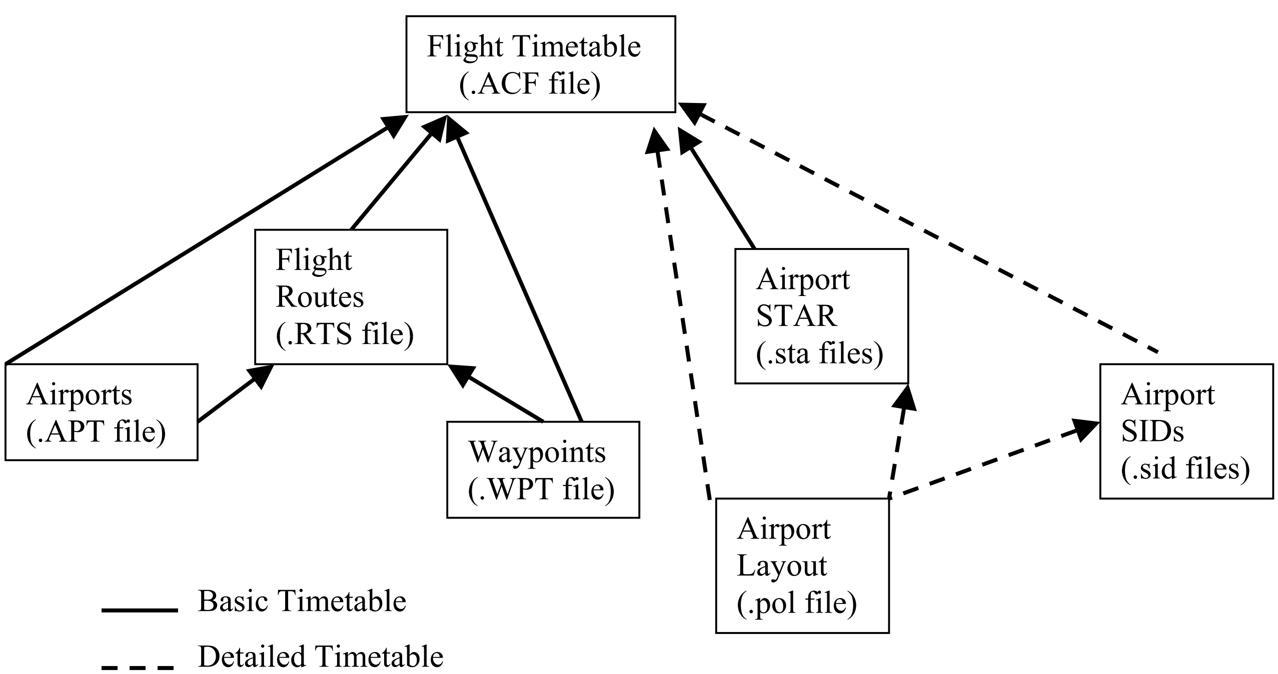


Figure 3.14: TAAM Plus Data Hierarchy

the Timetable file was then generated. ETMS data were screened for departure times and airspeeds for various flight segments. Distances and trajectories between O-D pairs were calculated using the Great Circle to account for curvature of the Earth as aircraft maintain their flight paths at designated altitudes. Timetable files included all aircraft in each simulation run – SATS, commercial (passenger and freight), military, and GA traffic. Each flight was designated by aircraft type, flight ID and contained the flight's estimated time of departure (ETD). Based on the Great Circle distance between O-D pairs and aircraft performance characteristics, flight times and estimated times of arrival (ETA) were determined. Total time of flight for each sortie was calculated. All of these data were combined and entered into a structure to create the Timetable file. ETD and all other times were synchronized with the computer clock to insure that every flight would be generated and executed at the correct time on the computer clock during simulation runs.

3.9 Scenario Development

Several scenarios were developed to thoroughly test the SATS concept. All SATS scenarios were developed using a mix of single-engine propeller and jet aircraft. At the time of this experiment, the initial aircraft that were designated as potential SATS vehicles were were manufactured by Lancair, Cirrus and Eclipse. SATS surrogate flights were generated from among these three new aircraft – the Lancair Columbia 300, Cirrus SR-20/21, and Eclipse 500. Since these new aircraft were not represented in TAAM, the decision was made to substitute aircraft with like flight performance characteristics. In the pre-processor, SATS flights were substituted as follows – the Cessna C-206 Stationair was used to replicate the Cirrus SR-20/21, the C-337 Super Skymaster was used for Lancair Columbia 300 flights, and the C-500 Citation I was used to replicate Eclipse 500 jet traffic. Several other aircraft substitutions were required in order to execute all ETMS flights which, in some cases, had aircraft not in the TAAM Plus database. At the forefront of the substitution process was achieving like aerodynamic performance and similar flight envelope for all aircraft. Aircraft substitutions may be found in the pre-processor source code found in Appendix A.

Various strategies were considered to best capture SATS system performance, and the scenarios were developed accordingly. A reasonable assumption is that the implementation of SATS will be an incremental process – all SATS airports will not open overnight. However, designation of future SATS airports and an approved timetable for conversion may be several years away. Therefore, the same SATS airport set is used for all scenarios in order to establish a reliable baseline case to serve as the benchmark for future scenarios of increased traffic.

3.9.1 Baseline Case

The baseline case contains projected SATS flights into other SATS airports in the Virginia SATS testbed. Additionally, numerous other sorties – commercial, military, and GA, alike – conducted operations from outside the SATS testbed either as overflights or to destination airports inside the Virginia SATS network. Calendar year (CY) 2000 forecasted traffic levels were used to generate SATS demand. These flights took place concurrently with CY 2000 forecasted GA and military air traffic. Also, the newest available ETMS data were used to generate CY2000 traffic and corresponding flight schedules. The simulation results for this scenario provided a benchmark by which to measure the overall impact of increases in both SATS and GA/commercial/military traffic as NAS air traffic volumes grow. Table 3.7 shows traffic levels modeled in the SATS baseline case.

SATS Market Penetration	11/12/2000	11/12/2010	11/12/2015
0%	SATS: 0 ETMS: 4299 GA: 1191 Overflights: 2140 Total: 7630	SATS: 0 ETMS: 5353 GA: 1249 Overflights: 2734 Total: 9336	SATS: 0 ETMS: 5569 GA: 1279 Overflights: 2852 Total: 9700
5%	SATS: 5219 ETMS: 4299 GA: 1191 Overflights: 2140 Total: 12849	SATS: 6739 ETMS: 5353 GA: 1249 Overflights: 2734 Total: 16075	SATS: 7021 ETMS: 5569 GA: 1279 Overflights: 2852 Total: 16721
10%	SATS: 8957 ETMS: 4299 GA: 1191 Overflights: 2140 Total: 16587	SATS: 11958 ETMS: 5353 GA: 1249 Overflights: 2734 Total: 21294	SATS: 12455 ETMS: 5569 GA: 1279 Overflights: 2852 Total: 22155

***ETMS** includes Air Carrier, Air Taxi/Commuter, Charter, Freight, and Military Aircraft

Table 3.7: November 12 Traffic Levels

3.9.2 Future Cases with Forecasted Data

The same methodology was used to generate traffic for calendar years 2010 and 2015. Table 3.7 shows traffic levels to be modeled in the future scenarios. Demand data came from the same sources discussed earlier. High-altitude commercial flight data were obtained from the FAA's ETMS forecasts for these years. These scenarios were designed to furnish empirical results by which to gauge the progression of SATS implementation versus NAS growth. Based on data report structure and analysis, sources of airborne "bottle necks," or potential locations of future airspace deconfliction challenges, can be derived. Since SATS was not implemented in any form during the year 2000, the proposed baseline scenario with 5% and 10% SATS market penetration will likely furnish overstated numbers of conflicts if those results are compared to real-world air traffic levels for the year 2000. Anticipated midair conflicts should become less overstated for the years 2010 and 2015 – that is, for the 5% and 10% scenarios – because the proposed SATS network and forecasted air traffic densities will reflect a fairly mature SATS framework in accordance with National General Aviation Roadmap. Future scenarios, particularly the 15-year case, should more accurately illustrate airspace system constraints (than the CY2000 baseline) as SATS reaches full maturity in Virginia.

3.9.3 Stochastic Nature of the Simulation

To insure randomness across all scenarios and runs in this simulation, random number streams were generated and applied during virtually every phase of input data pre-processing. Random variates were used to assign departure times to SATS flights within a one-hour time block bounding the actual departure time of parent commercial aircraft sorties. This insured an appropriate distribution of SATS surrogate flights sufficient to service travelers consistent with the SATS market penetration schema. These flights departed airports of origin at random times within 30 minutes either side of the parent commercial flight departure time. Among each of the five runs for the nine SATS scenarios, airports of origin from the applicable SATS clusters were randomized to achieve the appropriate mix of traffic using the four-category airport selection policy developed for the SATS flights: 10% Hub-to-Hub; 15% SATS-to-Hub; 15% Hub-to-SATS; 60% SATS-to-SATS. Based on travel distances between O-D pairs, SATS sorties were randomized among substitute aircraft replicating the three specified SATS aircraft. General aviation O-D pairs based on GA flight distances and GA departure times were randomized for each of the 45 overall simulation runs using random variates applied to empirical distributions and corresponding Cumulative Distribution Functions. This created random GA flight schedules, with varied O-D pairs and departure times with upper limits defined by the maximum number of GA sorties designated to depart on the simulated date, November 12th.

3.9.4 Experimental Design

Table 3.8 displays the critical elements of the experimental design, to include independent and dependent variables, as well as type and number of simulation runs.

Independent Variables	(1) Traffic densities (all types) (2) SATS market penetration level (3) Pax capacity of SATS aircraft conflict resolution strategies
Dependent Variable	Number of blind conflicts
Simulation runs	(1) Baseline case (2000) (2) Future cases (2010, 2015)
Number of Replications	- 45 total runs - Five per each of nine cases [November 12, 2000 – 0% SATS, November 12, 2000 – 5% SATS, November 12, 2000 – 10% SATS, November 12, 2010 – 0% SATS, November 12, 2010 – 5% SATS, November 12, 2010 – 10% SATS, November 12, 2015 – 0% SATS, November 12, 2015 – 5% SATS, November 12, 2015 – 10% SATS]

Table 3.8: Experimental Design

3.9.5 Determining Required Number of Simulation Runs

In order to determine useful descriptive statistics during the experiment, a sufficient number of simulation runs must be accomplished. This is determined mathematically in several steps. To set a rigid criterion for the number of blind conflicts, I chose to specify within 3% of the sample mean for the 0% SATS case in the baseline year, 2000 with a 90% confidence interval. First, I determined the degrees of freedom (d.f.) for the *t*-value:

$$n \geq \left(Z_{\alpha/2} \cdot \frac{S}{e} \right)^2 = \left(-1.96 \cdot \frac{201.09}{(6296 \cdot 0.03)} \right)^2 = (2.087)^2 = 4.354 \approx 5$$

I used the estimated degrees of freedom to find the t-value at $\frac{\alpha}{2} = \frac{0.1}{2} = 0.05$ and n-1 d.f. = 3.

$$n \geq \left(t_{(\alpha/2, n-1)} \cdot \frac{s}{e} \right)^2 = \left(t_{(0.05,3)} \cdot \frac{201.09}{(6295.6 \cdot 0.03)} \right)^2 = (1.893)^2 = 3.582 \approx 4$$

3.9.6 Executing the Simulation

Generally speaking, air traffic distributions are bimodal. That is, in a standard 24-hour day, the overall distribution of aircraft in the air at any one time has two distinct peaks. In practical terms, this means that people travel most during early to mid-morning hours, as well as during the late afternoon and early-evening hours. Because the characteristics of these peaks are similar between the morning and evening travel periods, it was assumed that modeling one travel period or the other will provide useful information that can be extrapolated to describe the general behavior of the overall system for a given 24-hour day. This was done to reduce simulation run times and to alleviate problems associated with limited memory on PC work stations. As such, the simulations in this research focused on the morning travel period. Each SATS scenario was run from 02:00 to 20:00 Zulu, or 21:00-15:00 E.S.T. Within this period, the morning peak occurs approximately from 12:00-16:00Z, or 07:00-11:00L. These times were determined by examining the distribution of flights operating in the airspace sector designated as *SATS AOI*. This sector includes both of the other airspace sectors in the simulation—those designated as *Commonwealth of Virginia* (perimeter boundary of Virginia) and *Wash* (Washington, D.C. terminal area). This sector was chosen primarily because it gives the widest geographical representation of traffic levels across the entire area of interest. This is especially true given that aircraft departing to or arriving from areas other than Virginia will have to traverse this airspace and, therefore, be counted. Additionally, by using SATS AOI, it is expected that aircraft—particularly general aviation—will be operating in varying weather conditions, which will give a truer picture of air traffic levels across the entire area of interest. Given that SATS AOI includes portions of Maryland, West Virginia, Tennessee and North Carolina, a more representative sample of air traffic behavior can be gained, as compared to examining strictly Virginia, and even more so, just Washington, D.C. Figure 3.14 depicts the air travel trends representative across the SATS AOI.

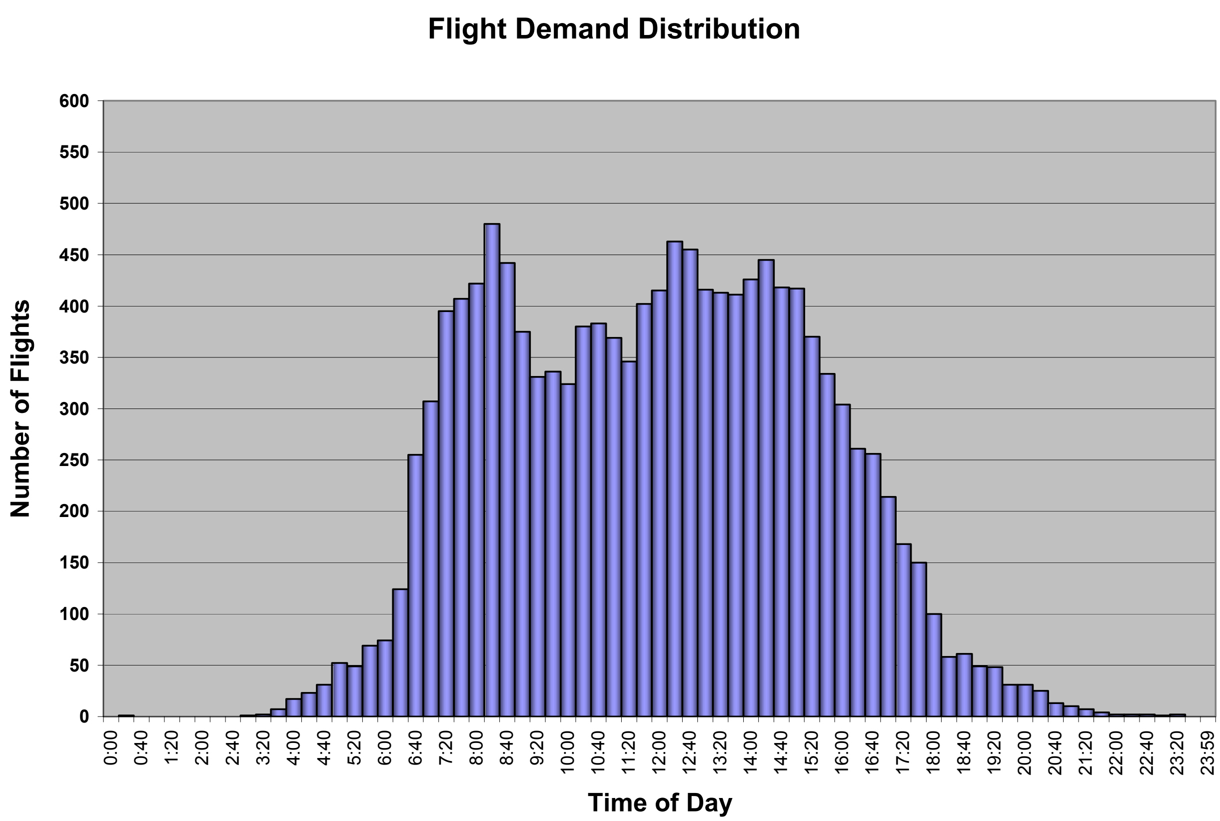


Figure 3.15: Distribution of Air Traffic within SATS AOI over 36-hour Time Period

Given the experimental design employed, SATS flights will invariably operate in conjunction with different traffic volumes. SATS aircraft will travel less impeded during off-peak hours. Likewise, the chance of an unmitigated conflicts would likely increase during peak periods.

3.9.7 Midair Conflicts in SATS

The probability of midair conflicts is expected to increase with the introduction of SATS if the system is not modified at all. This is due to the increase of smaller aircraft that fly largely IFR at a level that coincides with some general aviation and commuter traffic, as well as high-level commercial flights that are transitioning during takeoff and landing. SATS flights may arrive or depart busy terminal areas in several ways. The desired end state will be for SATS aircraft to communicate with each other and modify conflicting flight paths to achieve effective self-separation. This is largely technology-dependent. A foreseeable intermediate step may have SATS flight routes intersect with fixes represented in terminal area arrival and departure procedures. Specifically, SATS flight routes may consist of the direct flight segment between the last fix of the Standard Instrument Departure (SID) and the first fix of the Standard Arrival procedure (STAR) at airports with published instrument flight procedures.

The severity of midair conflicts will be determined by the amount of required separation that is violated between two given aircraft. In the most benign case, TAAM Plus will report when two aircraft encounter one another inside 150% to 200% of the required separation. This equates to aircraft separation distance, x, of between 7.5 and 10 NMs. Conflicts are also registered if two aircraft violate separation standards in accordance with the following breakdown:

120-150% ($6 \leq x < 7.5$ NMs);
100-120% ($5 \leq x < 6$ NMs);
50-100% ($2.5 \leq x < 5$ NMs);
20-50% ($1 \leq x < 2.5$ NMs);
Less than 20% (< 1 NM).

In the most severe case, a given conflict might result in a midair collision. Figure 3.15 contains a spatial representation of the accepted aircraft separation standards employed by TAAM Plus and in the actual NAS. Conflicts can occur through violation of one or more of the published separation standards – vertical, lateral and longitudinal (time). Airspace models can either employ conflict resolution measures to mitigate midair conflicts, or allow aircraft to fly without intervention. The latter case allows us to isolate conflicts based purely air traffic volumes, as opposed to the degree of effectiveness of various conflict resolution strategies. This is the method that was selected for this research.

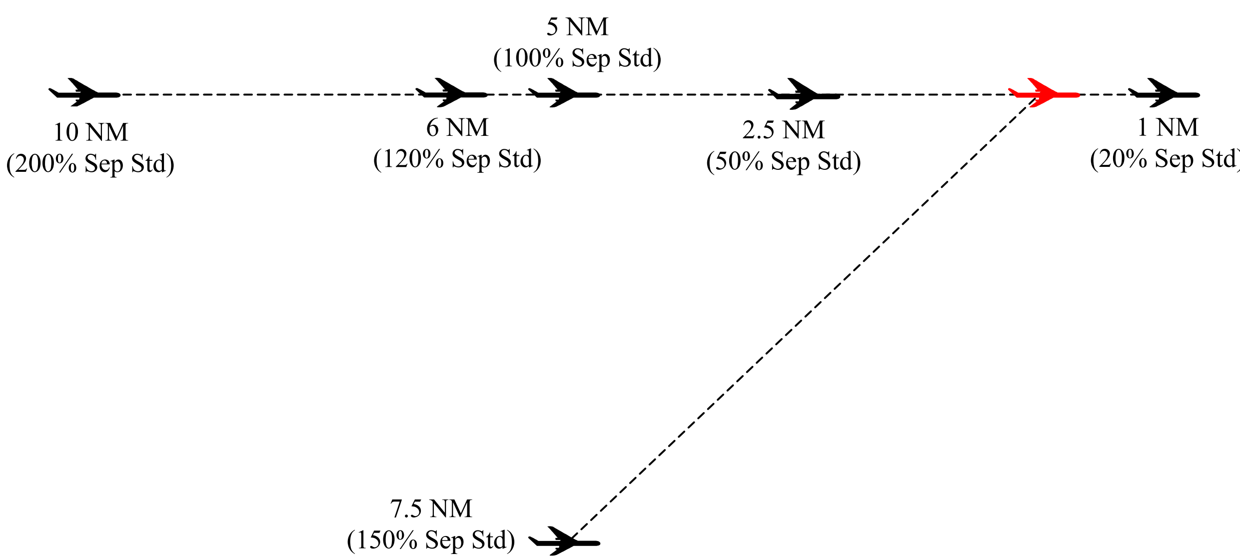


Fig. 3.16: Aircraft Separation Standards

3.10 Conflict Analysis

The Preston Group (1997) states that TAAM Plus has a robust system of conflict reporting. As previously stated, all flights in the various scenarios did not execute the predefined conflict resolution strategies when faced with a midair conflict. This provides an unbiased assessment of potential conflicts based solely on traffic volumes, versus delays or conflicts that result from aircraft deviating from their preassigned flight routes to avoid a conflict. Conflicts were reported based on the sector where they occurred. Altitude limits on reporting conflicts were based on the specified altitudes bounding the polygons that make up the SATS network model created in TAAM. Given a two-aircraft conflict, reported information included the sector designation where aircraft #1 and #2 were located at the time the conflict occurred, time of closest approach, minimum horizontal distance between the aircraft, as well as the ground speed, heading, and altitude change rate (ft/min) for both aircraft. Aircraft separation data at the time of conflict were also collected. TAAM Plus furnished the required and available vertical separation standards (in feet), as well as required and available horizontal separation standards (in NMs). TAAM recorded the latitude and longitudinal coordinates of the point of closest approach, as well as the altitude at which the conflict occurred.

Analysis was conducted by an assessment of the mean number of conflicts that occurred under various traffic densities, as well as the severity of these conflicts—determined by the required separation distance remaining at the point of closest approach. Validation of the SATS concept in Virginia was accomplished through a detailed examination of this critical metric to identify trends exhibited by the overall network. By examining the set of all conflicts encountered in the various scenarios, both a qualitative and quantitative analysis of the overall effectiveness of SATS is presented.

3.11 SATS Network Simulation

The primary metric used to evaluate SATS in this research was the mean number of *blind conflicts*, or those conflicts characterized by proximate pairs of aircraft that do not execute evasive maneuvers to avoid one another when they violate published separation standards in flight. This research establishes a framework by which the sample mean, $\bar{x}$, may be found. This work presents sample means for several conflicts of varying severity. The analytical framework encompasses a discussion of statistical methods employed, to include construction of appropriate confidence intervals. An estimator for the standard deviation, $\hat{\sigma}$, was also determined and used. Cumulative conflicts are presented for each scenario, and these are expressed as a function of the average number of aircraft in each scenario.

A three-dimensional SATS network was constructed in TAAM. It contains the three sectors discussed earlier – the Washington, D.C. terminal area, airspace over the Commonwealth of Virginia, and the expanded SATS AOI including the border regions around Virginia. Figure 3.17 depicts the airspace sectors in the SATS network model. Each of these sectors is mutually

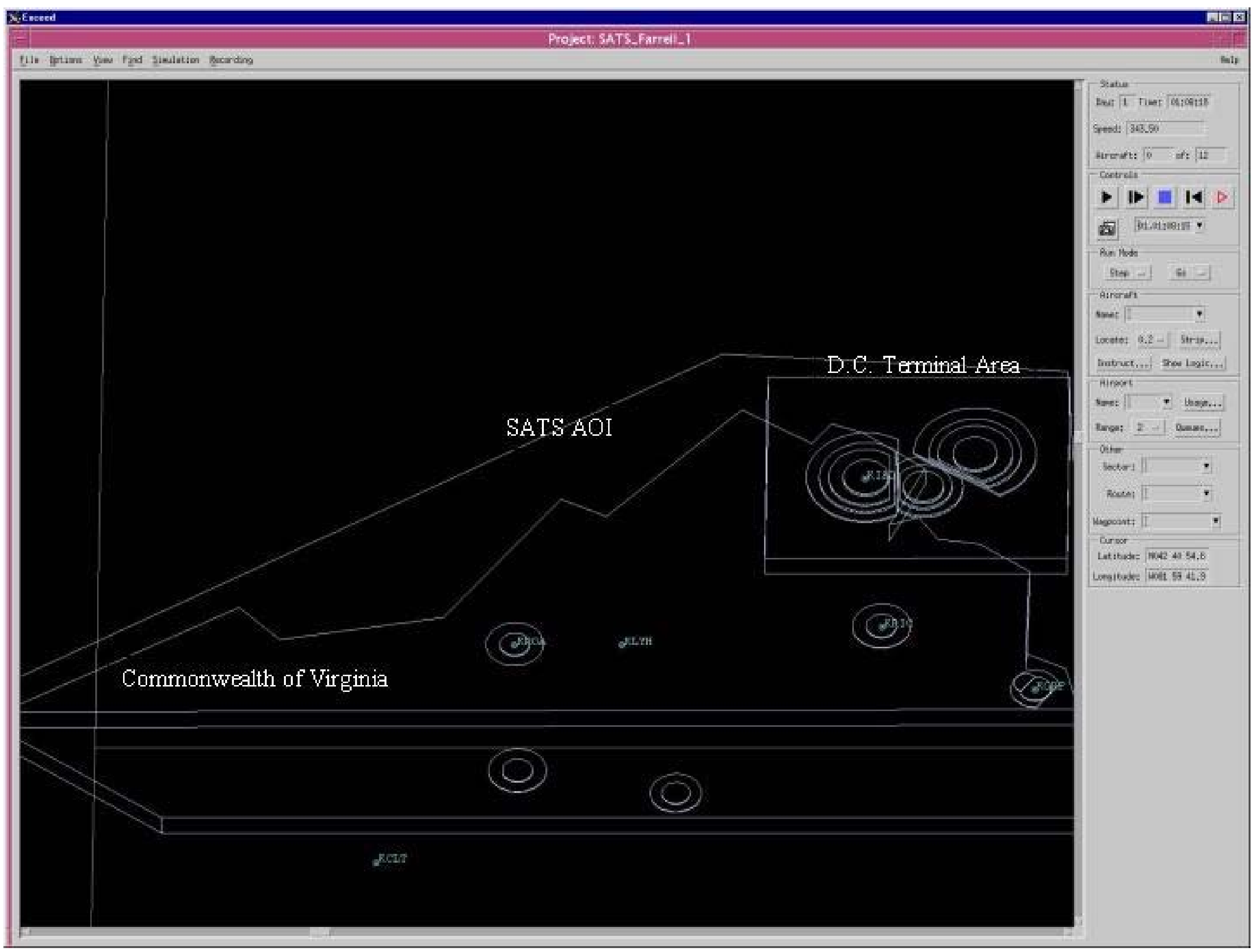


Figure 3.17: TAAM Plus Graphic User Interface - SATS Area of Interest

exclusive. For instance, if a conflict occurs in the D.C. Terminal Area, then it is registered in that sector and not in the Virginia or expanded SATS AOI sectors. The same is true for aircraft detection and counting. The sectors above are *n*-sided polygons, ranging from the surface to FL650. Within these sectors, SATS airports were included in the model. Many of the smaller airports were represented as sources/sinks, where flights simply originate and terminate to the airport's coordinates. However, around the larger airports – those with accompanying Class C airspace – sectors were developed in greater detail as in Figure 3.18.

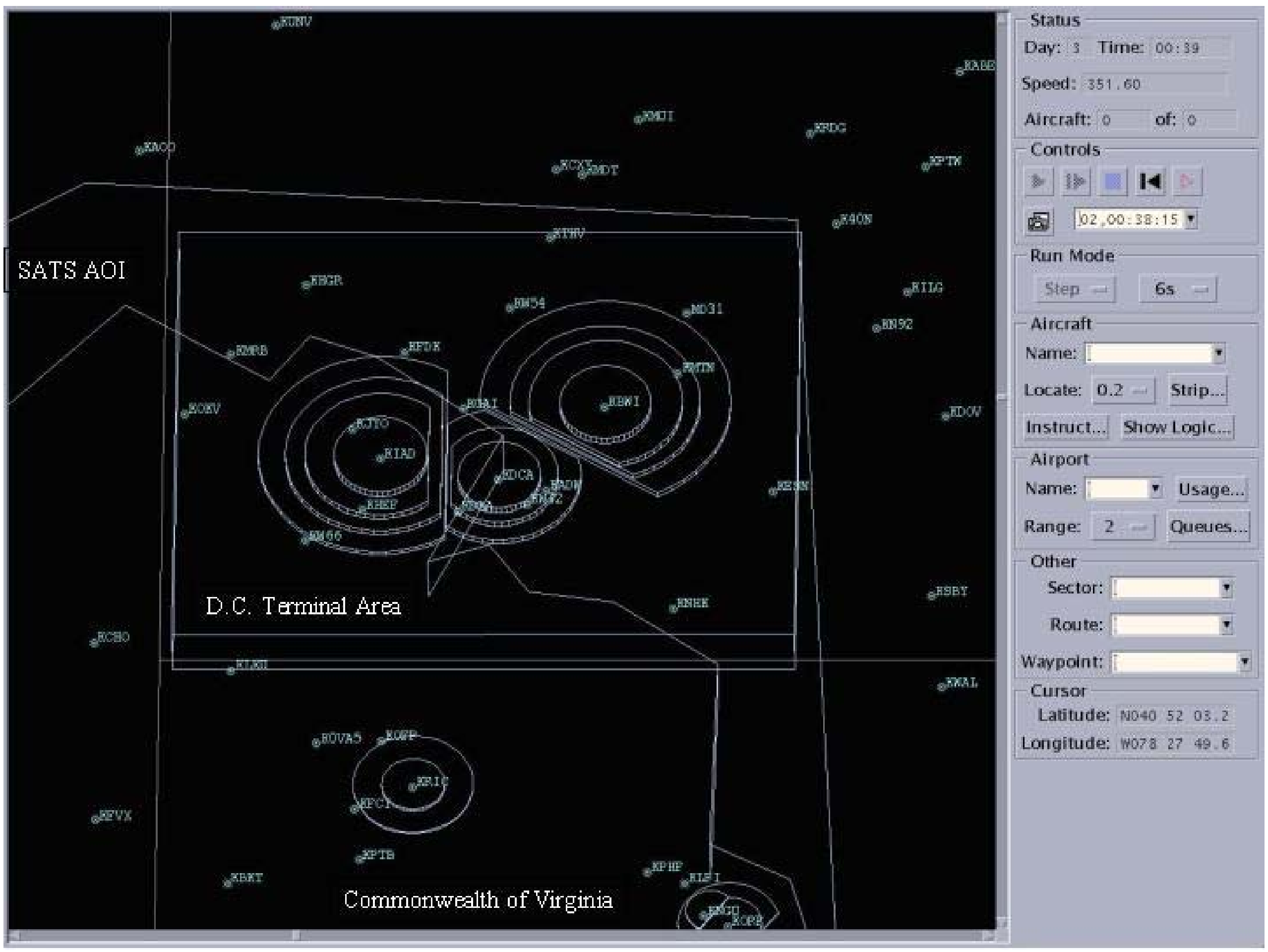


Figure 3.18: TAAM Plus Graphic User Interface - Washington, D.C. Terminal Area

Conflict data for the Commonwealth of Virginia were aggregated as a separate category, and sector, in the model because it is the virtual keystone of the SATS network simulation. In order to make conclusions about the future of SATS in Virginia, we needed to be able to examine those data specifically. Likewise, many of the SATS clusters have one or more of their component airports in Virginia.

Chapter 4

Computational Results and Analysis

4.1 SATS Simulation Results

This chapter furnishes conflict data in terms of the degree to which required separation standards were violated during a midair conflict between proximate aircraft pairs. Conflict data are presented for each of the nine scenarios in accordance with the experimental design. Mean conflicts are broken down by individual sector in which they occurred. Additionally, aggregate conflict data for the entire SATS network are presented graphically for each of the three target years.

Several of the *SATS cluster hubs* identified in this model exhibit substantial traffic levels at peak periods of the day. This is especially evident in the SATS cluster around Washington, D.C. containing Dulles International Airport (IAD), Reagan National Airport (DCA), and Baltimore-Washington International Airport (BWI), due to the heavy flight volumes. This airspace was designated as its own individual sector for data collection purposes. Since ground-based conflicts on active runways, taxiways and tarmac were not of interest in this research, airports were not modeled to this level of detail. Once aircraft in the simulation model break contact with the ground upon take-off, they now register in one-and-only-one of the three primary airspace sectors at a time. This insures no double-counting of blind conflicts, a vital aspect of the simulation design and data collection schema since any large-scale miscount of conflict data can lead to the wrong conclusions on SATS feasibility and implementation challenges. The data collected pursuant to the simulation runs were:

(1) number of blind conflicts [among aircraft proximate pairs];
(2) number of aircraft [operating in each sector of the model];
(3) type of aircraft, by primary classification [i.e. wide- and narrow-body jets, light jets, turbo-props, and piston-engine].

Figure 4.1 shows the interaction of commercial, charter/ air taxi, freight, GA, and SATS

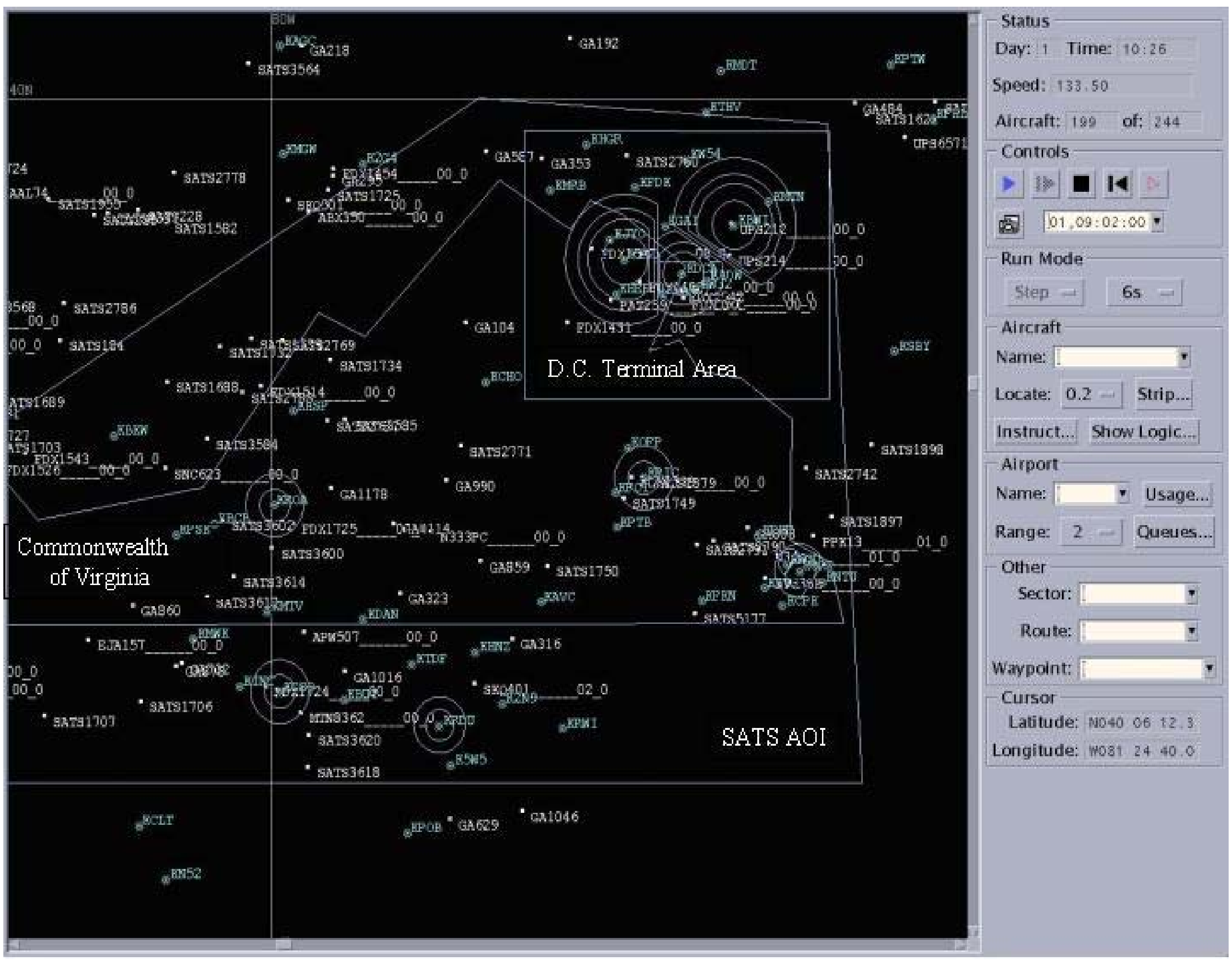


Figure 4.1: TAAM Plus Graphic User Interface - Daily Flight Operations with SATS

aircraft during the morning peak travel period.Simulation runs were conducted with strict adherence to the experimental design at Table 3.6. Five runs were executed for each of the nine scenarios. TAAM Plus provided a unique visual perspective on air traffic densities over the entire SATS AOI for both current and future scenarios. This was particularly apparent in the case of the Washington, D.C. Class B terminal area airspace. Simulation traffic levels represented both historic and forecasted flight trends, and the peak travel periods generally produced unmitigated blind conflicts at a much higher level than expected.

4.2 Mean Conflicts for the Virginia SATS Model

Conflict data were compiled after each successive simulation run. The sample means for each of these data were determined as described in Chapter 3. The data are presented throughout, numerically, for individual sectors, and graphically for aggregate scenario conflict data. Parametric conflict curves for the three dates modeled with SATS are presented later in this chapter after conflict data and analysis.

Table 4.1 and Figure 4.2 show the aircraft that were operating with between 7.5 NMs and 10 NMs distance, $S_{x,y,z}$, between them. Ten nautical miles is twice the current required

SATS Market Penetration	11/12/2000	11/12/2010	11/12/2015
0%	D.C. Term. Area: 22 Virginia: 29 SATS AOI: 15	D.C. Term. Area: 28 Virginia: 40 SATS AOI: 22	D.C. Term. Area: 31 Virginia: 41 SATS AOI: 25
5%	D.C. Term. Area: 95 Virginia: 98 SATS AOI: 36	D.C. Term. Area: 126 Virginia: 141 SATS AOI: 63	D.C. Term. Area: 138 Virginia: 161 SATS AOI: 72
10%	D.C. Term. Area: 185 Virginia: 186 SATS AOI: 60	D.C. Term. Area: 256 Virginia: 276 SATS AOI: 119	D.C. Term. Area: 284 Virginia: 307 SATS AOI: 141

Table 4.1: Mean Sector Conflicts per Sq. Nautical Mile ($7.5 \leq S_{x,y,z} < 10$ NM Separation)

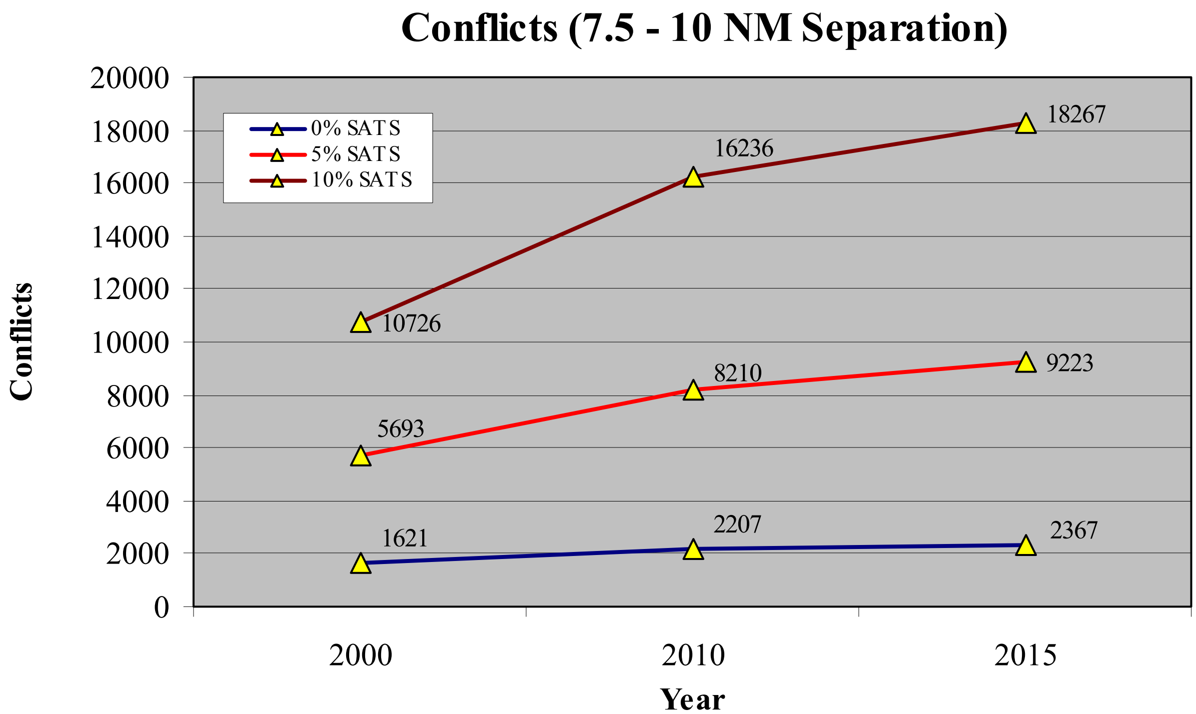


Figure 4.2: Mean Conflicts per Sq. Nautical Mile ($7.5 \leq S_{x, y, z} < 10$ NM Separation)

separation standard for IFR traffic. Enumeration of these blind conflicts is important because the result illustrates that a substantial share of the aircraft, though operating safely at a given instant in time, might inadvertently fly or be diverted by air traffic services such that they induce more subsequent conflicts.

This is particularly true in the case of blind conflicts between two light or very light SATS jets, or a SATS jet and one or more heavy commercial airliners. These aircraft all fly at much higher speeds than piston-engine aircraft or turbo-props. Therefore, the rate of closure between and among such aircraft is much more rapid. These conflicts generally account for between 25% and 30% of total conflicts in the scenarios simulated. This is a relatively large share of the conflicts and is an intuitive result given that conflicts are detected earlier and, hence, at a much greater distance than others.

Table 4.2 and Figure 4.3 display the blind conflicts registered when proximate pairs of aircraft in the simulation were between 6 and 7.5 NMs apart. These figures are important for the same reason as the previous case – because even a single sortie with inadequate air traffic services, navigation and/or height-keeping errors, could quickly influence other aircraft in NAS.

SATS Market Penetration	11/12/2000	11/12/2010	11/12/2015
0%	D.C. Term. Area: 20 Virginia: 26 SATS AOI: 13	D.C. Term. Area: 23 Virginia: 33 SATS AOI: 17	D.C. Term. Area: 25 Virginia: 35 SATS AOI: 20
5%	D.C. Term. Area: 87 Virginia: 87 SATS AOI: 31	D.C. Term. Area: 109 Virginia: 119 SATS AOI: 53	D.C. Term. Area: 117 Virginia: 135 SATS AOI: 61
10%	D.C. Term. Area: 160 Virginia: 163 SATS AOI: 52	D.C. Term. Area: 220 Virginia: 232 SATS AOI: 100	D.C. Term. Area: 242 Virginia: 265 SATS AOI: 119

Table 4.2: Mean Sector Conflicts per Sq. Nautical Mile ($6 \leq S_{x, y, z} < 7.5$ NM Separation)

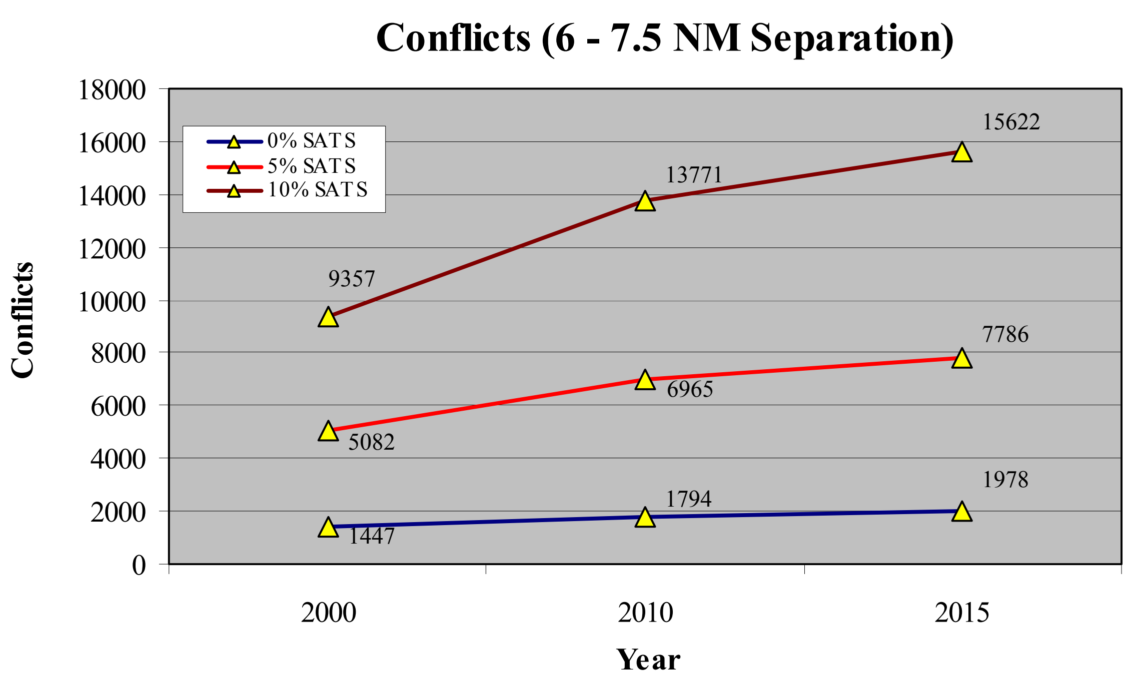


Figure 4.3: Mean Conflicts per Sq. Nautical Mile ($6 \leq S_{x, y, z} < 7.5$ NM Separation)

The number of conflicts per square mile (NM) are slightly less when comparing those generated by aircraft with 7.5-10 NM of required separation with aircraft that had 6-7.5 NM separation.

Table 4.3 and Figure 4.4 display the conflicts that occurred when aircraft were between 5 and 6 NMs apart. This level of conflict is at the current IFR separation standard and slightly above it.

SATS Market Penetration	11/12/2000	11/12/2010	11/12/2015
0%	D.C. Term. Area: 13 Virginia: 17 SATS AOI: 9	D.C. Term. Area: 15 Virginia: 22 SATS AOI: 12	D.C. Term. Area: 16 Virginia: 22 SATS AOI: 13
5%	D.C. Term. Area: 52 Virginia: 55 SATS AOI: 22	D.C. Term. Area: 68 Virginia: 77 SATS AOI: 36	D.C. Term. Area: 74 Virginia: 86 SATS AOI: 43
10%	D.C. Term. Area: 100 Virginia: 104 SATS AOI: 36	D.C. Term. Area: 139 Virginia: 149 SATS AOI: 71	D.C. Term. Area: 158 Virginia: 167 SATS AOI: 80

Table 4.3: Mean Sector Conflicts per Sq. Nautical Mile ($5 \leq S_{x,y,z} < 6$ NM Separation)

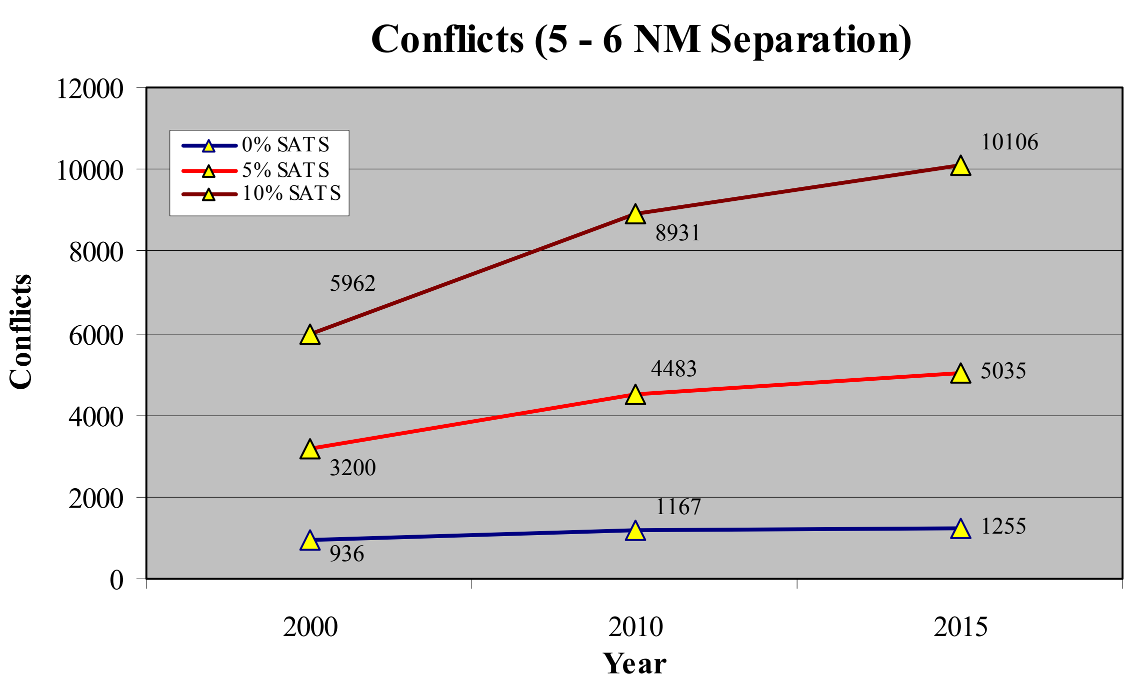


Figure 4.4: Mean Conflicts per Sq. Nautical Mile ($5 \leq S_{x,y,z} < 6$ NM Separation)

Conflicts that registered between 5 and 6 NMs accounted for approximately 15% of all conflicts. Though less numerous than the previous two sets of aircraft conflicts, insights are gained with respect to how many aircraft are operating at or near the published separation standard for the forecasted traffic levels at any one time. These aircraft were sufficiently spaced when TAAM registered the conflict. But additional conflicts with other aircraft may occur if one or both pilots deviate from their assigned courses.

Table 4.4 and Figure 4.5 depict the mean number of conflicts, both *total* and *by sector*, where aircraft had between 2.5 and 5 NMs of spacing at the time the conflicts registered. This conflict range is the first in which aircraft are inside the 5-NM published IFR separation standard. The volume of these conflicts represents more than 25% of all conflicts for the various scenarios simulated. The incidence of conflicts per square NM, though not as numerous as those conflicts of aircraft with up to 10 NM of separation, are in the same general range. This could be from a

SATS Market Penetration	11/12/2000	11/12/2010	11/12/2015
0%	D.C. Term. Area: 21 Virginia: 31 SATS AOI: 17	D.C. Term. Area: 26 Virginia: 41 SATS AOI: 24	D.C. Term. Area: 28 Virginia: 45 SATS AOI: 26
5%	D.C. Term. Area: 99 Virginia: 104 SATS AOI: 41	D.C. Term. Area: 121 Virginia: 144 SATS AOI: 67	D.C. Term. Area: 137 Virginia: 165 SATS AOI: 80
10%	D.C. Term. Area: 183 Virginia: 194 SATS AOI: 66	D.C. Term. Area: 252 Virginia: 284 SATS AOI: 133	D.C. Term. Area: 282 Virginia: 317 SATS AOI: 151

Table 4.4: Mean Sector Conflicts per Sq. Nautical Mile ($2.5 \leq S_{x,y,z} < 5$ NM Sep.)

number of factors. Considering aircraft trajectories and the fact that all conflict resolution strategies for the aircraft in the simulation were disabled, it is reasonable to assume that once an initial conflict is registered, the proximity pair of aircraft will either enter a more severe conflict category with each other; or they will diverge and encounter other aircraft, thus initiating other conflicts. When one considers the possibility of reducing current IFR separation standards to accommodate the high volume of aircraft associated with SATS implementation, this phenomenon will require examination and mitigation.

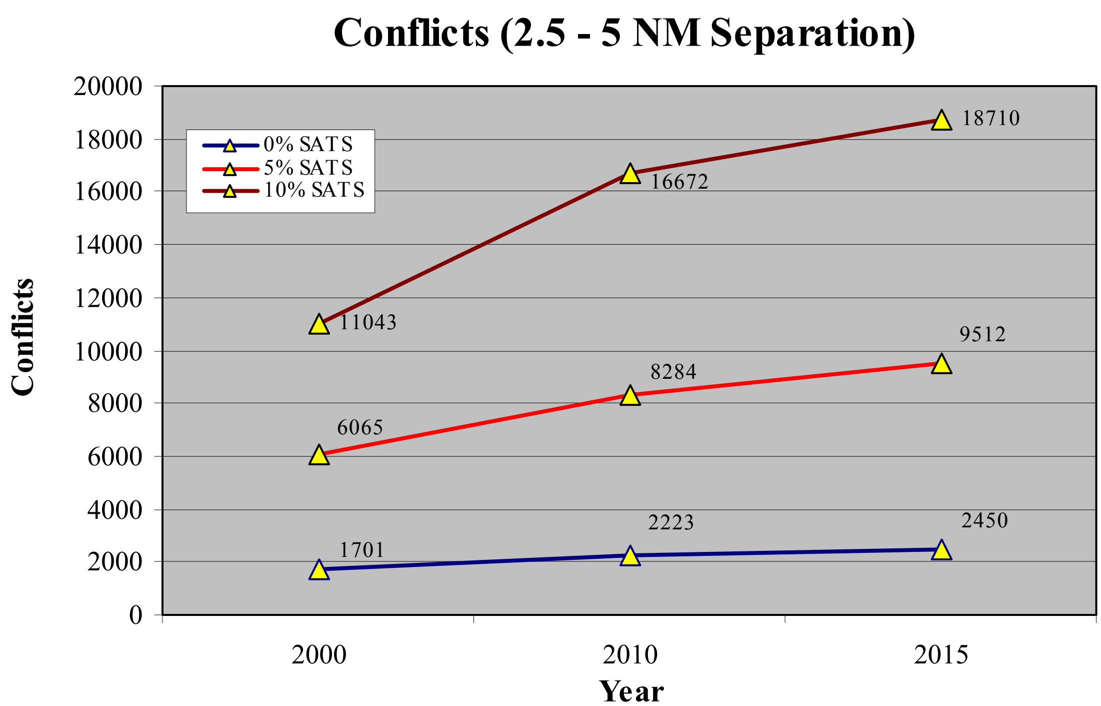


Figure 4.5: Mean Conflicts per Sq. Nautical Mile ($2.5 \leq S_{x, y, z} < 5$ NM Sep.)

Table 4.5 and Figure 4.6 present the conflicts that registered in TAAM when aircraft proximate

SATS Market Penetration	11/12/2000	11/12/2010	11/12/2015
0%	D.C. Term. Area: 6 Virginia: 9 SATS AOI: 5	D.C. Term. Area: 7 Virginia: 11 SATS AOI: 6	D.C. Term. Area: 8 Virginia: 13 SATS AOI: 7
5%	D.C. Term. Area: 28 Virginia: 30 SATS AOI: 11	D.C. Term. Area: 34 Virginia: 42 SATS AOI: 18	D.C. Term. Area: 38 Virginia: 49 SATS AOI: 22
10%	D.C. Term. Area: 54 Virginia: 55 SATS AOI: 19	D.C. Term. Area: 74 Virginia: 85 SATS AOI: 41	D.C. Term. Area: 85 Virginia: 93 SATS AOI: 53

Table 4.5: Mean Sector Conflicts per Sq. Nautical Mile ($1 \leq S_{x, y, z} < 2.5$ NM Sep.)

pairs were between 1 NM and 2.5 NM from each other. These conflicts account for less than 10% of all conflicts for the various scenarios. Since the conflict profiles presented are getting increasingly more severe, it is worth noting that both the total number of conflicts and the conflicts per square mile are reduced. The conflicts are representative of those that occur both in the enroute airspace as well as in the terminal areas surrounding the airports in the SATS network. If one considers current airspace procedures, as a given aircraft nears its destination, it will enter the traffic pattern in accordance with standard aviation rules. In Visual Meteorological Condition (VMC), an aircraft will generally enter the traffic pattern at a 45-degree angle, midfield on the downwind leg of the pattern. A pilot and/or ATC personnel may also opt to

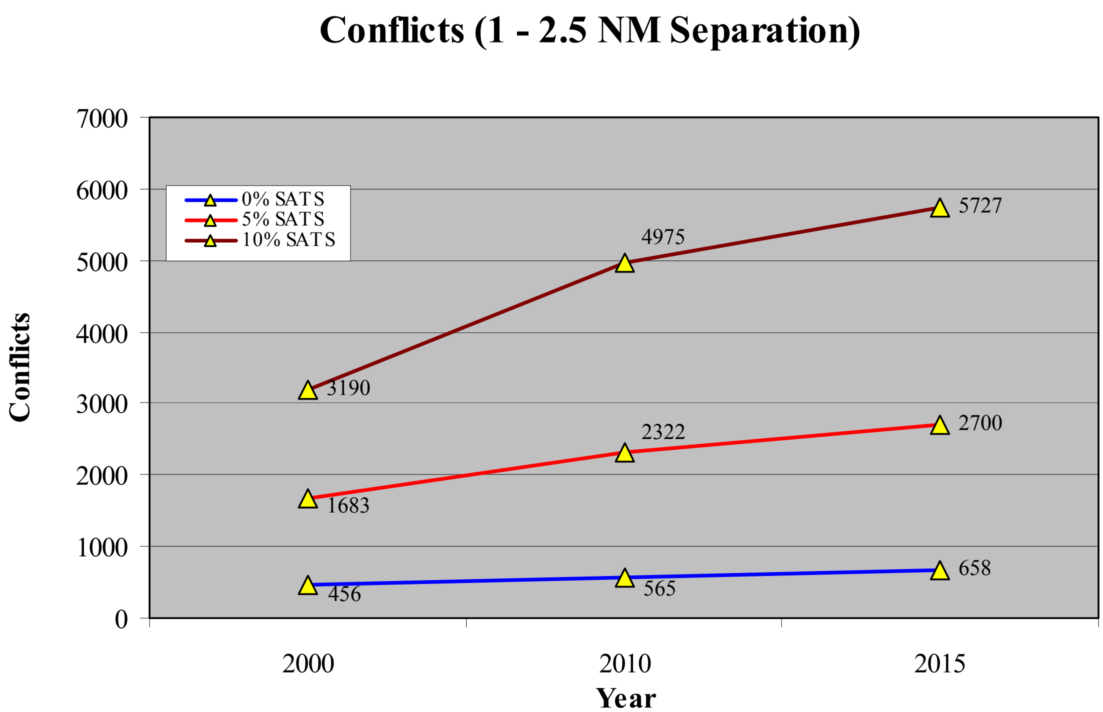


Figure 4.6: Mean Conflicts per Sq. Nautical Mile ($1 \leq S_{x, y, z} < 2.5$ NM Sep.)

bring the aircraft into the pattern by extending one of the legs – crosswind, downwind, or base – depending on the arrival direction of the aircraft and other traffic in the pattern or those departing and entering the aerodrome, or airfield. In IMC, a pilot will fly published Instrument Approach Procedures (IAP) to get oriented on the final approach course to the active runway. In SATS, aircraft will fly as close as they can to the destination airport and aircraft will likely execute self-spacing enabled by advanced navigational and collision-avoidance equipment. At 1 NM to

2.5 NMs, an inbound aircraft is in one of the critical phases of flight – landing. So those aircraft in the simulation that were able to safely accomplish an approach and landing without collision avoidance procedures speaks well for the potential that SATS exhibits – numerous, largely autonomous vehicles competing for the same airspace but doing so in accordance with a technology-enhanced protocol. Since the aircraft are posturing for landing at this point, the relatively few numbers of conflicts of this range compared to previous, less severe conflict profiles is indeed encouraging.

Table 4.6 and Figure 4.7 show the number of sector and aggregate conflicts where less than 1 NM of the required lateral, vertical, and/or longitudinal separation minima existed at the instant the encounter occurred. In the context of flying, this is known as a *near-miss*. Given a proximate pair of aircraft, a near-miss might result in one or both aircrews losing control of their respective aircraft due to abrupt evasive maneuvers putting the aircraft into an unusual attitude.

SATS Market Penetration	11/12/2000	11/12/2010	11/12/2015
0%	D.C. Term. Area: 2 Virginia: 3 SATS AOI: 2	D.C. Term. Area: 2 Virginia: 3 SATS AOI: 2	D.C. Term. Area: 2 Virginia: 4 SATS AOI: 2
5%	D.C. Term. Area: 7 Virginia: 9 SATS AOI: 5	D.C. Term. Area: 8 Virginia: 12 SATS AOI: 7	D.C. Term. Area: 9 Virginia: 15 SATS AOI: 9
10%	D.C. Term. Area: 15 Virginia: 17 SATS AOI: 8	D.C. Term. Area: 20 Virginia: 26 SATS AOI: 17	D.C. Term. Area: 21 Virginia: 29 SATS AOI: 24

Table 4.6: Mean Sector Conflicts per Sq. Nautical Mile ($S_{x, y, z}$ < 1 NM Separation)

In this SATS simulation, less than 5% of the blind conflicts might be categorized as near-misses. Correspondingly, the number of conflicts per square mile is the smallest of all categories of conflict severity examined in this research. Once again, this is a good sign when one considers the ideal zero accident rate aspired to by the FAA. If one considers the converse – where the number of blind conflicts increases with the level of conflict severity that would not bode well for SATS. But a low incidence of blind conflicts of greatest severity might even be improved thru the advent of advanced technologies. One might think that the greatest number of blind conflicts might occur around a busy destination airport where numerous vehicles – commercial air, some military, GA, and of course SATS aircraft, operate. The airport is a common destination, and the various directions from which people fly in become choke points the closer one gets to the airport center. However, the dynamic that actually exists at those points, and others where the most severe blind conflicts occur, is counterintuitive.

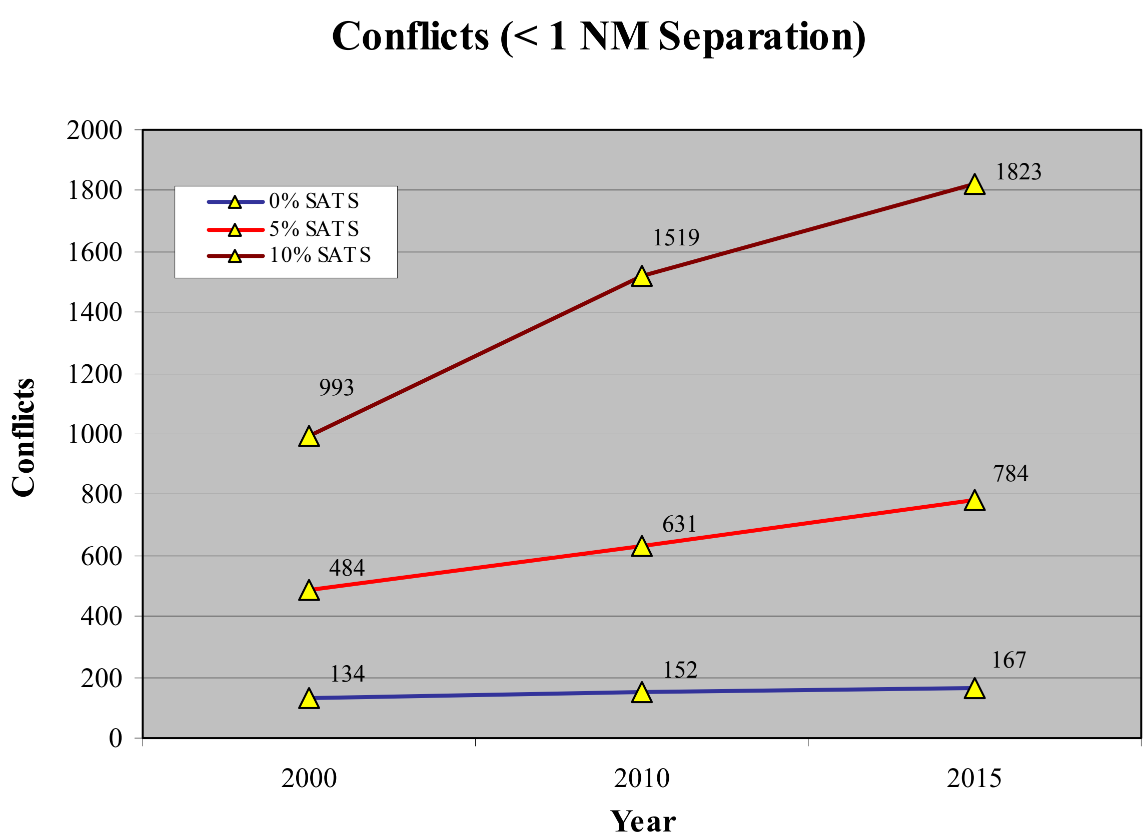


Figure 4.7: Mean Conflicts per Sq. Nautical Mile ($S_{x, y, z}$ < 1 NM Separation)

The mean (total) number of conflicts that occurred in the simulation phase of this research are found in Table 4.7 and Figure 4.8. These conflicts were aggregated as a means of learning the overall order of magnitude of mean blind conflicts in the SATS network, and the breakdown/ proportion of blind conflicts in the three airspace sectors developed by the researcher

SATS Market Penetration	11/12/2000	11/12/2010	11/12/2015
0%	D.C. Term. Area: 2015 Virginia: 2835 SATS AOI: 1445	D.C. Term. Area: 2457 Virginia: 3662 SATS AOI: 1991	D.C. Term. Area: 2681 Virginia: 3926 SATS AOI: 2268
5%	D.C. Term. Area: 9134 Virginia: 9502 SATS AOI: 3576	D.C. Term. Area: 11579 Virginia: 13298 SATS AOI: 6018	D.C. Term. Area: 12751 Virginia: 15188 SATS AOI: 7102
10%	D.C. Term. Area:17365 Virginia: 17937 SATS AOI: 5974	D.C. Term. Area: 23960 Virginia: 26208 SATS AOI: 11940	D.C. Term. Area: 24619 Virginia: 26858 SATS AOI: 12335

Table 4.7: Cumulative Conflicts (by Sector), $\bar{x}_i$, on November 12

for the 45 total simulation runs. Though different in terms of conflict severity and the urgency by which evasive action would have to be taken if this involved actual manned aviation vehicles. The value of combining conflicts comes in the form of the absolute upper bound that can be

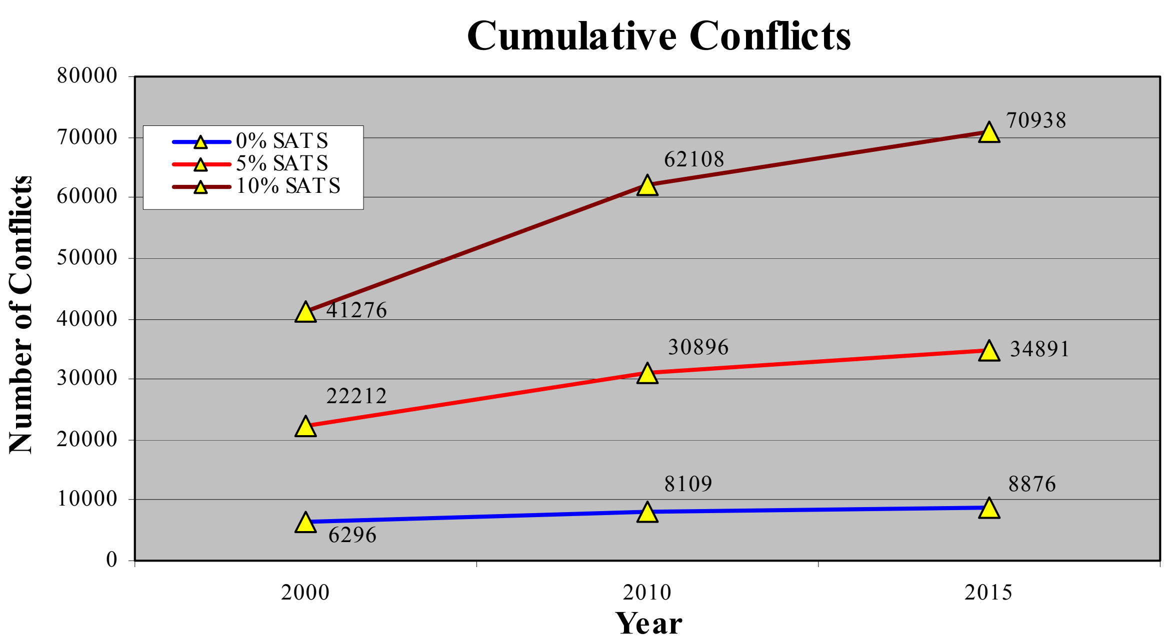


Figure 4.8: Mean Conflicts Conflicts per Sq. Nautical Mile (all cases) on November 12

determined. This is crucial in assessing the overall acceptability of the traffic densities associated with various SATS market penetration scenarios. With the overall population of blind conflicts, it also gives insights into the vast number of more severe conflicts that may be induced by the errant actions of air traffic controllers, aviators, or a combination of the two. The average numbers of aircraft that were determined to be operating in one or more of the airspace sectors and were involved in the blind conflicts that have been presented are in Table 4.8. The total number of aircraft in the SATS simulations are between ten- and twenty-thousand for

SATS Market Penetration	11/12/2000	11/12/2010	11/12/2015
0%	D.C. Term. Area: 2109 Virginia: 3225 SATS AOI: 4728	D.C. Term. Area: 2554 Virginia: 4083 SATS AOI: 6090	D.C. Term. Area: 2692 Virginia: 4303 SATS AOI: 6401
5%	D.C. Term. Area: 3655 Virginia: 5041 SATS AOI: 7053	D.C. Term. Area: 4521 Virginia: 6609 SATS AOI: 9398	D.C. Term. Area: 4760 Virginia: 6977 SATS AOI: 9913
10%	D.C. Term. Area: 4790 Virginia: 6424 SATS AOI: 8633	D.C. Term. Area: 6012 Virginia: 8568 SATS AOI: 11878	D.C. Term. Area: 6077 Virginia: 8661 SATS AOI: 12011

Table 4.8: Average Number of Aircraft Detected (by Sector) During Simulation Runs

November 12, 2000, and between thirteen- and thirty-thousand for the forecasted November 12, 2015 scenario. The overall growth in average daily traffic – between 30% and 40% in the SATS network – between the year 2000 and 2015 – is important to note. A linear increase in the number of expected conflicts with a linear increase in traffic might be significant – in this case, that would be an approximate one-third increase over the course of 15 years. But, in this case, the relationship between number of aircraft and the expected number of blind conflicts may be exponential in nature – perhaps quadratic or cubic.

For each scenario, the mean number of conflicts and aircraft were used to determine the Conflict Ratio, or the proportion of blind conflicts to aircraft in a given SATS scenario. Table 4.9 displays these values. This is another way to express conflict data as a means of quantitatively characterizing the dynamic between aircraft in a given scenario. The smaller the ratio, the fewer conflicts there are in the network assuming that numbers of aircraft are held constant within n simulation runs where $n = 1, .., 5$ of the nine unique SATS scenarios.

Scenario	Mean Conflicts	Mean Aircraft	Ratio (# Conf/Acft)
2000-0%	6296	10062	0.63
2000-5%	22212	15749	1.41
2000-10%	41276	19847	2.08
2010-0%	8109	12727	0.64
2010-5%	30896	20528	1.51
2010-10%	62108	26458	2.35
2015-0%	8876	13396	0.66
2015-5%	34891	21649	1.61
2015-10%	70938	26749	2.65

Table 4.9: Conflict Factors and Frequencies

For the 0% SATS case, there were less than one conflict per aircraft in the scenario. With 5% SATS market penetration, there were approximately 3/2 conflicts per aircraft. Finally, for the 10% SATS case, there is an average of more than two conflicts per aircraft in the scenario. This makes intuitive sense; since the volume of airspace remains the same, more aircraft in the same region might be expected to produce more blind conflicts despite flight trajectories dependent upon random assignment of GA aircraft and SATS departure times within a constrained window. For November 12, 2000, the rate of change between the 0% and 5% SATS cases is 2.8. Between the 5% and 10% SATS cases, the rate of change is 4.7. The rate at which midair conflicts are increasing given forecasted traffic levels is 1.7 times greater after 2010 than it is in 2000. That is due to the increased commercial traffic spawning more SATS surrogate sorties and regular NAS growth for General Aviation, among other factors.

Figure 4.9 is a graphical representation of the functional relationship between blind conflicts and aircraft of all types operating in the SATS test bed for November 12 in the years 2000, 2010, and 2015. As one can readily see, the growth of these data are characterized by scaled growth in the

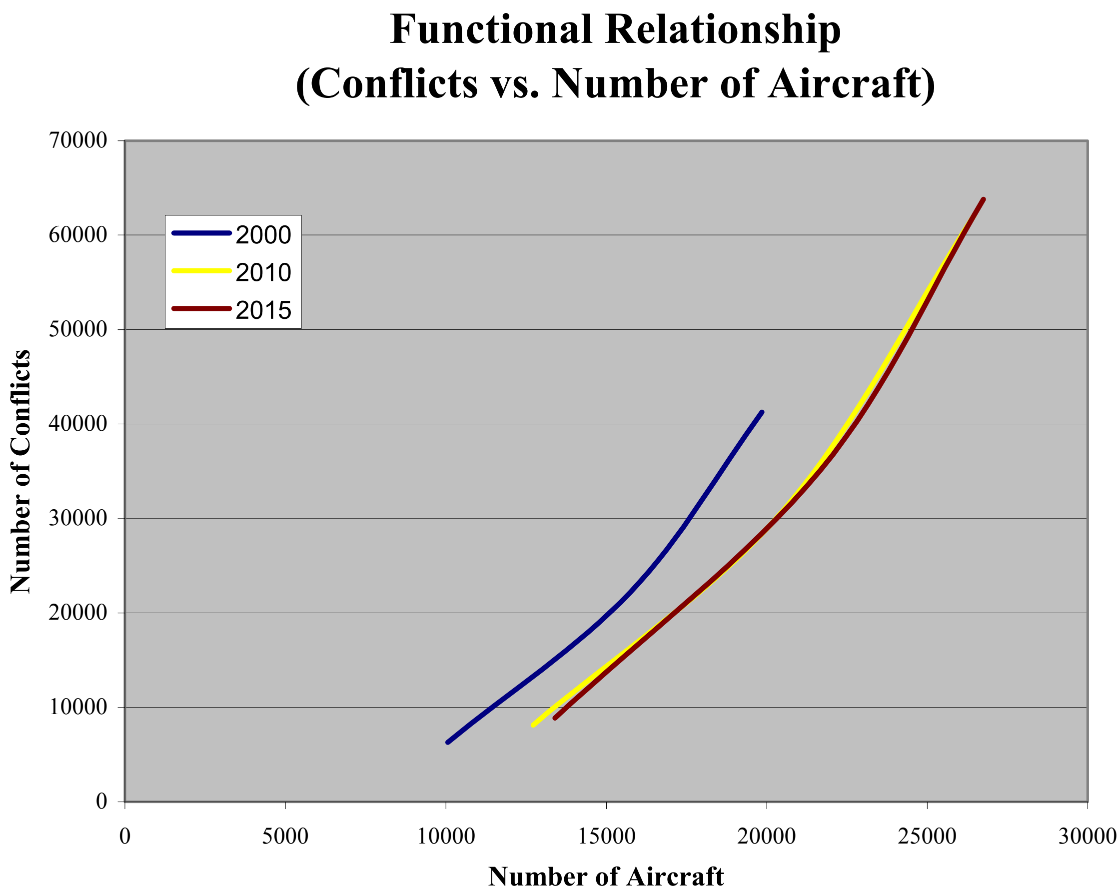


Figure 4.9: Mean Conflicts Versus Number of Aircraft

independent variable, number of aircraft in the system, with the 5% and 10% SATS scenarios. And there is a corresponding increase in the number of blind conflicts. In all cases, the curves are constrained by the number of aircraft. For the CY 2000 baseline, the curve is shorter than those representing the CYs 2010 and 2015. For the two latter dates in the simulation, the curves representing are translated to the right along the "Aircraft" axis and translated slightly upward on the "Conflicts" axis. Finally, they (2010 and 2015) are physically located closer together on the graph than they are to the CY 2000 curve because 2010 and 2015 are closer to each other in terms of size.

4.3 Parametric Conflict Curves

The simulation registered and logged blind conflicts – our outputs – in terms of conflict severity, or the distance between aircraft at the time the conflict occurred. In this case, it was possible to examine each of the three dates in the simulation separately. That is, conflicts associated with each of the three simulation years – 2000, 2010, and 2015 – may be depicted as a series of parametric curves. These curves can be examined to determine which types of conflicts (in terms of severity) are most likely to occur and what effect the level of SATS market penetration has on this variable. But one of the most useful aspects of looking at these parametric curves is to gain insights into whether or not aircraft separation standards might be reduced to accommodate the sharp increase in air traffic that would accompany full SATS implementation. Figure 4.10 displays parametric curves for the baseline (0%), 5% and 10% SATS scenarios for

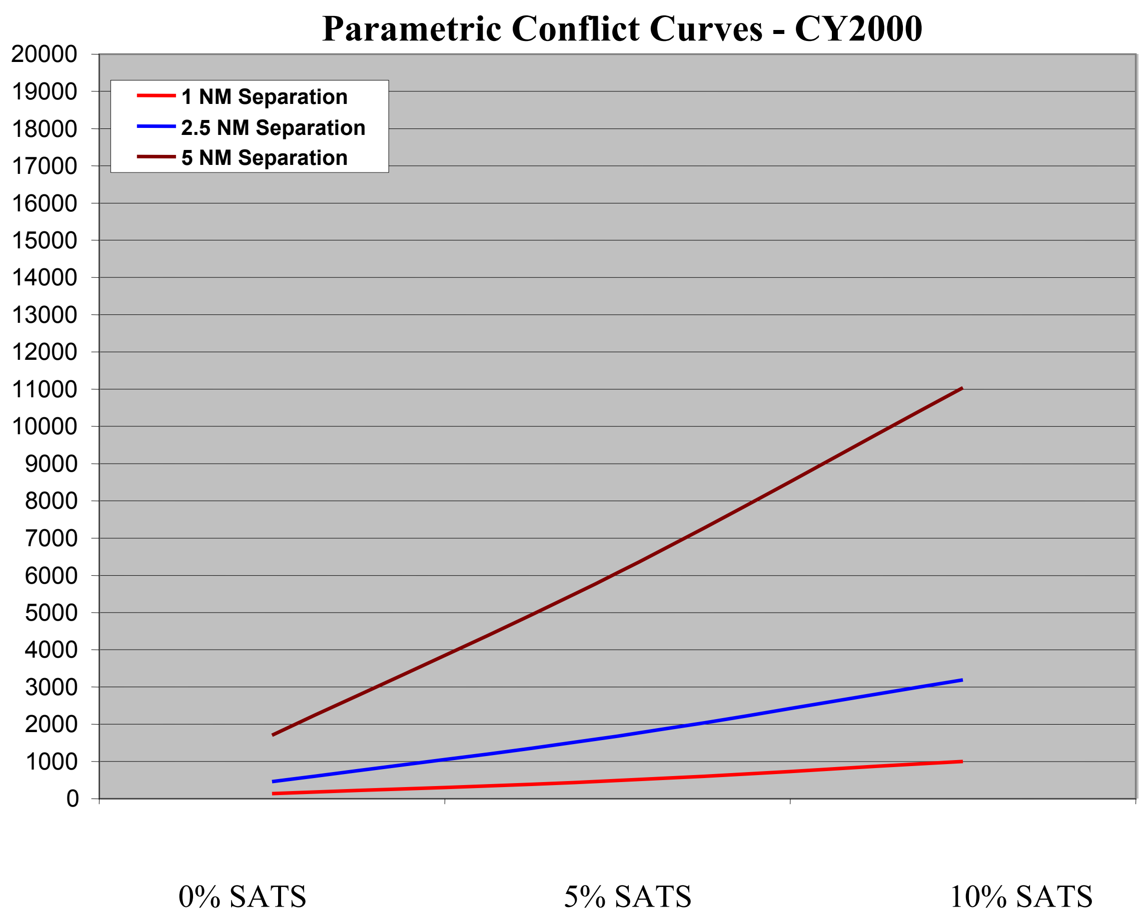


Figure 4.10: Parametric Conflict Curves: CY2000

November 12, 2000. In this case, proximate aircraft had between out to 5 NMs of separation when they encountered each other. These conflicts contributed most to the overall SATS simulation conflict levels, and they also grew the most in magnitude among the three scenarios – 0%, 5%, and 10% SATS market share. Aircraft with 1 NM to 2.5 NMs of the required separation produce the next most conflicts, but these are substantially less. Aircraft that produce near-misses certainly generated less than the other two categories, but they are still significant nonetheless. If one considers an absolute upper bound for numbers of conflicts, then it is easier to make some assertions on reducing aircraft separation standards for SATS. One assumption that we must make is that conflicts of less severity, or those that occurred in the actual simulation runs but that are greater than 5 NM and out to as much as 10 NMs are disregarded. It is useful to compare the parametric curves to one another, discuss their characteristics, and interpret what they can tell us about the potential of SATS. Let's assume the maximum allowable number of conflicts to be 25,000. In the baseline case – CY 2000, I believe there is potential for both SATS growth and reduction of aircraft separation standards at all levels of SATS market penetration. In the 0% and 5% SATS cases, I would reduce the separation standard to 1 NM after additional modeling, simulation and thorough assessment. For the 10% SATS case, I believe the separation standard might be reduced by 50% to 2.5 NM or even slightly less. At the current traffic level, the 10% SATS case generated approximately 15,000 conflicts of <5 NM, <2.5 NM and <1 NM of separation. That gives us a buffer of approximately 10,000 conflicts at 10% SATS market share. The 0% and 5% cases have even more buffer. So, cutting the required aircraft separation standard in half to 2.5 NMs is feasible.

Figure 4.11 displays the parametric curves for the SATS simulation with November 12, 2010 air traffic volumes. The number of blind conflicts at each separation distance has increased in the 2010 simulation. Once again, let's assume a 25,000 upper limit as the number of allowable blind conflicts for evaluation. In the year 2010, there is still potential for SATS growth and a possible reduction in aircraft separation standards at the 0% and 5% level of SATS market penetration. At these levels, the number of blind conflicts (given the three conflict categories for severity) total less than 4,000 and 12,000, respectively. So we should be able to safely reduce the standard to 1 NM and confirm with additional simulation. At 10% SATS market share, the number of total conflicts pictured is over 23,000 among the three cases of separation distance. So there isn't much room to reduce aircraft separation standards at that level of traffic.

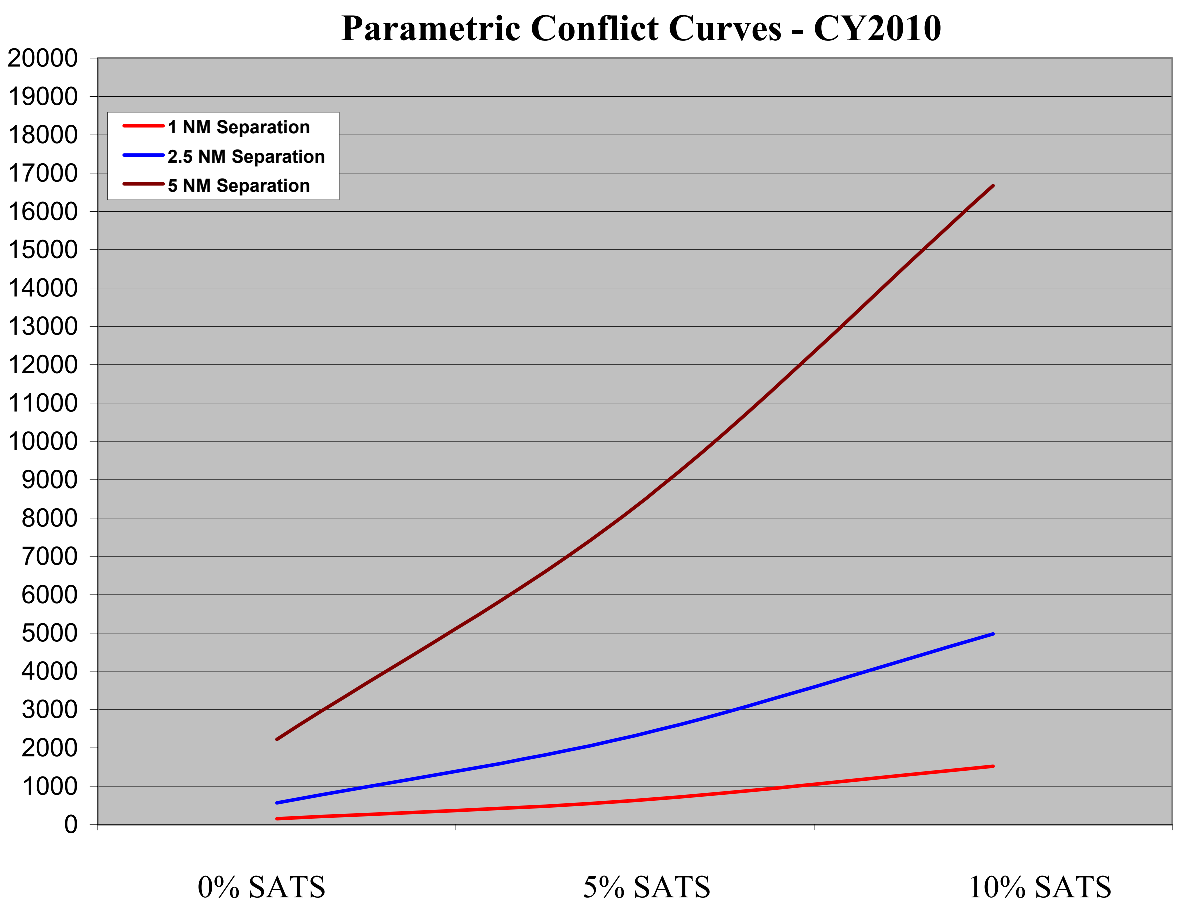


Figure 4.11: Parametric Conflict Curves: CY2010

Figure 4.12 displays the parametric curves for the SATS simulation with November 12, 2015 traffic. The number of blind conflicts at each separation distance is greater still in the 2015 simulation. Once again, a 25,000 upper bound is assumed to be the number of allowable blind conflicts. In the year 2015, there is still some potential for SATS growth and possible reduction in aircraft separation standards, but only at the at the 0% and 5% levels of SATS market penetration. At these levels, the number of blind conflicts are less than 4,000 and 14,000, respectively. So we should be able to safely reduce the standard to 1 NM at 0% SATS and to the 2.5-NM standard for 5% SATS market penetration. It might be possible to reduce further to 1

NM at 5% SATS, but that could become problematic given our assumed constraint of 25,000 blind conflicts. At 10% SATS, the number of conflicts pictured is already greater than 25,000. So the system is effectively maxed out given our self-imposed limit for blind conflicts.

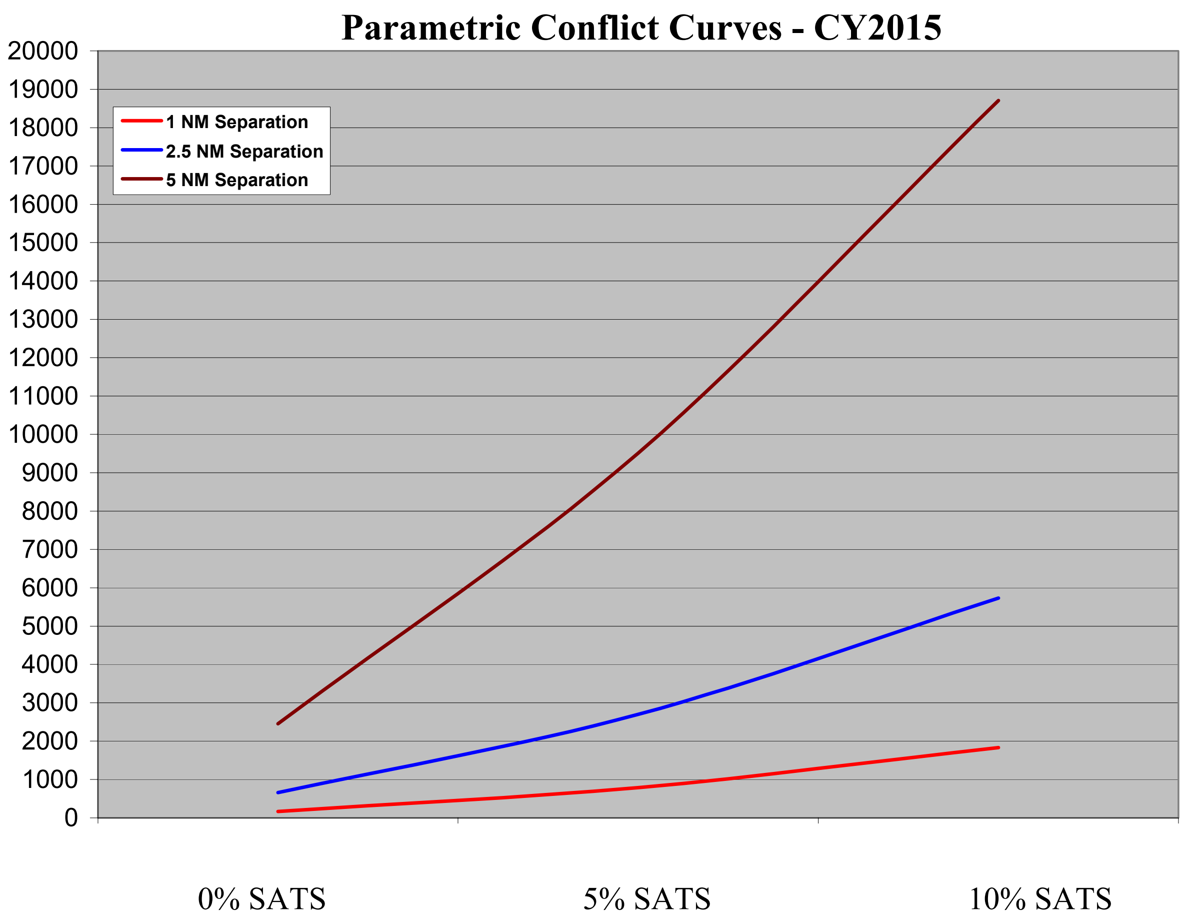


Figure 4.12: Parametric Conflict Curves: CY2015

4.4 Statistical Testing

The *t*-distribution was chosen for statistical testing on the simulation output data from TAAM Plus. A simulation on the order of the one executed for SATS in the free flight construct requires substantial time and computing power per run. As stated earlier, five simulation runs were conducted for each of the nine scenarios. This enabled a single sample mean for each of nine SATS scenarios – the baseline case as well as those replicating 5% and 10% market penetration. The *sample mean* number of conflicts for each SATS scenario consisted of an aggregation of the three subject airspace sectors – the Washington, D.C. terminal area and the Commonwealth of Virginia and SATS AOI defined 3-dimensional volumes of airspace. With $n = 5$, x_i represents an unbiased point estimator for μ, the population mean number of blind conflicts. The experimental design produced one sample mean for each of the three SATS market penetration levels for flights on November 12th in 2000, 2010 and 2015.

4.4.1 Confidence Intervals

A 95% confidence interval was used. Critical points were determined for the confidence intervals using $\alpha = 0.05$ and n-1 degrees of freedom. Table 4.11 contains the mean, standard deviation, upper and lower limits for the 95% confidence intervals of each of the nine (9) SATS market penetration scenarios in this research.

Scenario	**2000, 0% SATS**	**2010, 0% SATS**	**2015, 0% SATS**
Mean	6295.60	8108.80	8876.00
Std. Dev.	201.09	143.20	187.21
C.I. (Lower)	6045.92	7930.99	8643.55
C.I. (Upper)	6545.28	8286.61	9108.45
Scenario	**2000, 5% SATS**	**2010, 5% SATS**	**2015, 5% SATS**
Mean	22211.60	30895.80	34891.00
Std. Dev.	182.77	472.98	417.71
C.I. (Lower)	21984.67	30308.52	34372.35
C.I. (Upper)	22438.53	31483.08	35409.65
Scenario	**2000, 10% SATS**	**2010, 10% SATS**	**2015, 10% SATS**
Mean	41276.40	62107.80	70938.40
Std. Dev.	613.49	463.10	849.35
C.I. (Lower)	40514.65	61532.78	69883.79
C.I. (Upper)	42038.15	62682.82	71993.01

Table 4.10: Sample Mean, Standard Deviation, and Confidence Intervals

4.4.2 Box-and-Whisker Plots

Figure 4.13 is a Box-and-Whisker plot displaying mean and quartile blind conflict data for the November 12, 2000 scenario – with 0% SATS baseline case, as well as the 5% and 10% SATS

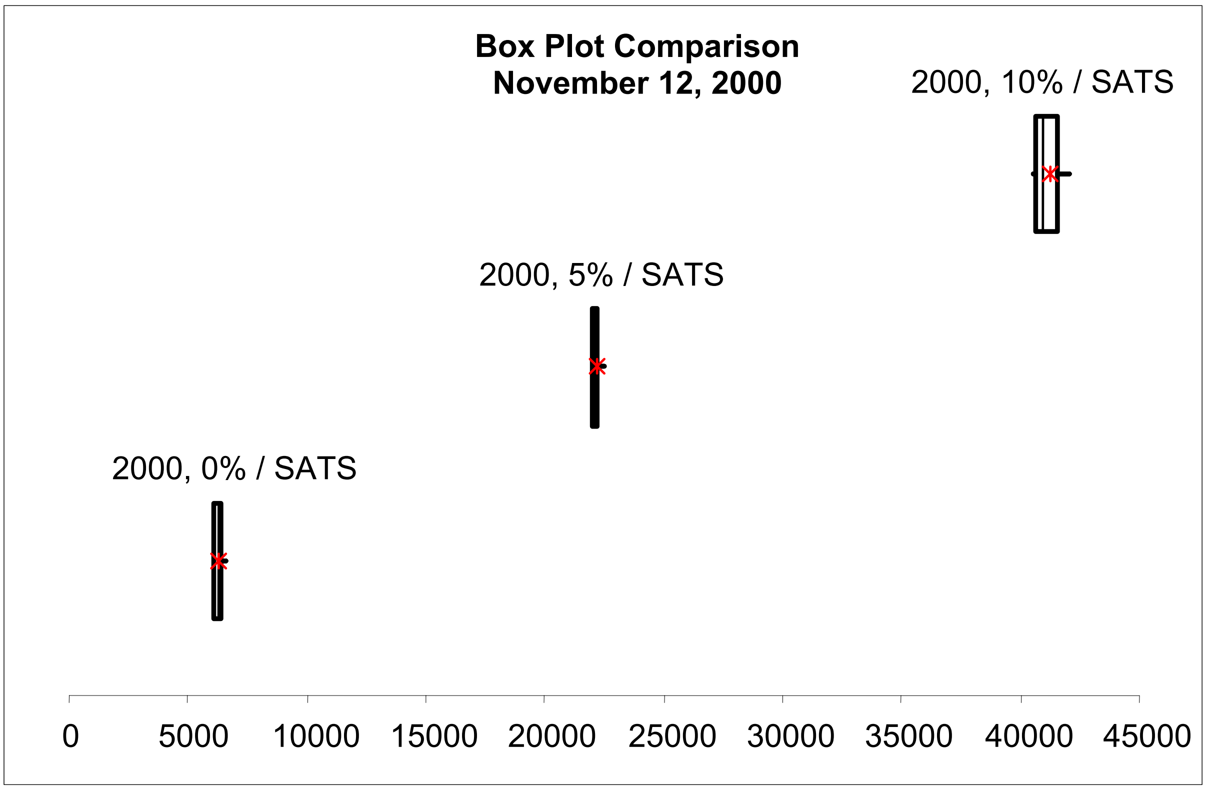


Figure 4.13: Box-and-Whisker Plot: Mean Conflict Data (November 12, 2000)

market cases. Box-and-Whisker plots for November 12th in the years 2010 and 2015 look similar. As can readily be seen, the intuitive trend of increasing blind conflicts accompanying marked air traffic increases with SATS is apparent within each box plot, or date studied. But there is also a successive jump in order of magnitude among the three dates studied. This shows the two-tiered air traffic dilemma that will continue to challenge airspace planners and administrators well into the 21st Century. That is, commercial air traffic will likely increase in the U.S. as the population increases. It is assumed that the SATS market share will not exceed 10%, at least in the near term. So the number of SATS surrogate flights will likewise increase as the number of commercial sorties increases.

Figure 4.14 shows the mean and quartile data for a representative case – the baseline, 0% SATS scenario, for November 12, 2000.

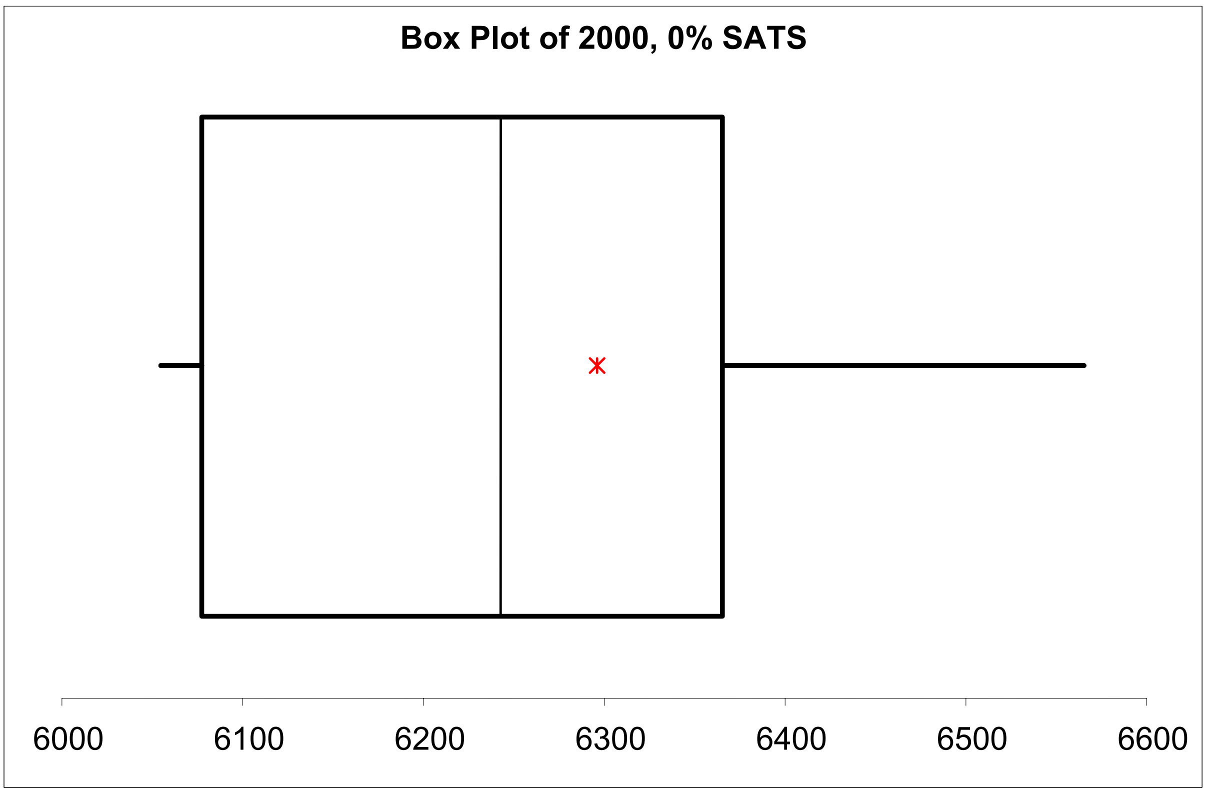


Figure 4.14: Box-and-Whisker Plot: November 12, 2000 Traffic with 0% SATS Flights

Figure 4.15 thru Figure 4.24 display mean and quartile data for the 5 % and 10% SATS cases for November 12th, 2000. They also show the aggregate 2010 and 2015 plots, and individual plots for the remaining nine SATS scenarios in 2000, 2010, and 2015.

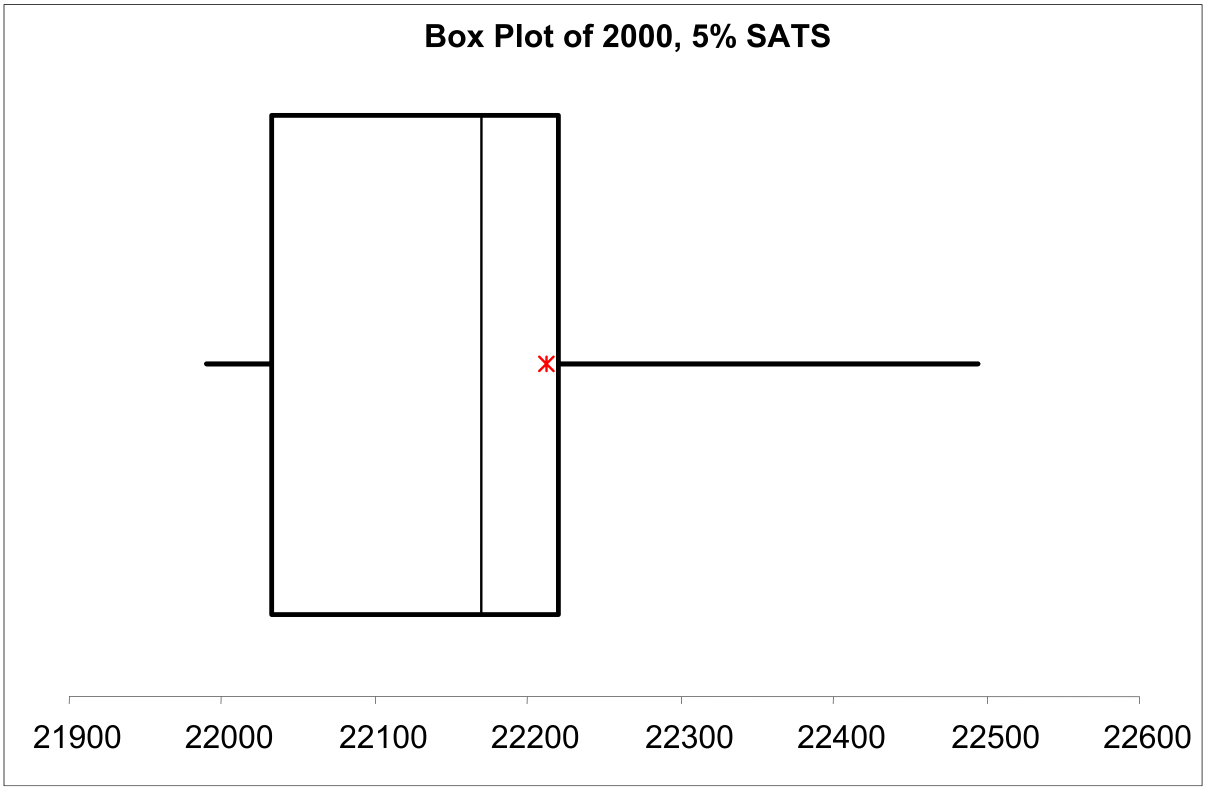


Figure 4.15: Box-and-Whisker Plot: November 12, 2000 Traffic with 5% SATS Flights

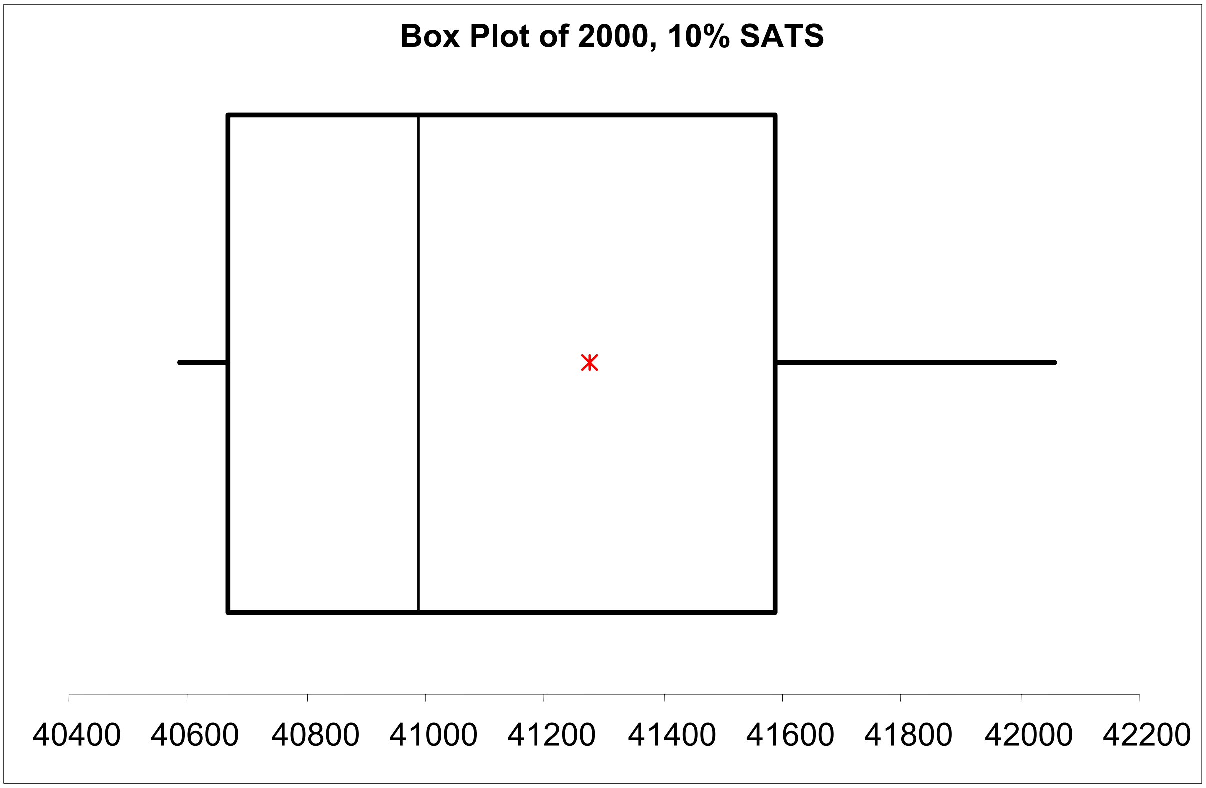


Figure 4.16: Box-and-Whisker Plot: November 12, 2000 Traffic with 10% SATS Flights

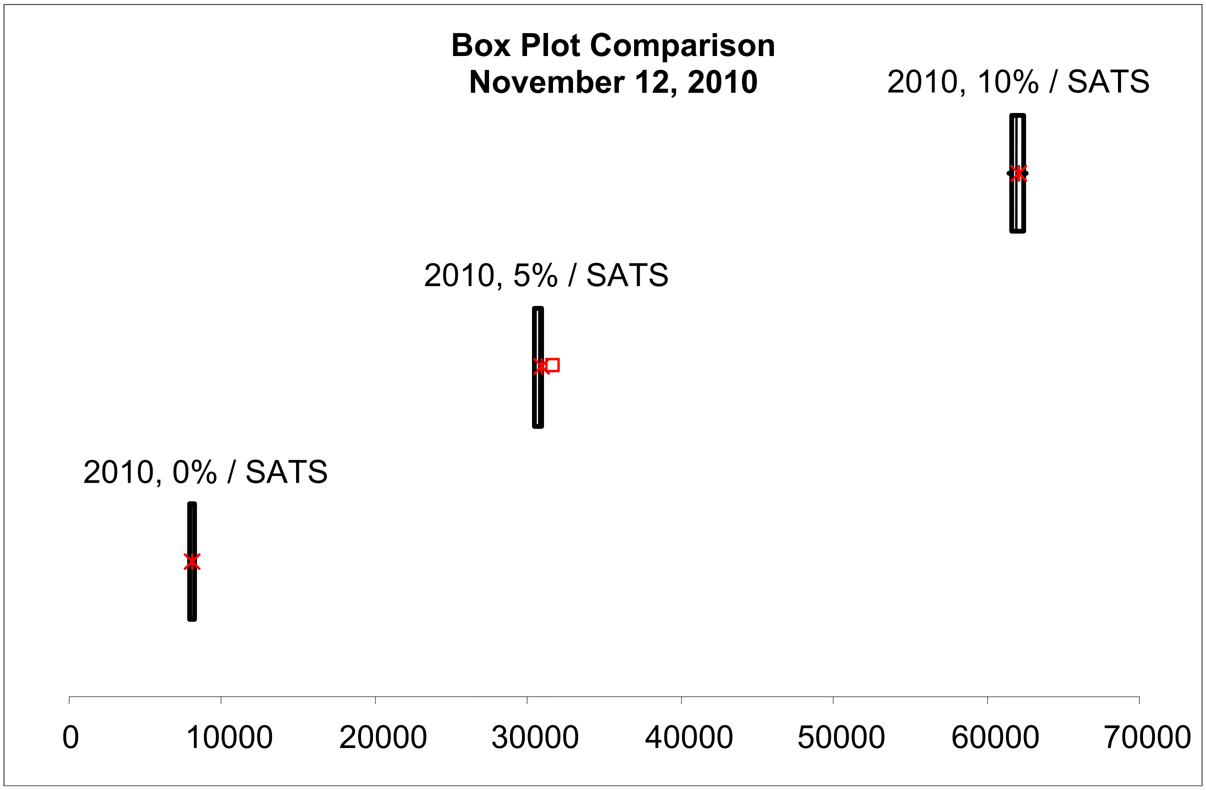


Figure 4.17: Box-and-Whisker Plot: Mean Conflict Data (November 12, 2010)

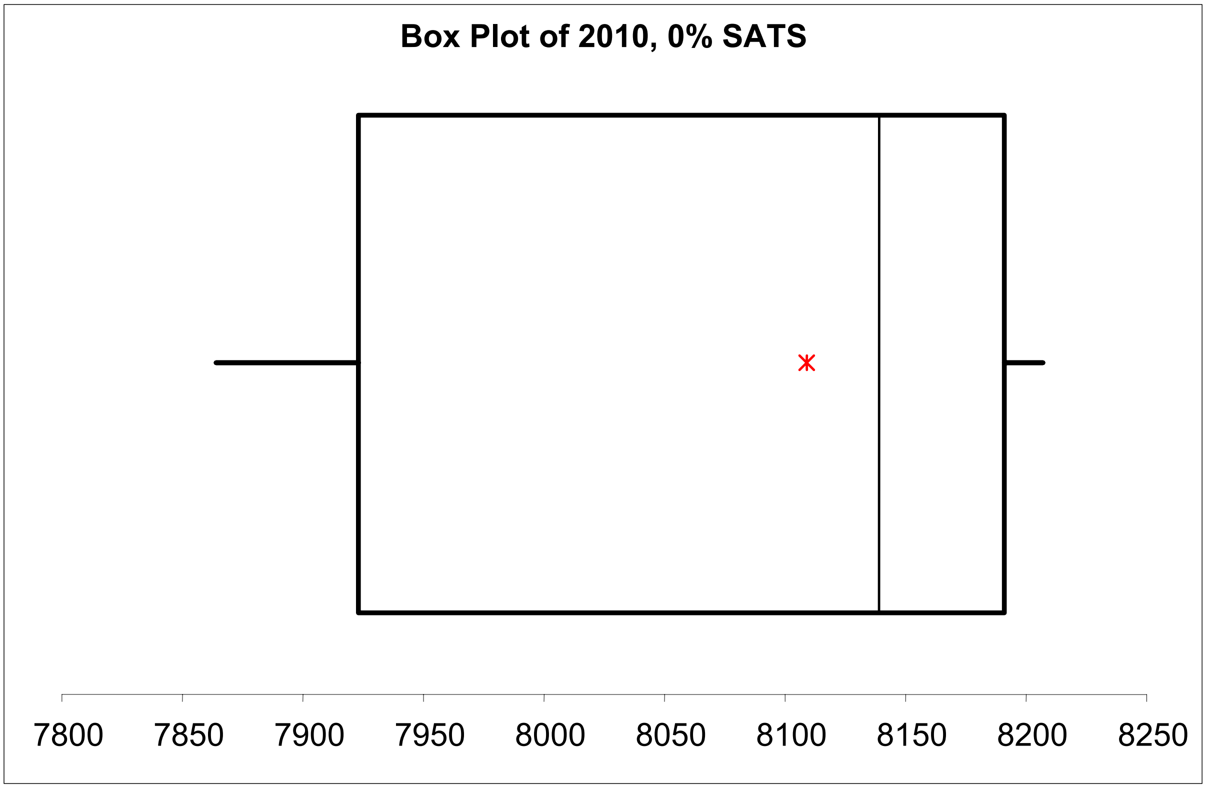


Figure 4.18: Box-and-Whisker Plot: November 12, 2010 Traffic with 0% SATS Flights

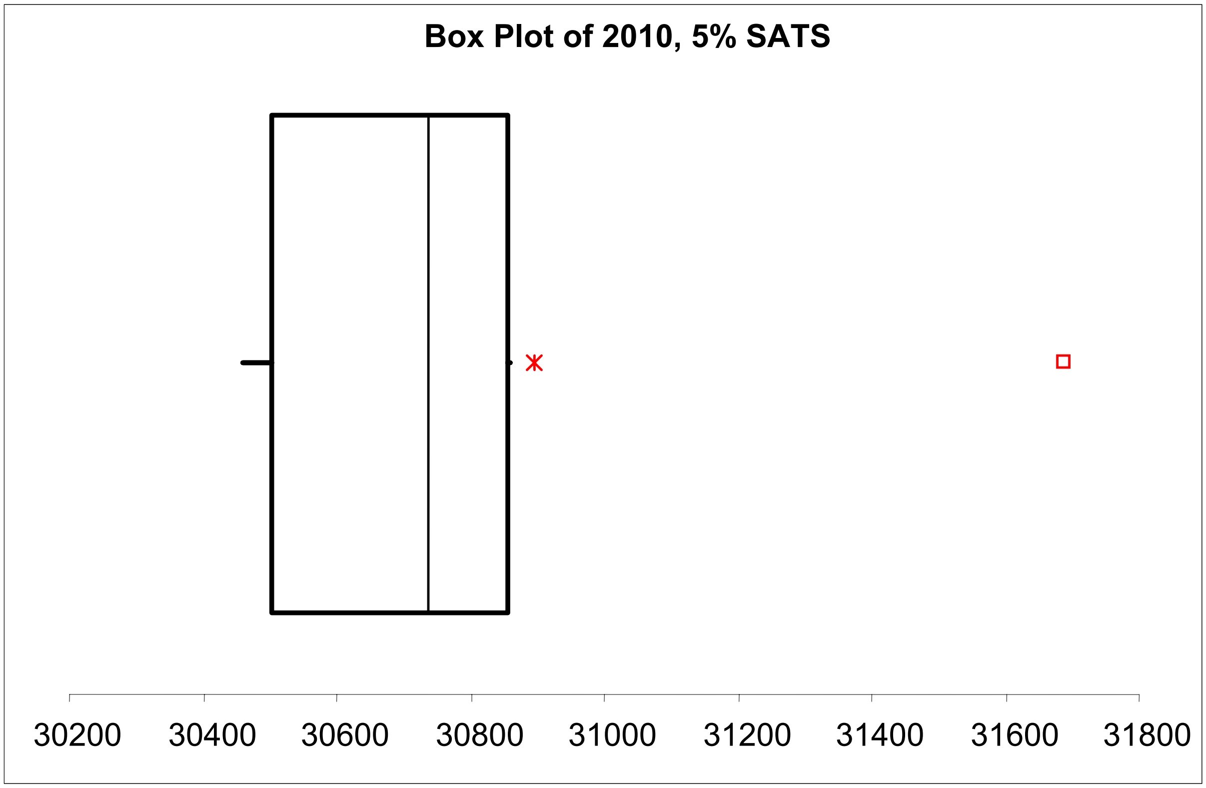


Figure 4.19: Box-and-Whisker Plot: November 12, 2010 Traffic with 5% SATS Flights

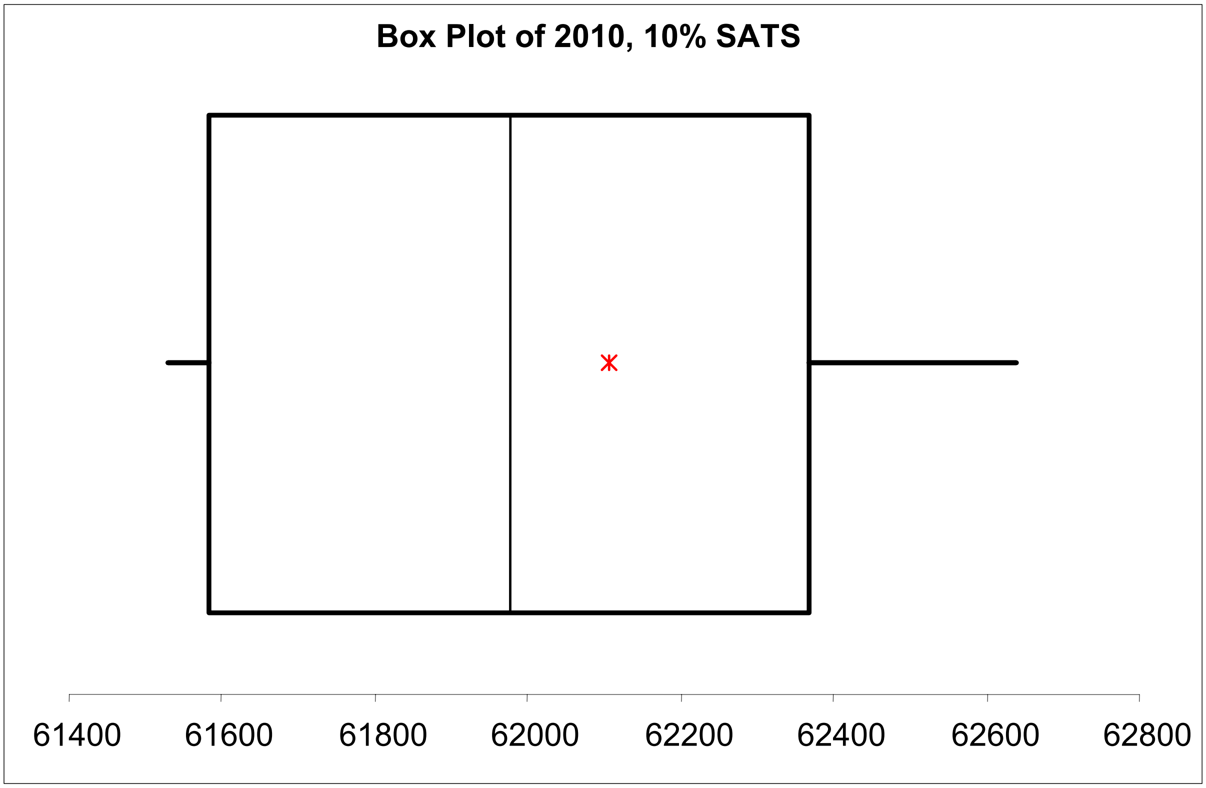
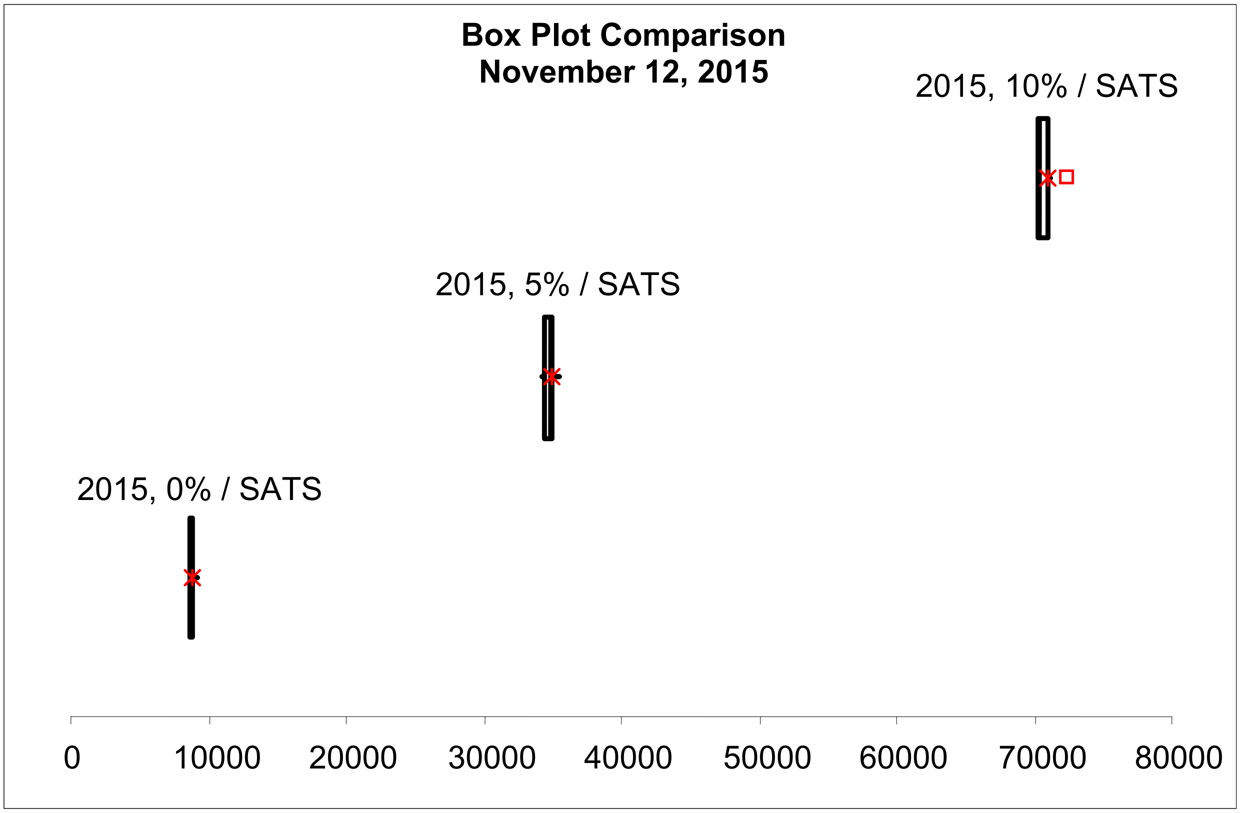


Figure 4.20: Box-and-Whisker Plot: November 12, 2010 Traffic with 10% SATS Flights



4.21: Box-and-Whisker Plot: Mean Conflict Data (November 12, 2015)

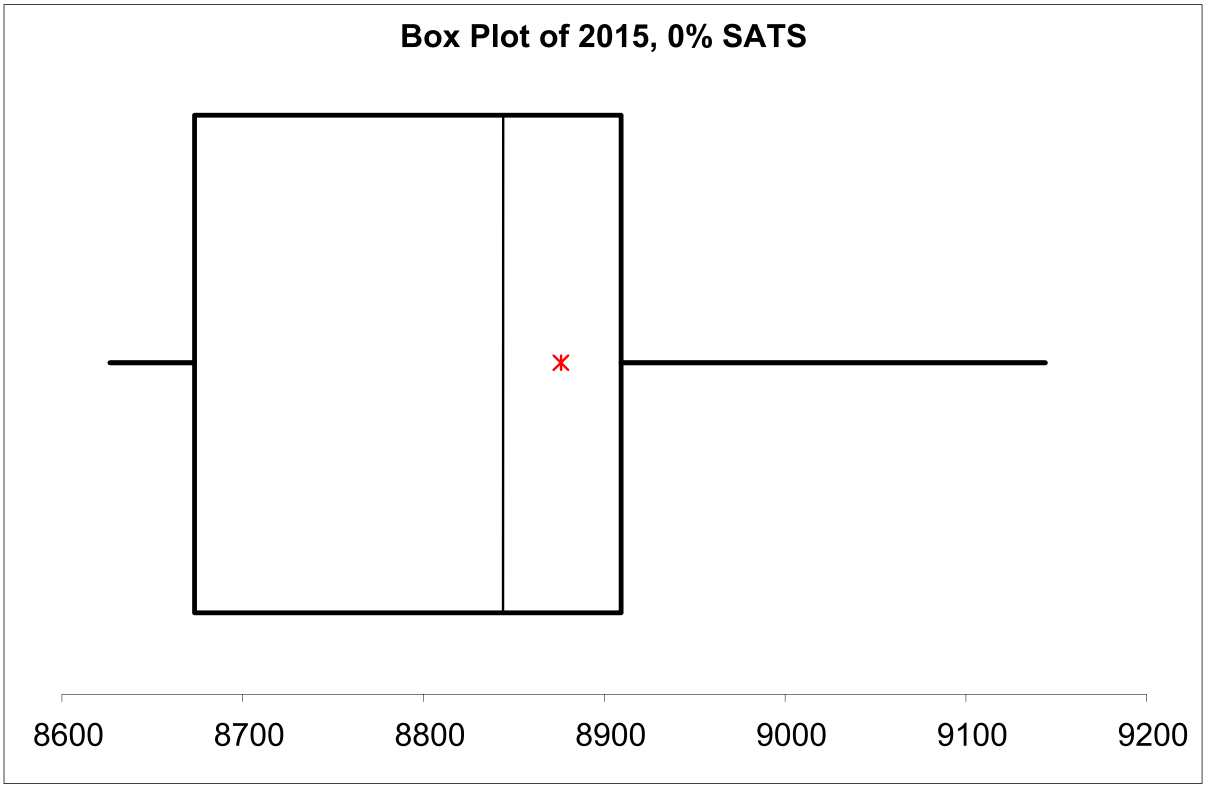


Figure 4.22: Box-and-Whisker Plot: November 12, 2015 Traffic with 0% SATS Flights

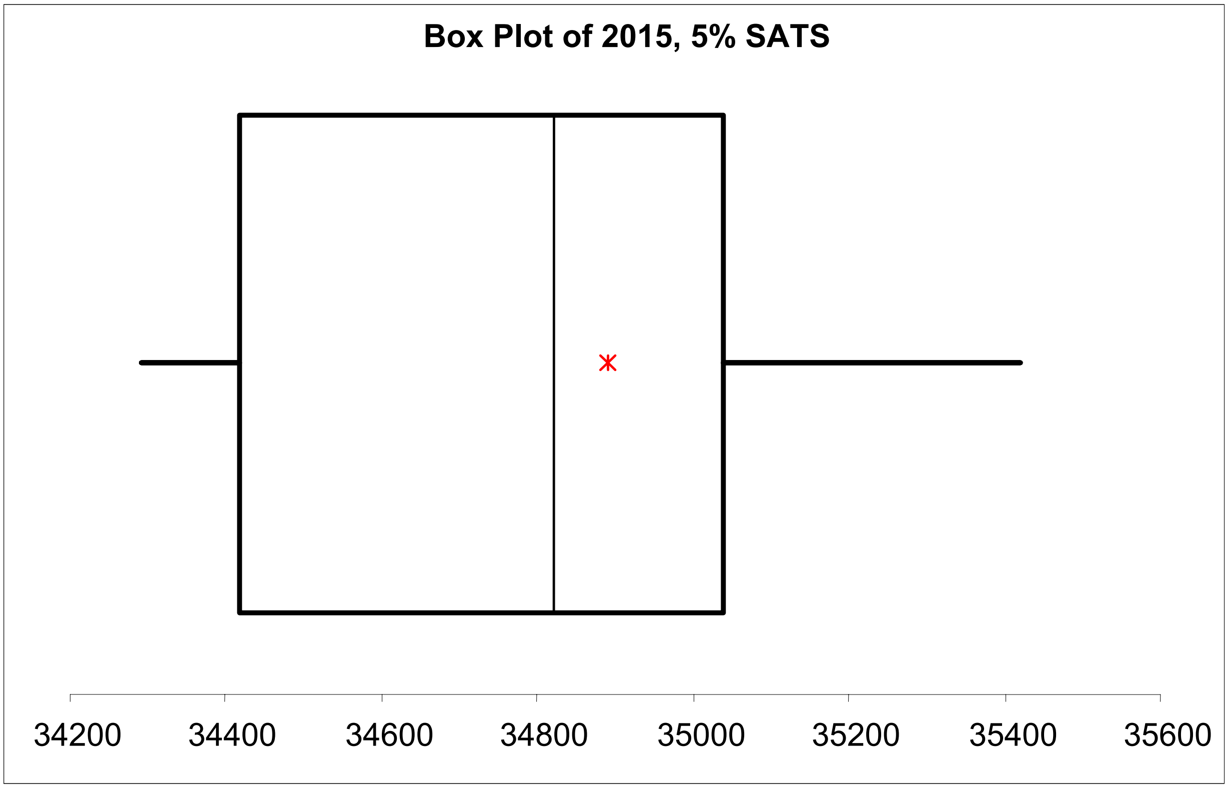


Figure 4.23: Box-and-Whisker Plot: November 12, 2015 Traffic with 5% SATS Flights

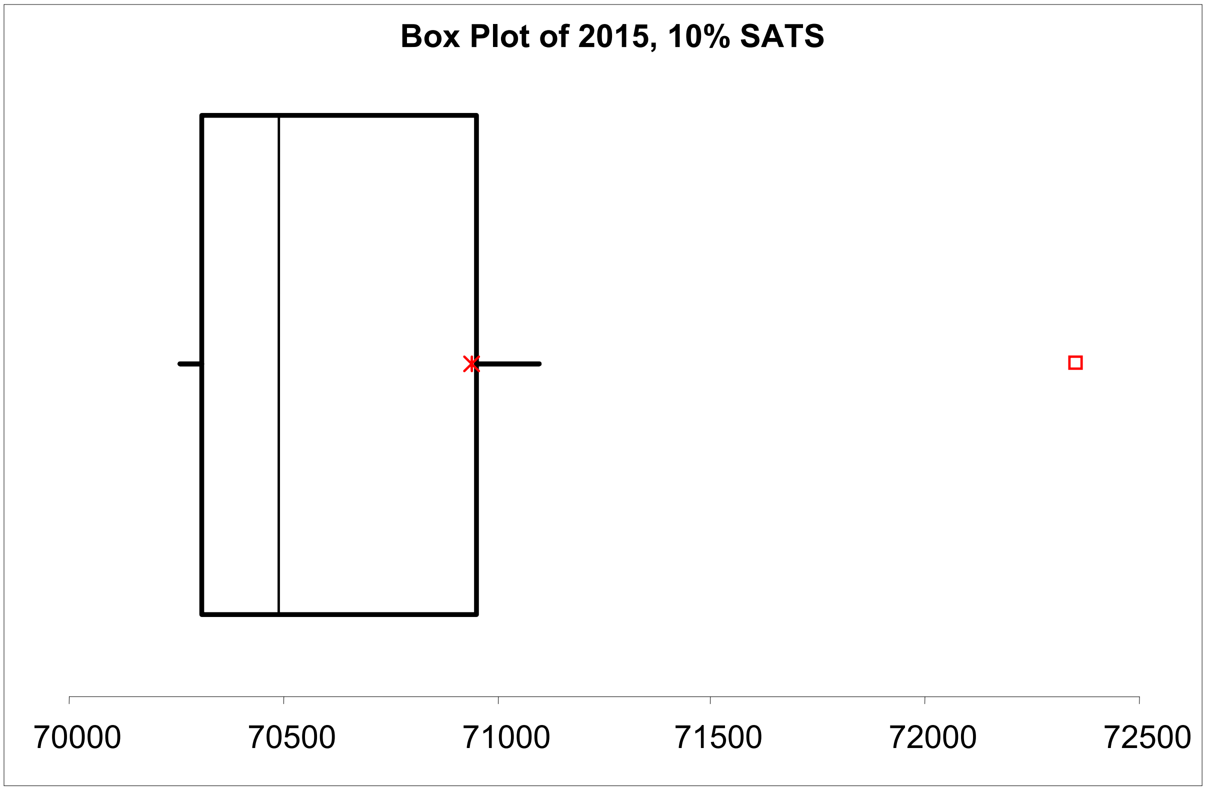


Figure 4.24: Box-and-Whisker Plot: November 12, 2015 Traffic with 5% SATS Flights

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Chapter 5

Conclusion

5.1 Summary

This thesis provides a sound framework by which to both quantitatively and qualitatively assess the inherent safety of our nation's airspace – both with current commercial aircraft and with the introduction of SATS. The methodology presented here provides the means by which a highly complex dynamic such as SATS can be studied at both the micro- and macroscopic levels. That is the value of this research and one of its contributions to the body of knowledge on SATS and future airspace modeling and simulation efforts. This thesis uses the concept of free flight and how this idea applies to the Small Aircraft Transportation System (SATS). In this research, the SATS program headed by NASA Langley Research Center and the FAA was examined thoroughly in order to gain insights into the selection process for SATS-compliant airports from the large pool of currently underutilized airports and other landing facilities. I found that the general process to designate SATS airports for study in Virginia is not unlike the process I used to create the Virginia SATS test bed and corresponding simulation model. Virginia is a rather large, diverse state. Selecting SATS airports, especially at the very early stages of SATS development, is very important. It helps get a SATS foothold in the various regions, but it is also provides the means air travel customers may learn about SATS and rally behind it as a desired service that certainly has a place in the future of this country. The decision was made to use the Commonwealth of Virginia as a test bed to model SATS networks.

I developed some basic socio-economic criteria as a means by which to substantiate the need for SATS across the Commonwealth. Among these was the use Average Per Capita Income as a metric by which to establish the basis for SATS' economic viability in a certain area. I populated these criteria with real data, and they were used to identify potential, future SATS airports within Virginia and the surrounding region. I also established a more general term that undoubtedly has applicability to this and other, future studies – that is, establishing the criterion of "Strategic Geographic Significance. The concept of the *SATS cluster* was introduced into the vernacular by the author and used to construct the SATS network model. Laws and policies were adopted to develop a realistic model that complements the current NAS.

TAAM Plus was chosen as the simulation tool to be utilized, and the Virginia SATS network was constructed in the software. The most current FAA data available were gathered, parsed, and used to create realistic air traffic densities for current and future scenarios. For airports in the SATS clusters for which CODAS data were available, creation of surrogate SATS flights based on commercial traffic flying on November 12, was straightforward. For smaller airports in the clusters for which explicit SATS data were not available, a methodology to create a hybrid SATS airport based on aggregation of surrounding airports was developed and employed.

The simulation was tailored to reflect a complete peak morning travel period on a standard day for which detailed flight data were available. A comprehensive simulation strategy was developed, to include number of runs and scenario characteristics. A key decision was made to use *mean blind conflicts* as the primary metric for the study. This was done to create an unbiased baseline conflict level, paving the way for the future introduction of the full range of conflict resolution strategies into the simulation. Conflict and aircraft data were collected for the various sectors built into the model. Intuitively the number of midair conflicts should increase as the number of aircraft in the constrained volume of airspace increases. This study shows that the number of blind conflicts will increase as air traffic volumes in the AOI increase. It was shown that blind conflicts will generally increase by a factor of between 3 and 4 if SATS achieves 5%

market penetration. Overall, SATS can be expected to directly affect an overall increase in the number of blind conflicts by a factor of between 6.5 and 8 as SATS matures to a 10% market share. This level of blind conflicts was nearly double what was anticipated. Figure 5.1 shows the factors of increase from the baseline case up to and including a 10% SATS market share. It is clear that blind conflicts in the year 2000 continue to change at a lesser rate than the years 2010 and 2015. In 2015, the incidence of blind conflicts continues to increase at a high rate and

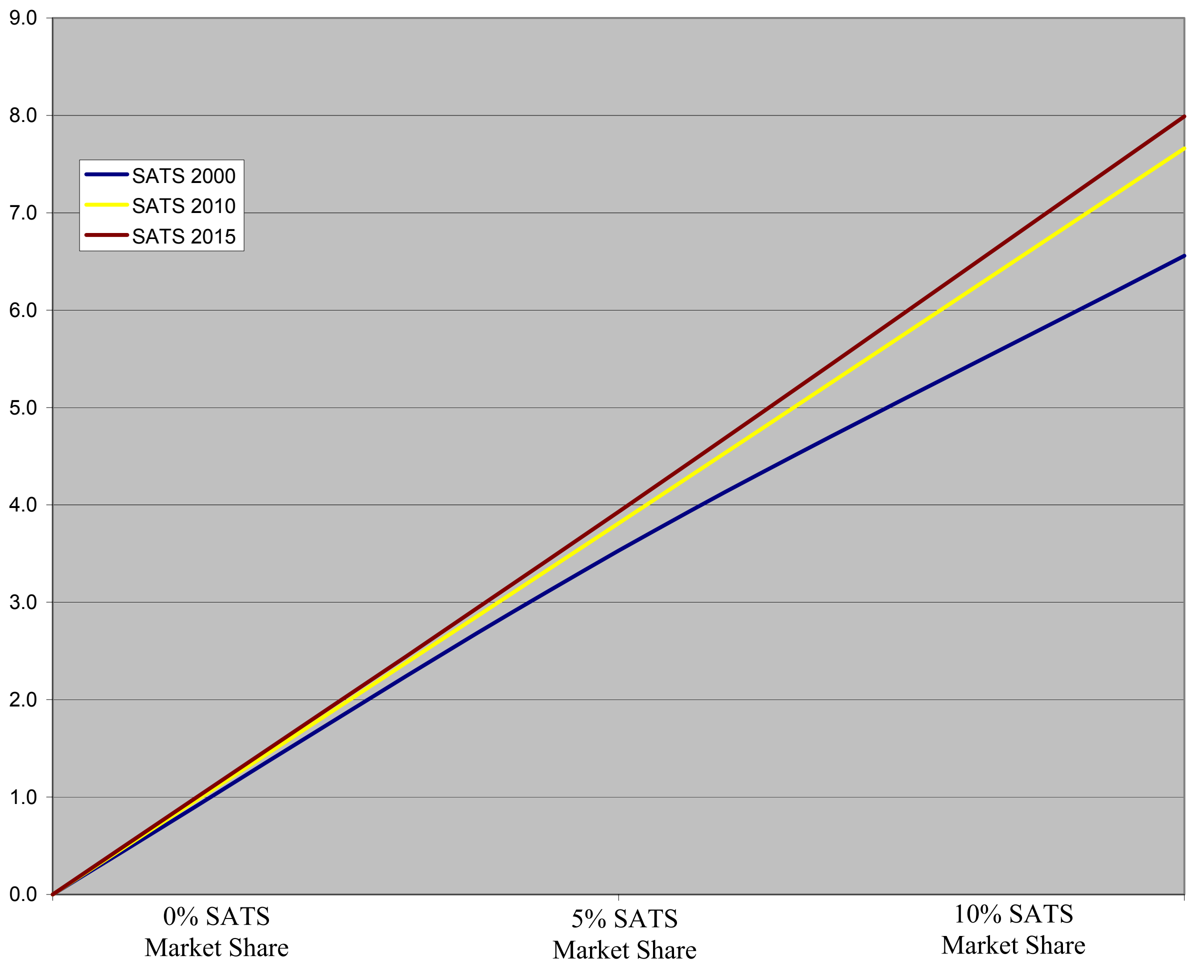

Figure 5.1: Factors of Increase: Blind Conflicts of Proximate Aircraft Pairs

doesn't seem to retard at all. The generally held expectation is that the number of conflicts will increase by 1.5 to 2 times the baseline case with current air traffic volumes and no SATS flights represented. If the SATS program gains traction and exceeds the proposed 10% level, the effects will be even more pronounced.

In terms of the relationship between conflicts and the number of aircraft in flight, applicable ratios were determined. It was found that, in the baseline case (0% SATS), there would be between 0.6 and 0.7 conflicts per aircraft. In the 5% SATS case, the model produced between 1.4 and 1.6 conflicts per aircraft. With 10% market penetration, this figure can be expected to further increase to between 2 and 2.5 conflicts per aircraft. These figures hold true for November 12 in the years 2000, 2010 and 2015. However, this methodology is valid for a much wider range of days with consistent air traffic.

Finally, parametric conflict curves were created for the three SATS scenarios – 2000, 2010 and 2015. The graphs depicted three parametric curves – one each for conflicts with 1 NM separation distance or less, 1 NM - 2.5 NMs separation, and out to 5 NMs. In many cases, I determined that there was room for both increased SATS traffic beyond the levels simulated as well as the potential to reduce the current required separation standard of 5 NMs. For the CY2000 scenario, I determined that it was possible to reduce the separation standard to 1 NM for both the 0% and 5% SATS cases; for 10% SATS, I asserted that the required separation distance might be halved to 2.5 NMs. For 2010, I once again asserted that the standard could be reduced to 1 NM for both the 0% baseline and 5% SATS market share. Slight increases in traffic levels may be possible at the 10% market share, but that is all. For 2015, the separation standard could be reduced to 1 NM at the 0% SATS level and 2.5 NM for 5% SATS. There is no room for marked change at the 10% SATS level in 2015 due to the already large number of conflicts.

From this research, I conclude that SATS is indeed viable despite larger than anticipated increases in the number of blind conflicts encountered in the simulation. The metrics I am calling on for this conclusion are the number of conflicts per square (nautical) mile for each of the scenarios as well as the ratio of conflicts per aircraft. In the case of conflicts per square mile, the Virginia sector in the simulation model always had the most conflicts without exception. Expect that this is due to the large number of SATS clusters and associated SATS-compliant airports within the Commonwealth of Virginia. So, there is undoubtedly room for optimization of the SATS network developed in the research, and particular emphasis should be placed on Virginia as the dominant portion of this SATS model. In order to safely implement SATS, it is highly likely that required separation standards be reduced to accommodate the substantial increase in air traffic volumes that will accompany SATS. Arguably, the biggest part of SATS are its enablers, the foremost of which is the general set of emerging technologies that will revolutionize SATS vehicles and airports, alike. The promise and potential of these programs makes me very optimistic that SATS can and will become a reality someday.

5.2 Future Research

The opportunities for future SATS research are vast. In the context of this thesis, there are several measures that should be taken in order to fully exploit the methodology developed herein. First and foremost is the conduct of additional simulation runs. Simulation runs using TAAM Plus with the heavy air traffic volumes inherent to this research were very time intensive. However, the research method is sound and can only benefit from more refined input data. Application of Transportation System Analysis Model (TSAM) to accomplish trip assignment, trip distribution, and modal split for larger SATS simulations across the country would add even greater accuracy to the simulation effort. Using a greater subset of the 3,415 airports on which TSAM has been employed would also be useful.

The prospect of enabling and varying conflict resolution strategies for collision avoidance is fascinating and should be explored. Automated collision avoidance procedures could be explored; those are procedures where the aircraft may initiate evasive maneuvers for the pilot or actually execute the entire maneuver on its own. A stochastic method may also be employed to model human pilot responses to sudden airborne conflict warnings. In this case, different pilots will execute a large variety of maneuvers – some are more sound and safer than others. Of particular interest might be the effects that these measures will have on subsequent conflicts. In these type scenarios – where one or both aircraft in a proximate pair execute evasive maneuvers to maintain adequate separation – a "ripple effect" might be expected whereby second, third, and *n*-order conflicts occur as a result. Will conflicts indeed decrease, as one might expect, given the nature of collision avoidance measures? Or will these procedures in fact increase the frequency and length of in-flight delays, as well as the incidence of midair conflicts? The nation's airspace is a classic cause-and-effect system in practice. It is highly unlikely that a flight that is vectored away from a potential conflict by ATC will not impact any other flights at all. At peak hours in some of the nation's busiest airports, the effects may be substantial.

The SATS network should be expanded, to include several states or cooperatives. The methodology in this thesis may be applied to each of these statewide SATS networks.

Additionally, these states may be linked together to model an integrated SATS *region* of the United States. The optimal end state should be a comprehensive simulation model that replicates nationwide SATS implementation fully integrated into NAS. Modeling and simulation methods are a tested means by which to create realistic data in a benign, safe environment. That is why they will invariably become critical tools at the center of SATS feasibility studies and operational concept validation. Several facets of this model would have to be tailored or expanded, depending on the characteristics and size of the SATS network to be modeled. Computer processing power will also have to be expanded beyond its current capacity, particularly if TAAM Plus is utilized in such a large-scale simulation. TAAM Plus has proven to be a very flexible tool by which to accomplish airspace simulation. Should TAAM or similar software be used to model the future NAS, we – the FAA, NASA, commercial airlines and freight carriers, as well as academia – will collectively be better postured for long term success if we develop institutional knowledge and proficiency in the application of this and other specialized tools now.

In terms of new research directions, again, the opportunities are vast. There is much room for discrete optimization methods and applications. Entities in a SATS model that might be optimized are fairly obvious. A given optimization problem may seek to minimize the number of conflicts and/or the length of enroute delays. One may also seek to maximize the distance between aircraft proximate pairs. A potential optimization problem may have a multi-goal objective function, as well as numerous constraints that allow the airspace to be utilized fully but not to unsafe levels. In the future, it may be wise to start examining the reduction of required separation minima under instrument flight rules. As airborne technologies improve, this may be both possible and warranted in order to expand air traffic densities in the same constrained volume of airspace. There are numerous other potential applications. Airspace sectors may be targeted for improved performance. Non-linear optimization tools may be employed to maximize the number of aircraft inside a convex region while simultaneously minimizing the number of conflicts. All of these situations are subject to constraints, of course. Genetic algorithms and neural networks may also be suited to SATS network performance applications. Other areas which the author has already begun exploring as a means of defining and optimizing performance of SATS clusters are Graph Theory and the application of a Mixed Integer Linear

Programming model. These methods served as the foundation for two senior capstone courses taught by the author to cadets enrolled in MA491, Research Seminar in Applied Mathematics, at the United States Military Academy at West Point. These and many other potential research directions should be explored to determine if they have merit.

Due to numerous factors, including advances in avionics, weather forecasting, navigation and propulsion systems, *free flight* will likely be realized as a prevalent flight profile in NAS during this century. Commercial air carriers, in conjunction with the FAA, are already testing this concept operationally. Though in its infancy, free flight will be a concept that continues to be expanded and improved, both out of necessity and convenience. The airspace in this country and around the world continues to become increasingly crowded. This is fact is particularly poignant in Europe.

Commercial airlines are constantly looking for ways to maximize their profit margins by reducing operating costs. Two points that continue to drive the airlines are the fact that many American commercial carriers are in various stages of Chapter 11 bankruptcy proceedings. Additionally, the strong emergence of tier 2 airlines such as Southwest Airlines, Air Tran and others continue to compete formidably in the consumer marketplace. And the air traveler is always looking for a more convenient, expeditious and economical way to fly from point A to point B. With respect to the consumer, SATS is a concept that simply makes practical sense. If this concept becomes proven with the advent of advanced technologies – and becomes affordable – for the masses, then SATS may eventually become a viable air travel alternative. The accompanying reality is the huge increase in number of airborne vehicles – albeit "smart" ones – that will simultaneously operate in the NAS. This research shows that there are risks inherent to further saturation of the already crowded airspace over the United States. But this may ultimately be the price that we, as a society, must be prepared to pay in order to globally bridge to the daily means of travel made famous in the 1962 introduction of "The Jetsons" animated series. Highways-in-the-sky and smart air vehicles are in our future, to be sure. SATS may be the first step in getting us there.

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Appendix A

Source Code:
Pre-processor Main Module

```
% This Program
%
%   1) reads the ETMS (Enhancement Traffic Management System) data
%   2) creates both flight and passenger OD tables for VA, and
%   3) create three data files for TAAM: WPT, RTS, and ACF.
%


function flightDataEtms = OD_ETMS_3(fileName)

%-----------------------------------------------
% Parameters
%-----------------------------------------------
loadFactor        = .70;
maxSatsFlightDist = 1000; %miles
maxGaFlightDist   = 1000; %miles


avgOccupancyGA    = 2;
avgOccupancySats  = 2.5;

maxNumAirports    = 200;
satsPercentFromAC = 0.1;
radiusForSmallAirport = 30; %miles

percentHubHub = .1; % breaking rule of the hub->hub SATS demand
percentHubSml = .15;
percentSmlHub = .15;
percentSmlSml = .6;

stdDevETD     = 30; %min
%-----------------------------------------------
% Variable initalization
%-----------------------------------------------
global totNum totRoute
totEtmsFlights   = 0;
totRoute         = 0;
totSatsFlights   = 0;
totGaFlights     = 0;
totNum           = 0;
totRoute         = 0;
vaFlights        = 0;

% Initialize all O/D matrix
odPassengers     = zeros(maxNumAirports, maxNumAirports);
odFlights        = zeros(maxNumAirports, maxNumAirports);
odPassengersGap  = zeros(maxNumAirports, maxNumAirports);
odFlightsGap     = zeros(maxNumAirports, maxNumAirports);
odPassengersSats = zeros(maxNumAirports, maxNumAirports);
odFlightsSats    = zeros(maxNumAirports, maxNumAirports);
dist             = zeros(maxNumAirports, maxNumAirports);


%-----------------------------------------------
% Files
%-----------------------------------------------
odFile = fopen('OD.out','w')
```

```
wayPointsFile = fopen('SATS.WPT','w');
routeFile     = fopen('SATS.RTS','w');
timeStampFile = fopen('SATS.ACF','w');


fprintf(timeStampFile,'## WAYPOINT files used: [usa_all.WPT]\n');
fprintf(timeStampFile,'## AIRPORT files used: [master.APT]\n');
fprintf(timeStampFile,'## ROUTE files used: [NY_all_routes3.RTS]\n');
fprintf(timeStampFile,'#       File format for timetable is :\n');
fprintf(timeStampFile,'#       Fl_no Type MkSeg Rt Alt Etd Eta P/Rnav Ads &
Haul\n');
fprintf(timeStampFile,'#       @SID runway  SID_number\n');
fprintf(timeStampFile,'#       @STAR runway  STAR_number\n');
fprintf(timeStampFile,'#       @R Route name\n');
fprintf(timeStampFile,'#       @P Airway name  Start point  End point\n');
fprintf(timeStampFile,'#       @W Waypoint Name\n');
fprintf(timeStampFile,'#       @A Airport Name\n');
fprintf(timeStampFile,'#       @LL Latitude Longitude\n');
fprintf(timeStampFile,'#       Point Lat Long alt IFR/VFR P/Rnav_Offset
left/right\n');
fprintf(timeStampFile,'#       0 => No or Left or VFR \n');
fprintf(timeStampFile,'#       1 => Yes or Right or IFR \n');
fprintf(timeStampFile,'#       Any field with ? means that field is not
set\n');
fprintf(timeStampFile,'#       Field with ? will then be set by the
system\n\n\n');



%-----------------------------------------------
% Program Begin
%-----------------------------------------------
%Airports Information
vaAirports = strvcat('DCA', 'GAI', 'HEF', 'IAD', 'JYO', 'W32', 'BWI', 'FDK',
'MTN', 'W54', 'MRB', ...
                              'HGR', 'OKV', 'FCI', 'OFP', 'PTB', 'RIC', 'BCB',
'PSK', 'ROA', 'LYH', 'FVX', ...
                     'CPK', 'ORF', 'PHF', 'PVG', '0A9', 'TRI', 'VJI', 'GSO',
'INT', 'DAN', 'MTV', ...
                              'BUY', 'CHO', 'SHD', 'RDU', 'AVC', 'HNZ', 'TDF',
'2N9', 'LWB', 'BKW', 'BLF'); % concaternate vertically

allAirports   = vaAirports;
numVaAirports = size(vaAirports, 1);

%-----------------------------------
%Hub-small airports Information
%-----------------------------------
hubAirports(1).hub  = 'DCA'; hubAirports(1).smallName  = strvcat('GAI', 'HEF',
'JYO', 'W32');
hubAirports(2).hub  = 'IAD'; hubAirports(2).smallName  = strvcat('GAI', 'HEF',
'JYO', 'W32');
hubAirports(3).hub  = 'BWI'; hubAirports(3).smallName  = strvcat('FDK', 'MTN',
'W54');
hubAirports(4).hub  = 'MRB'; hubAirports(4).smallName  = strvcat('HGR',
'OKV');
```

```
hubAirports(5).hub  = 'RIC'; hubAirports(5).smallName  = strvcat('FCI', 'OFP',
'PTB');
hubAirports(6).hub  = 'ROA'; hubAirports(6).smallName  = strvcat('BCB',
'PSK');
hubAirports(7).hub  = 'LYH'; hubAirports(7).smallName  = strvcat('FVX');
hubAirports(8).hub  = 'ORF'; hubAirports(8).smallName  = strvcat('CPK');
hubAirports(9).hub  = 'PHF'; hubAirports(9).smallName  = strvcat('PVG');
hubAirports(10).hub = 'TRI'; hubAirports(10).smallName = strvcat('0A9',
'VJI');
hubAirports(11).hub = 'GSO'; hubAirports(11).smallName = strvcat('BUY', 'DAN',
'INT', 'MTV');
hubAirports(12).hub = 'CHO'; hubAirports(12).smallName = strvcat('SHD');
hubAirports(13).hub = 'LWB'; hubAirports(10).smallName = strvcat('BKW',
'BLF');
hubAirports(14).hub = 'RDU'; hubAirports(10).smallName = strvcat('2N9', 'AVC',
'HNZ', 'TDF');

for i = 1:size(hubAirports, 2)
   vaHubAirports = strvcat(vaHubAirports, hubAirports(i).hub);
   for j = 1 : size(hubAirports(i).smallName, 1)
      hubAirports(i).smallIndex(j) = strmatch(hubAirports(i).smallName(j,1:3),
vaAirports); % ex, index for GAI = 2 in vaAirports
   end
end

%------------------------------
%aircraft type information
%------------------------------
aircraftType  = strvcat('C26', 'C310', 'AT42', 'BA14', 'D328', 'EA32', 'B757',
'B767', 'B747');
aircraftSeats =         [10,    20,     30,     40,     50,     60,     70,
80,     90];

aircraftSubstitution(1).main = 'B767';  aircraftSubstitution(1).sub =
strvcat('B757', '', '', '');
aircraftSubstitution(2).main = '';  aircraftSubstitution(2).sub = strvcat('',
'', '', '');
aircraftSubstitution(3).main = '';  aircraftSubstitution(3).sub = strvcat('',
'', '', '');
aircraftSubstitution(4).main = '';  aircraftSubstitution(4).sub = strvcat('',
'', '', '');
aircraftSubstitution(5).main = '';  aircraftSubstitution(5).sub = strvcat('',
'', '', '');
aircraftSubstitution(6).main = '';  aircraftSubstitution(6).sub = strvcat('',
'', '', '');


satsAircraftType   = strvcat('C182', 'C185', 'C310', 'C500');
satsAircraftMinAlt =         [3000    3000   15000   15000];
satsAircraftMaxAlt =         [16000   18000  41000   41000];

gaAircraftType   = strvcat('C150', 'C172', 'C182', 'PA24', 'PA28', 'PA30',
'PA31', 'PA34');
gaAircraftMinAlt =         [3000    3000    3000    3000    3000    3000
3000    3000];
gaAircraftMaxAlt =         [12000   15000   12000   16000   13000   15000
25000   25000];
```

```
%------------------------------------------------------------------------
% daily departures & arrivals for GA (from Terminal Area Forecast, TAF)
%------------------------------------------------------------------------
dailyOriginsTAF(1)  =  20; dailyDestinsTAF(1)   = 21;%'DCA'
dailyOriginsTAF(2)  =  13; dailyDestinsTAF(2)   = 14;%'GAI'
dailyOriginsTAF(3)  =  33; dailyDestinsTAF(3)   = 33;%'HEF'
dailyOriginsTAF(4)  =  23; dailyDestinsTAF(4)   = 23;%'IAD'
dailyOriginsTAF(5)  =   2; dailyDestinsTAF(5)   =  2;%'JYO'
dailyOriginsTAF(6)  =   0; dailyDestinsTAF(6)   =  1;%'W32'

dailyOriginsTAF(7)  = 100; dailyDestinsTAF(7)   = 100;%'BWI'
dailyOriginsTAF(8)  =  10; dailyDestinsTAF(8)   = 100;%'FDK'
dailyOriginsTAF(9)  =  10; dailyDestinsTAF(9)   = 100;%'MTN'
dailyOriginsTAF(10) =  10; dailyDestinsTAF(10)  = 100;%'W54'

dailyOriginsTAF(11) =  10; dailyDestinsTAF(11)  = 100;%'MRB'
dailyOriginsTAF(12) =  10; dailyDestinsTAF(12)  = 100;%'MRB'
dailyOriginsTAF(13) =  10; dailyDestinsTAF(13)  =  10;%'OKV'

dailyOriginsTAF(14) =  10; dailyDestinsTAF(14)  =  10;%'FCI'
dailyOriginsTAF(15) =  10; dailyDestinsTAF(15)  =  10;%'OFP'
dailyOriginsTAF(16) =  10; dailyDestinsTAF(16)  =  10;%'PTB'
dailyOriginsTAF(17) = 100; dailyDestinsTAF(17)  = 100;%'RIC'

dailyOriginsTAF(18) =  10; dailyDestinsTAF(18)  =  10;%'BCB'
dailyOriginsTAF(19) =  10; dailyDestinsTAF(19)  =  10;%'PSK'
dailyOriginsTAF(20) = 100; dailyDestinsTAF(20)  = 100;%'ROA'

dailyOriginsTAF(21) =  10; dailyDestinsTAF(21)  =  10;%'FVX'
dailyOriginsTAF(22) =  10; dailyDestinsTAF(22)  =  10;%'LYH'

dailyOriginsTAF(23) =  10; dailyDestinsTAF(23)  =  10;%'CPK'
dailyOriginsTAF(24) =  10; dailyDestinsTAF(24)  =  10;%'ORF'
dailyOriginsTAF(25) =  10; dailyDestinsTAF(25)  =  10;%'PHF'
dailyOriginsTAF(26) =  10; dailyDestinsTAF(26)  =  10;%'PVG'

dailyOriginsTAF(27) =  10; dailyDestinsTAF(27)  =  10;%'0A9'
dailyOriginsTAF(28) =  10; dailyDestinsTAF(28)  =  10;%'TRI'
dailyOriginsTAF(29) =  10; dailyDestinsTAF(29)  =  10;%'VJI'

dailyOriginsTAF(30) =  10; dailyDestinsTAF(30)  =  10;%'BUY'
dailyOriginsTAF(31) =  10; dailyDestinsTAF(31)  =  10;%'DAN'
dailyOriginsTAF(32) =  10; dailyDestinsTAF(32)  =  10;%'GSO'
dailyOriginsTAF(33) =  10; dailyDestinsTAF(33)  =  10;%'INT'
dailyOriginsTAF(34) =  10; dailyDestinsTAF(34)  =  10;%'MTV'

dailyOriginsTAF(35) =  10; dailyDestinsTAF(35)  =  10;%'CHO'
dailyOriginsTAF(36) =  10; dailyDestinsTAF(36)  =  10;%'SHD'

dailyOriginsTAF(37) =  10; dailyDestinsTAF(37)  =  10;%'BKW'
dailyOriginsTAF(38) =  10; dailyDestinsTAF(38)  =  10;%'BLF'
dailyOriginsTAF(39) =  10; dailyDestinsTAF(39)  =  10;%'LWB'

dailyOriginsTAF(40) =  10; dailyDestinsTAF(40)  =  10;%'2N9'
dailyOriginsTAF(41) =  10; dailyDestinsTAF(41)  =  10;%'AVC'
dailyOriginsTAF(42) =  10; dailyDestinsTAF(42)  =  10;%'HNZ'
```

```
dailyOriginsTAF(43) =  10; dailyDestinsTAF(43)  =  10;%'RDU'
dailyOriginsTAF(44) =  10; dailyDestinsTAF(44)  =  10;%'TDF'


% read Lat, long data for 360 airports and save them into "airportsId",
"airportsLat", "airportsLong"
airportsFile = fopen('airportsLatLong.txt','r')
i = 0;
while(feof(airportsFile) == 0)
      i = i+ 1;
      airportId        = fscanf(airportsFile,'%s',1);

      airportLat_deg   = fscanf(airportsFile,'%s',1);
      airportLat_min   = fscanf(airportsFile,'%s',1);
      airportLat_sec   = fscanf(airportsFile,'%s',1);

      airportLong_deg  = fscanf(airportsFile,'%s',1);
      airportLong_min  = fscanf(airportsFile,'%s',1);
      airportLong_sec  = fscanf(airportsFile,'%s',1);

   if(airportId(1) == 'K')
      airportId = airportId(2:size(airportId,2)); % remove 'K'
   end

      airportsId   = strvcat(airportsId, airportId);

   if(airportLat_deg(1) == 'N') % positive
      airportsLat(i) = str2Num(airportLat_deg(2:3)) +
str2num(airportLat_min)/60 + str2num(airportLat_sec)/3600;
   else
      airportsLat(i) = -1.0 * (str2Num(airportLat_deg(2:3)) +
str2num(airportLat_min)/60 + str2num(airportLat_sec)/3600);
   end

   if(airportLat_deg(1) == 'E') % positive
      airportsLong(i) = str2Num(airportLong_deg(2:size(airportLong_deg,2))) +
str2num(airportLong_min)/60 + str2num(airportLong_sec)/3600;
   else
      airportsLong(i) = -1.0 *
(str2Num(airportLong_deg(2:size(airportLong_deg,2))) +
str2num(airportLong_min)/60 + str2num(airportLong_sec)/3600);
   end
end %while

fclose(airportsFile);


for i = 1: size(vaAirports,1) % find lat. and long. for VA airports
   aa = vaAirports(i,:);
   airportIndex      = strmatch(aa, airportsId);

   if(~isempty(airportIndex))
      allAirportsLat(i)  = airportsLat(airportIndex);
      allAirportsLong(i) = airportsLong(airportIndex);
   else
      pause;
   end
```

```
end


% aircraft type and seats

tic
f1 = fopen(fileName,'r')
f = 0;
fname=fscanf(f1,'%s',1);

while(feof(f1) == 0)

   % read ETMS data
   fname  = upper(fname);                move = fscanf(f1,'%s',1);     clear
move; % flight name
   fmodel = upper(fscanf(f1,'%s',1)); move = fscanf(f1,'%s',[1 2]); clear
move;
   origin = upper(fscanf(f1,'%s',1));
   dest   = upper(fscanf(f1,'%s',1));

  % orgIndex      = strmatch(origin, allAirports); %check this origin
airport is in VA
  % desIndex      = strmatch(dest,   allAirports); %check this destination
airport is in VA

   orgIndexVa    = strmatch(origin, vaAirports); %check this origin
airport is in VA
   desIndexVa    = strmatch(dest,   vaAirports); %check this destination
airport is in VA

   aircraftIndex = strmatch(fmodel, aircraftType);

   if(isempty(aircraftIndex)) % this aircraft type is not in our Lat/Long data
list
      aircraftType                = strvcat(aircraftType, fmodel);
      aircraftIndex               = size(aircraftType, 1);
      aircraftSeats(aircraftIndex) = 100;
%*****************************************************************
   end

if(~isempty(orgIndexVa) | ~isempty(desIndexVa)) % this etms flight is either
VA->VA, VA->others, or other->VA.
                                                  % then, generate SATS flights
if O-D distance is < maxSatsFlightDist (=1000 miles)

   % Read and Write TAAM data for this Virginian ETMS flight
            totEtmsFlights        = totEtmsFlights + 1;
            flightDataEtms.fname  = fname;
            flightDataEtms.fmodel = fmodel;
            flightDataEtms.origin = origin;
            flightDataEtms.dest   = dest;
            %move=fscanf(f1,'%s',[1 10]);
            %clear move;
            flightDataEtms.n      = fscanf(f1,'%d',1);    % number of way
points

      temp_wp           = zeros(flightDataEtms.n, 6);
```

```
      flightDataEtms.wp = zeros(flightDataEtms.n, 8); % initialize the way
points from ETMS data

            for(i = 1 : flightDataEtms.n)
                 move = fscanf(f1,'%s',1);
                 clear move;
                 temp_wp(i, 1:6) = fscanf(f1,'%f',[1 6]);
                    %temp_wp(i, 1) = latitude
                 %temp_wp(i, 2) = longitude
                 %temp_wp(i, 3) = altitude
                 %temp_wp(i, 4) = time (seconds)
              %temp_wp(i, 5) = unknown
                 %temp_wp(i, 6) = unknown
           end

            flightDataEtms.wp(:,7) = temp_wp(:, 3);% altitude
            flightDataEtms.wp(:,8) = temp_wp(:, 4);% time stamp

      %Convert lat. & long from decimal to degree
            temp_lat  = temp_wp(:,1);

            lat_degree = floor(temp_lat);
            lat_min    = floor( (temp_lat - lat_degree) .* 60 );
            lat_sec    = ((temp_lat - lat_degree) .* 60 - lat_min ) * 60;

            flightDataEtms.wp(:,1) = lat_degree;
            flightDataEtms.wp(:,2) = lat_min;
            flightDataEtms.wp(:,3) = lat_sec;

            temp_long  = temp_wp(:,2);

            long_degree = floor(temp_long);
            long_min    = floor( (temp_long - long_degree) .* 60 );
            long_sec    = ((temp_long - long_degree) .* 60 - long_min ) * 60;

            flightDataEtms.wp(:,4) = long_degree;
            flightDataEtms.wp(:,5) = long_min;
            flightDataEtms.wp(:,6) = long_sec;


      %flightDataEtms(f).wp(:,1:3) = temp_wp(:, 1:3);
            %flightDataEtms(f).twp(:,1) = temp_wp(:, 4);
            %clear temp_wp;

            %temp = flightDataEtms(f).wp(:, 1);
            %flightDataEtms(f).wp(:, 1) = -flightDataEtms(f).wp(:, 2);
            %flightDataEtms(f).wp(:, 2) = temp;
            %clear temp;

    printTaamData_1(routeFile, timeStampFile, wayPointsFile, flightDataEtms);


   % Update "odPassengers", "odFlights" and "airportAll".
   vaFlights  = vaFlights + 1;
   fprintf(odFile, '%d: %s->%s (%s) \n', vaFlights, origin, dest, fmodel);
```

```
   if(~isempty(orgIndexVa) & ~isempty(desIndexVa)) % this flight is VA airport
-> VA airport.

      orgAirportIndex = orgIndexVa;
      desAirportIndex = desIndexVa;
         orgVaHubAirportIndex = strmatch(origin, vaHubAirports);
         desVaHubAirportIndex = strmatch(dest,   vaHubAirports);

   elseif( isempty(orgIndexVa) & ~isempty(desIndexVa)) % this flight is a non-
VA airport -> VA airport.

      desAirportIndex = desIndexVa;
         orgVaHubAirportIndex = [];
         desVaHubAirportIndex = strmatch(dest,   vaHubAirports);

      airportIndex     = strmatch(origin, airportsId);
      orgAirportIndex  = strmatch(origin, allAirports); % we have this
airpotr's lat. and long data

      if(isempty(airportIndex)) % we have this airport's lat. and long data

         disp('this origin airport is not in the list');
         origin
         orgAirportIndex = [];

      else

         if(isempty(orgAirportIndex))% this is a new airport to "allAirports"

            allAirports                            = strvcat(allAirports,
origin);
               allAirportsLat(size(allAirports,1))  =
airportsLat(airportIndex);
               allAirportsLong(size(allAirports,1)) =
airportsLong(airportIndex);
            orgAirportIndex                                =
size(allAirports,1);

         end

      end


   else % this flight is a VA airport -> non-VA airport.

      orgAirportIndex      = orgIndexVa;
         orgVaHubAirportIndex = strmatch(origin, vaHubAirports);
         desVaHubAirportIndex = [];

      airportIndex        = strmatch(dest, airportsId);
      desAirportIndex     = strmatch(dest, allAirports);


      if(isempty(airportIndex))% we don't have this airpotr's lat. and long
data

         disp('this dest. airport is not in the list: ');
```

```
         dest
         desAirportIndex = [];

      else

         if(isempty(desAirportIndex)) % we don't have this airport in our all
airport list yet

            allAirports                                      =
strvcat(allAirports, dest); % detsination is one of existing other airoprts
            allAirportsLong(size(allAirports,1)) = airportsLong(airportIndex);
            allAirportsLat(size(allAirports,1))  = airportsLat(airportIndex);
            desAirportIndex                      = size(allAirports,1);

          end

      end
      %fprintf(odFile, '%d: %s->%s (%s) \n', vaFlights, origin, dest, fmodel);
   end % if(~isempty(orgIndexVa) & ~isempty(desIndexVa))

   %----------------------------------------------------------------------
   % update the etms flights & pax
   % create SATS demands & TAAM data file for SATS
   %----------------------------------------------------------------------
   if(~isempty(orgAirportIndex) & ~isempty(desAirportIndex))

      % update the etms flights & pax
      odFlights(orgAirportIndex, desAirportIndex)    =
odFlights(orgAirportIndex, desAirportIndex) + 1;
      pax                                            =
round(aircraftSeats(aircraftIndex) * loadFactor);
      odPassengers(orgAirportIndex, desAirportIndex) =
odPassengers(orgAirportIndex, desAirportIndex) + pax;

      % compute the distance between o-d pair
       orgAirportLatLong = [allAirportsLat(orgAirportIndex)
allAirportsLong(orgAirportIndex)];
       desAirportLatLong = [allAirportsLat(desAirportIndex)
allAirportsLong(desAirportIndex)];
       distOrgDest = round(calcDistance(orgAirportLatLong,
desAirportLatLong));


      % if the distance <= maxSatsFlightDist, then generate Sats fligths
       if(distOrgDest <= maxSatsFlightDist)

       %origin
       %allAirportsLong(orgAirportIndex)
       %dest
       %allAirportsLong(desAirportIndex)
       %distOrgDest

        % flight direction (E->W or W->E)
        if (allAirportsLong(orgAirportIndex) >
allAirportsLong(desAirportIndex))
            flightDirection = 'W';
        else
```

```
            flightDirection = 'E';
        end

        flightDataSats.n       = 2; % 2 waypoints

        if(~isempty(orgVaHubAirportIndex) & ~isempty(desVaHubAirportIndex)) %
VA Hub->VA Hub

           satsPaxHubHub = round(pax * satsPercentFromAC * percentHubHub);
           satsPaxHubSml = round(pax * satsPercentFromAC * percentHubSml);
           satsPaxSmlHub = round(pax * satsPercentFromAC * percentSmlHub);
           satsPaxSmlSml = round(pax * satsPercentFromAC * percentSmlSml);

           satsFltHubHub = ceil(satsPaxHubHub / avgOccupancySats);
           satsFltHubSml = ceil(satsPaxHubSml / avgOccupancySats);
           satsFltSmlHub = ceil(satsPaxSmlHub / avgOccupancySats);
           satsFltSmlSml = ceil(satsPaxSmlSml / avgOccupancySats);

           if(satsPaxHubHub > 0)
              %update SATS demands
              odPassengersSats(orgAirportIndex, desAirportIndex) ...
                             = odPassengersSats(orgAirportIndex,
desAirportIndex) + satsPaxHubHub/satsFltHubHub;
              odFlightsSats(orgAirportIndex, desAirportIndex) ...
                             = odFlightsSats(orgAirportIndex,
desAirportIndex) + 1;

              %update TAAM data
              orgAirportName = vaHubAirports(orgVaHubAirportIndex, 1:3);
              desAirportName = vaHubAirports(desVaHubAirportIndex, 1:3);

              for i = 1 : satsFltHubHub
                 %totRoute       = totRoute + 1;
% for route naming
                 etd            = randn * stdDevETD + flightDataEtms.wp(1,8);
%expected time for departure
                 eta            = etd + 60;
                 totSatsFlights = totSatsFlights + 1;

                 %generate & write TAAM data
                 flightDataNew        = generateFlightDataNew(orgAirportName,
desAirportName, orgAirportLatLong, desAirportLatLong, etd, eta);
                 flightDataNew.fname  = ['SATS', num2str(totSatsFlights)];
                 satsAircraftTypeIndex = ceil(rand * size(satsAircraftType,
1));
                 flightDataNew.fmodel  =
satsAircraftType(satsAircraftTypeIndex, :);

                 %(cruise alt.)
                    altGap            =
satsAircraftMaxAlt(satsAircraftTypeIndex) -
satsAircraftMinAlt(satsAircraftTypeIndex);
                 totNumAltGap      = floor(altGap / 2000);
                 distForEachAltGap = maxSatsFlightDist / totNumAltGap;
                 numAltGap         = ceil(distOrgDest / distForEachAltGap);

                 if(flightDirection == 'E') % assign odd thousand
```

```
                              cruiseAlt =
(satsAircraftMinAlt(satsAircraftTypeIndex) + 2000 * numAltGap) / 100;
                 else %(flightdiection == 'W') % assign even thousand
                              cruiseAlt =
(satsAircraftMinAlt(satsAircraftTypeIndex) + 1000 + 2000 * numAltGap) / 100;
                 end


                 printTaamData_2(routeFile, timeStampFile, wayPointsFile,
flightDataNew, cruiseAlt);

             end
           end % if(satsPaxHubHub > 0)

           if(satsPaxHubSml > 0)
              %update SATS demands

              %update TAAM data

               for i = 1 : satsFltHubSml
                 %totRoute       = totRoute + 1;
            % for route naming
                 orgAirportName = vaHubAirports(orgVaHubAirportIndex, 1:3);
                 totSatsFlights = totSatsFlights + 1;

                 j = ceil(rand *
size(hubAirports(desVaHubAirportIndex).smallIndex,2));  % index for small
airports around the hub airport
                 desAirportIndex =
hubAirports(desVaHubAirportIndex).smallIndex(j);
                 desAirportName  =
hubAirports(desVaHubAirportIndex).smallName(j, 1:3);

                    odPassengersSats(orgAirportIndex, desAirportIndex) ...
                            = odPassengersSats(orgAirportIndex,
desAirportIndex) + satsPaxHubSml/satsFltHubSml;
                 odFlightsSats(orgAirportIndex, desAirportIndex) ...
                         = odFlightsSats(orgAirportIndex, desAirportIndex) +
1;
                 etd      = randn * stdDevETD + flightDataEtms.wp(1,8);
%expected time for departure
                 eta            = etd + 60;

                 %generate & write TAAM data
                 flightDataNew = generateFlightDataNew(orgAirportName,
desAirportName, orgAirportLatLong, desAirportLatLong, etd, eta);
                 flightDataNew.fname = ['SATS', num2str(totSatsFlights)];
                 satsAircraftTypeIndex = ceil(rand * size(satsAircraftType,
1));
                 flightDataNew.fmodel  =
satsAircraftType(satsAircraftTypeIndex, :);

                 %(cruise alt.)
                    altGap             =
satsAircraftMaxAlt(satsAircraftTypeIndex) -
satsAircraftMinAlt(satsAircraftTypeIndex);
                 totNumAltGap      = floor(altGap / 2000);
```

```
                distForEachAltGap = maxSatsFlightDist / totNumAltGap;
                numAltGap         = ceil(distOrgDest / distForEachAltGap);

                if(flightDirection == 'E') % assign odd thousand
                              cruiseAlt =
(satsAircraftMinAlt(satsAircraftTypeIndex) + 2000 * numAltGap) / 100;
                else %(flightdiection == 'W') % assign even thousand
                              cruiseAlt =
(satsAircraftMinAlt(satsAircraftTypeIndex) + 1000 + 2000 * numAltGap) / 100;
                end


                printTaamData_2(routeFile, timeStampFile, wayPointsFile,
flightDataNew, cruiseAlt);
              end
          end % if(satsPaxHubHub > 0)

          if(satsPaxSmlHub > 0)
             %update SATS demands

             %update TAAM data

              for i = 1 : satsFltSmlHub
                %totRoute       = totRoute + 1;
           % for route naming
                desAirportName = vaHubAirports(desVaHubAirportIndex, 1:3);
                totSatsFlights = totSatsFlights + 1;

                j = ceil(rand *
size(hubAirports(orgVaHubAirportIndex).smallIndex,2));  % index for small
airports around the hub airport
                orgAirportIndex =
hubAirports(orgVaHubAirportIndex).smallIndex(j);
                orgAirportName  =
hubAirports(orgVaHubAirportIndex).smallName(j, 1:3);

                   odPassengersSats(orgAirportIndex, desAirportIndex) ...
                        = odPassengersSats(orgAirportIndex, desAirportIndex)
+ satsPaxSmlHub/satsFltSmlHub;
                odFlightsSats(orgAirportIndex, desAirportIndex) ...
                        = odFlightsSats(orgAirportIndex, desAirportIndex) +
1;
                etd      = randn * stdDevETD + flightDataEtms.wp(1,8);
%expected time for departure
                eta      = etd + 60;

                %generate & write TAAM data
                flightDataNew         = generateFlightDataNew(orgAirportName,
desAirportName, orgAirportLatLong, desAirportLatLong, etd, eta);
                flightDataNew.fname   = ['SATS', num2str(totSatsFlights)];
                satsAircraftTypeIndex = ceil(rand * size(satsAircraftType,
1));
                flightDataNew.fmodel  =
satsAircraftType(satsAircraftTypeIndex, :);

                %(cruise alt.)
```

```
                    altGap            =
satsAircraftMaxAlt(satsAircraftTypeIndex) -
satsAircraftMinAlt(satsAircraftTypeIndex);
                 totNumAltGap      = floor(altGap / 2000);
                 distForEachAltGap = maxSatsFlightDist / totNumAltGap;
                 numAltGap         = ceil(distOrgDest / distForEachAltGap);

                 if(flightDirection == 'E') % assign odd thousand
                               cruiseAlt =
(satsAircraftMinAlt(satsAircraftTypeIndex) + 2000 * numAltGap) / 100;
                 else %(flightdiection == 'W') % assign even thousand
                               cruiseAlt =
(satsAircraftMinAlt(satsAircraftTypeIndex) + 1000 + 2000 * numAltGap) / 100;
                 end


                 printTaamData_2(routeFile, timeStampFile, wayPointsFile,
flightDataNew, cruiseAlt);
               end
           end % if(satsPaxHubHub > 0)


            if(satsPaxSmlSml > 0)
              %update SATS demands

              %update TAAM data

               for i = 1 : satsFltSmlSml
                 %totRoute       = totRoute + 1;
            % for route naming
                 totSatsFlights = totSatsFlights + 1;

                 j = ceil(rand *
size(hubAirports(orgVaHubAirportIndex).smallIndex, 2));  % index for small
airports around the hub airport
                 orgAirportIndex =
hubAirports(orgVaHubAirportIndex).smallIndex(j);
                 orgAirportName  =
hubAirports(orgVaHubAirportIndex).smallName(j, 1:3);

                 j = ceil(rand *
size(hubAirports(desVaHubAirportIndex).smallIndex,2));  % index for small
airports around the hub airport
                 orgAirportIndex =
hubAirports(desVaHubAirportIndex).smallIndex(j);
                 orgAirportName  =
hubAirports(desVaHubAirportIndex).smallName(j, 1:3);

                    odPassengersSats(orgAirportIndex, desAirportIndex) ...
                            = odPassengersSats(orgAirportIndex,
desAirportIndex) + satsPaxSmlSml/satsFltSmlSml;
                 odFlightsSats(orgAirportIndex, desAirportIndex) ...
                         = odFlightsSats(orgAirportIndex, desAirportIndex) +
1;
                 etd      = randn * stdDevETD + flightDataEtms.wp(1,8);
%expected time for departure
                 eta      = etd + 60;
```

```
                 %generate & write TAAM data
                 flightDataNew       = generateFlightDataNew(orgAirportName,
desAirportName, orgAirportLatLong, desAirportLatLong, etd, eta);
                 flightDataNew.fname  = ['SATS', num2str(totSatsFlights)];
                 satsAircraftTypeIndex = ceil(rand * size(satsAircraftType,
1));
                 flightDataNew.fmodel  =
satsAircraftType(satsAircraftTypeIndex, :);

                 %(cruise alt.)
                    altGap            =
satsAircraftMaxAlt(satsAircraftTypeIndex) -
satsAircraftMinAlt(satsAircraftTypeIndex);
                 totNumAltGap      = floor(altGap / 2000);
                 distForEachAltGap = maxSatsFlightDist / totNumAltGap;
                 numAltGap         = ceil(distOrgDest / distForEachAltGap);

                 if(flightDirection == 'E') % assign odd thousand
                              cruiseAlt =
(satsAircraftMinAlt(satsAircraftTypeIndex) + 2000 * numAltGap) / 100;
                 else %(flightdiection == 'W') % assign even thousand
                              cruiseAlt =
(satsAircraftMinAlt(satsAircraftTypeIndex) + 1000 + 2000 * numAltGap) / 100;
                 end


                 printTaamData_2(routeFile, timeStampFile, wayPointsFile,
flightDataNew, cruiseAlt);
               end
           end % if(satsPaxHubHub > 0)



        elseif(isempty(orgVaHubAirportIndex) & ~isempty(desVaHubAirportIndex))
% non-VA Hub -> VA Hub

           satsPaxHubHub = round(pax * satsPercentFromAC * (percentHubHub +
percentSmlHub));
           satsPaxHubSml = round(pax * satsPercentFromAC * (percentHubSml +
percentSmlSml));
           totSatsPax    = satsPaxHubHub + satsPaxHubSml;

           satsFltHubHub = ceil(satsPaxHubHub / avgOccupancySats);
           satsFltHubSml = ceil(satsPaxHubSml / avgOccupancySats);
           totSatsFlt    = satsFltHubHub + satsFltHubSml;


           if(satsPaxHubHub > 0)
              %update SATS demands
              odPassengersSats(orgAirportIndex, desAirportIndex) ...
                            = odPassengersSats(orgAirportIndex,
desAirportIndex) + satsPaxHubHub/satsFltHubHub;
              odFlightsSats(orgAirportIndex, desAirportIndex) ...
                            = odFlightsSats(orgAirportIndex, desAirportIndex)
+ 1;
```

```
            %update TAAM data
            orgAirportName = origin;
            desAirportName = vaHubAirports(desVaHubAirportIndex, 1:3);


             for i = 1 : satsFltHubHub

               %totRoute             = totRoute + 1; % for route naming
               totSatsFlights       = totSatsFlights + 1;
                     flightDataNew.fname  = ['SATS',
num2str(totSatsFlights)];

               etd      = randn * stdDevETD + flightDataEtms.wp(1,8);
%expected time for departure
               eta      = etd + 60;

               %generate & write TAAM data
               flightDataNew = generateFlightDataNew(orgAirportName,
desAirportName, orgAirportLatLong, desAirportLatLong, etd, eta);
               flightDataNew.fname  = ['SATS', num2str(totSatsFlights)];
               satsAircraftTypeIndex = ceil(rand * size(satsAircraftType,
1));
               flightDataNew.fmodel  =
satsAircraftType(satsAircraftTypeIndex, :);

               %(cruise alt.)
                  altGap            =
satsAircraftMaxAlt(satsAircraftTypeIndex) -
satsAircraftMinAlt(satsAircraftTypeIndex);
               totNumAltGap      = floor(altGap / 2000);
               distForEachAltGap = maxSatsFlightDist / totNumAltGap;
               numAltGap         = ceil(distOrgDest / distForEachAltGap);

               if(flightDirection == 'E') % assign odd thousand
                            cruiseAlt =
(satsAircraftMinAlt(satsAircraftTypeIndex) + 2000 * numAltGap) / 100;
               else %(flightdiection == 'W') % assign even thousand
                            cruiseAlt =
(satsAircraftMinAlt(satsAircraftTypeIndex) + 1000 + 2000 * numAltGap) / 100;
               end


               printTaamData_2(routeFile, timeStampFile, wayPointsFile,
flightDataNew, cruiseAlt);

                end
         end % if(satsPaxHubHub > 0)

         if(satsPaxHubSml > 0)
            %update SATS demands

            %update TAAM data

             for i = 1 : satsFltHubSml
               %totRoute       = totRoute + 1;
            % for route naming
               orgAirportName = origin;
```

```
                    totSatsFlights = totSatsFlights + 1;

                j = ceil(rand *
size(hubAirports(desVaHubAirportIndex).smallIndex,2));  % index for small
airports around the hub airport
                desAirportIndex =
hubAirports(desVaHubAirportIndex).smallIndex(j);
                desAirportName  =
hubAirports(desVaHubAirportIndex).smallName(j, 1:3);

                    odPassengersSats(orgAirportIndex, desAirportIndex) ...
                            = odPassengersSats(orgAirportIndex,
desAirportIndex) + satsPaxHubSml / satsFltHubSml;
                odFlightsSats(orgAirportIndex, desAirportIndex) ...
                        = odFlightsSats(orgAirportIndex, desAirportIndex) +
1;
                etd      = randn * stdDevETD + flightDataEtms.wp(1,8);
%expected time for departure
                eta      = etd + 60;

                %generate & write TAAM data
                flightDataNew = generateFlightDataNew(orgAirportName,
desAirportName, orgAirportLatLong, desAirportLatLong, etd, eta);
                flightDataNew.fname  = ['SATS', num2str(totSatsFlights)];
                satsAircraftTypeIndex = ceil(rand * size(satsAircraftType,
1));
                flightDataNew.fmodel  =
satsAircraftType(satsAircraftTypeIndex, :);

                %(cruise alt.)
                    altGap             =
satsAircraftMaxAlt(satsAircraftTypeIndex) -
satsAircraftMinAlt(satsAircraftTypeIndex);
                totNumAltGap      = floor(altGap / 2000);
                distForEachAltGap = maxSatsFlightDist / totNumAltGap;
                numAltGap         = ceil(distOrgDest / distForEachAltGap);

                if(flightDirection == 'E') % assign odd thousand
                              cruiseAlt =
(satsAircraftMinAlt(satsAircraftTypeIndex) + 2000 * numAltGap) / 100;
                else %(flightdiection == 'W') % assign even thousand
                              cruiseAlt =
(satsAircraftMinAlt(satsAircraftTypeIndex) + 1000 + 2000 * numAltGap) / 100;
                end


                printTaamData_2(routeFile, timeStampFile, wayPointsFile,
flightDataNew, cruiseAlt);
                end
            end % if(satsPaxHubHub > 0)



        else % VA Hub -> non-VA Hub
```

```
            satsPaxHubHub = round(pax * satsPercentFromAC * (percentHubHub +
percentHubSml));
            satsPaxSmlHub = round(pax * satsPercentFromAC * (percentSmlHub +
percentSmlSml));

            satsFltHubHub = ceil(satsPaxHubHub / avgOccupancySats);
            satsFltSmlHub = ceil(satsPaxSmlHub / avgOccupancySats);
            totSatsFlt    = satsFltHubHub + satsFltSmlHub;

            if(satsPaxHubHub > 0)
               %update SATS demands
               odPassengersSats(orgAirportIndex, desAirportIndex) ...
                              = odPassengersSats(orgAirportIndex,
desAirportIndex) + satsPaxHubHub /satsFltHubHub;
               odFlightsSats(orgAirportIndex, desAirportIndex) ...
                              = odFlightsSats(orgAirportIndex,
desAirportIndex) + 1;

               %update TAAM data
               orgAirportName = vaHubAirports(orgVaHubAirportIndex, 1:3);
               desAirportName = dest;

               for i = 1 : satsFltHubHub
                     %totRoute = totRoute + 1; % for route naming
                  etd                  = randn * stdDevETD +
flightDataEtms.wp(1,8); %expected time for departure
                  eta      = etd + 60;
                  totSatsFlights       = totSatsFlights + 1;

                  %generate & write TAAM data
                  flightDataNew = generateFlightDataNew(orgAirportName,
desAirportName, orgAirportLatLong, desAirportLatLong, etd, eta);
                  flightDataNew.fname  = ['SATS', num2str(totSatsFlights)];
                  satsAircraftTypeIndex = ceil(rand * size(satsAircraftType,
1));
                  flightDataNew.fmodel  =
satsAircraftType(satsAircraftTypeIndex,:);

                  %(cruise alt.)
                     altGap            =
satsAircraftMaxAlt(satsAircraftTypeIndex) -
satsAircraftMinAlt(satsAircraftTypeIndex);
                  totNumAltGap      = floor(altGap / 2000);
                  distForEachAltGap = maxSatsFlightDist / totNumAltGap;
                  numAltGap         = ceil(distOrgDest / distForEachAltGap);

                  if(flightDirection == 'E') % assign odd thousand
                              cruiseAlt =
(satsAircraftMinAlt(satsAircraftTypeIndex) + 2000 * numAltGap) / 100;
                  else %(flightdiection == 'W') % assign even thousand
                              cruiseAlt =
(satsAircraftMinAlt(satsAircraftTypeIndex) + 1000 + 2000 * numAltGap) / 100;
                  end


                  printTaamData_2(routeFile, timeStampFile, wayPointsFile,
flightDataNew, cruiseAlt);
```

```
                end
            end % if(satsPaxHubHub > 0)


            if(satsPaxSmlHub > 0)
               %update SATS demands

               %update TAAM data

                for i = 1 : satsFltSmlHub
                  %totRoute = totRoute + 1;
      % for route naming
                  desAirportName = dest;
                     totSatsFlights       = totSatsFlights + 1;

                  j = ceil(rand *
size(hubAirports(orgVaHubAirportIndex).smallIndex,2));  % index for small
airports around the hub airport
                  orgAirportIndex =
hubAirports(orgVaHubAirportIndex).smallIndex(j);
                  orgAirportName  =
hubAirports(orgVaHubAirportIndex).smallName(j,1:3);

                     odPassengersSats(orgAirportIndex, desAirportIndex) ...
                             = odPassengersSats(orgAirportIndex,
desAirportIndex) + satsPaxSmlHub/satsFltSmlHub;
                  odFlightsSats(orgAirportIndex, desAirportIndex) ...
                           = odFlightsSats(orgAirportIndex, desAirportIndex) +
1;
                  etd      = randn * stdDevETD + flightDataEtms.wp(1,8);
%expected time for departure
                  eta      = etd + 60;

                  %generate & write TAAM data
                  flightDataNew = generateFlightDataNew(orgAirportName,
desAirportName, orgAirportLatLong, desAirportLatLong, etd, eta);
                  flightDataNew.fname  = ['SATS', num2str(totSatsFlights)];
                  satsAircraftTypeIndex = ceil(rand * size(satsAircraftType,
1));
                  flightDataNew.fmodel  =
satsAircraftType(satsAircraftTypeIndex, :);

                  %(cruise alt.)
                     altGap            =
satsAircraftMaxAlt(satsAircraftTypeIndex) -
satsAircraftMinAlt(satsAircraftTypeIndex);
                  totNumAltGap      = floor(altGap / 2000);
                  distForEachAltGap = maxSatsFlightDist / totNumAltGap;
                  numAltGap         = ceil(distOrgDest / distForEachAltGap);

                  if(flightDirection == 'E') % assign odd thousand
                              cruiseAlt =
(satsAircraftMinAlt(satsAircraftTypeIndex) + 2000 * numAltGap) / 100;
                  else %(flightdiection == 'W') % assign even thousand
                              cruiseAlt =
(satsAircraftMinAlt(satsAircraftTypeIndex) + 1000 + 2000 * numAltGap) / 100;
```

```
                 end


                 printTaamData_2(routeFile, timeStampFile, wayPointsFile,
flightDataNew, cruiseAlt);
               end
           end % if(satsPaxHubHub > 0)


        end % if(~isempty(orgVaHubAirportIndex) &
~isempty(desVaHubAirportIndex)) % VA Hub->VA Hub

     end % if(distOrigDest <= maxSatsFlightDist)

   end % if(~isempty(orgAirportIndex) & ~isempty(desAirportIndex))

else  % if(~isempty(orgIndexVa) | ~isempty(desIndexVa) i.e., this flight is
nothing to do with VA airports

      %move=fscanf(f1,'%s',[1 10]);
      %clear move;

      num = fscanf(f1,'%d',1); % total number of waypoints
      move = fscanf(f1,'%s',[1 num*7]);
      clear move;

end

  fname = fscanf(f1,'%s',1);

  if(vaFlights >= 100)
      break; %while
  end


end %end while


%-------------------------------------------------------------------
% Write some outputs (O-D table, Distance Table..)
%-------------------------------------------------------------------


%----------------------------------------------------
% Write ETMS O-D
%----------------------------------------------------
fprintf(odFile,'\n\n\n');

fprintf(odFile,' <FLT O-D from ETMS>\n ');
printOut(odFile, odFlights, allAirports);
fprintf(odFile,' <PAX O-D from ETMS>\n');
printOut(odFile, odPassengers, allAirports);


%----------------------------------------------------
% Write aircraft type and seats, Lat/Long
%----------------------------------------------------
```

```
fprintf(odFile,'<Aircraft type and seats>\n');
for  i = 1 : size(aircraftType, 1)
   fprintf(odFile,'%3d: %s %5d\n',i, aircraftType(i,:), aircraftSeats(i));
end

fprintf(odFile,'\n\n<Airport Lat. & Long.>\n');
for  i = 1 : size(allAirports, 1)
   fprintf(odFile,'%3d: %s %9.5d %9.5d\n',i, allAirports(i,:),
allAirportsLat(i), allAirportsLong(i));
end

%---------------------------------------------------
% Write distances table
%---------------------------------------------------
fprintf(odFile,'\n\n <Distance matrix, miles>\n');
fprintf(odFile,'         ');

for  i = 1 : size(allAirports, 1)
   fprintf(odFile,'%s ', allAirports(i,:));
end
fprintf(odFile,'tot \n');

for i = 1 : size(allAirports, 1)
   fprintf(odFile,'  %s ', allAirports(i,:));
   for j = 1 : size(allAirports, 1)
      orgAirportLatLong = [allAirportsLat(i) allAirportsLong(i)];
      desAirportLatLong = [allAirportsLat(j) allAirportsLong(j)];
      dist(i,j)   = round(calcDistance(orgAirportLatLong, desAirportLatLong));
      fprintf(odFile,'%5d', dist(i,j));
   end
   fprintf(odFile,'\n');
end
   fprintf(odFile,'\n\n\n');


%---------------------------------------------------
% Discrepancy O-D (=GA O-D table)
%---------------------------------------------------
% cummulative demand vs. time function
demandDist = [0.03 50; 0.07 100; 0.08 200; 0.09 300; 0.11 400; 0.12 500; 0.12
600; 0.11 700; 0.09 800; 0.08 900; 0.07 950; 0.03 1000]; %pdf
plot(demandDist(:,2), demandDist(:,1));
xlabel('Percentage of demand');
ylabel('Distance (mile)');
grid on;

cumDemandDist(:,2) = demandDist(:,2);
cumDemandDist(1,1) = demandDist(1,1); %cdf

for i = 2:size(demandDist,1)
   cumDemandDist(i,1) = cumDemandDist(i-1,1) + demandDist(i,1);%cdf
end

coeff_1            = polyfit(cumDemandDist(:,1),cumDemandDist(:,2),9);
cumDemandDist(:,3) = polyval(coeff_1, cumDemandDist(:,1));%estimated by
polyfit
```

```
plot(cumDemandDist(:,1),cumDemandDist(:,2),'b',cumDemandDist(:,1),cumDemandDis
t(:,3),'r');
xlabel('Percentage of demand');
ylabel('Distance (mile)');
grid on;

% adjust daily flights from ETMS to those from TAF using random numbers
% 1) for Oi's
for i = 1:size(vaAirports, 1)

   discrepancy = dailyOriginsTAF(i);% - sum(odFlights(i,:));% discrepancy =
TAF data - ETMS data
   for k = 1 : discrepancy
      fligthtDist = polyval(coeff_1, rand(1));

      %find the airport apart fligthtDist miles from this (i-th) airport
      minGap          = 99999;
      currGap         = 99999;
      theAirportIndex = 999;

      for j = 1: size(allAirports, 1)
         if(i~=j)
            currGap = abs(fligthtDist - dist(i,j));
            if(minGap > currGap)
               minGap          = currGap;
               theAirportIndex = j;
            end
         end
      end
      %fprintf(odFile, '%4d %4d %4d\n', round(fligthtDist), round(minGap),
theAirportIndex); %****************************************

      %increase the operations and pax.
      odFlightsGap(i,theAirportIndex)    = odFlightsGap(i,theAirportIndex) +
1;
      odPassengersGap(i,theAirportIndex) = odFlightsGap(i, theAirportIndex) *
avgOccupancyGA;
   end
      %fprintf(odFile, '-------------\n', round(fligthtDist), round(minGap),
theAirportIndex); %****************************************

end %for i = 1:size(vaAirports, 1)

fprintf(odFile,' <FLT O-D: Descrepancy (after adjust Oi)>\n  ');
printOut(odFile, odFlightsGap, allAirports);
fprintf(odFile,' <PAX O-D: Descrepancy (after adjust Oi)>\n');
printOut(odFile, odPassengersGap, allAirports);

% 2) for Dj's ---------------------------------------------------------------

for j = 1:size(vaAirports, 1)
   discrepancy = dailyOriginsTAF(j) - sum(odFlights(:,j)) -
sum(odFlightsGap(:,j));% discrepancy = TAF data - ETMS data
   for k = 1 : discrepancy
      fligthtDist = polyval(coeff_1, rand(1));

      %find the airport apart fligthtDist miles from this (i-th) airport
```

```
      minGap = 99999;
      for i = 1: size(allAirports, 1)
         if(j~=i)
            currGap = abs(fligthtDist - dist(i,j));
            if(minGap > currGap)
               minGap          = currGap;
               theAirportIndex = i;
            end
         end
      end

      %increase the operations and pax.
         odFlightsGap(theAirportIndex, j)    = odFlightsGap(theAirportIndex,
j) + 1;
      odPassengersGap(theAirportIndex, j) = odFlightsGap(theAirportIndex, j) *
avgOccupancyGA;
   end
end %for j = 1:size(vaAirports, 1)


fprintf(odFile,' <FLT O-D: Descrepancy (after adjust Dj)>\n ');
printOut(odFile, odFlightsGap, allAirports);
fprintf(odFile,' <PAX O-D: Descrepancy (after adjust Dj)>\n');
printOut(odFile, odPassengersGap, allAirports);


%---------------------------------------------------
% ADJUSTED Total O-D
%---------------------------------------------------
% add the odFligthsGap(i,j) to odFligths(i,j)
for i = 1:size(allAirports, 1)
   for j = 1:size(allAirports, 1)
         odFlights(i,j)    = odFlights(i,j)    + odFlightsGap(i,j);
         odPassengers(i,j) = odPassengers(i,j) + odPassengersGap(i,j);
   end
end

fprintf(odFile,' <FLT O-D: Total>\n ');
printOut(odFile, odFlights, allAirports);
fprintf(odFile,' <PAX O-D: Total>\n');
printOut(odFile, odPassengers, allAirports);


%---------------------------------------------------
% SATS O-D table
%---------------------------------------------------
% read Lat, long data for 360 airports and save them into "airportsId",
"airportsLat", "airportsLong"
numNonVaAirports = size(allAirports, 1) - numVaAirports; % assume that these
"NonVaAirports" are all hub-airports

%find small airports around these "NonVaAirports".
%for i = 1 : numNonVaAirports;
%   for j = 1 : size(airportsId, 1)
%      newAirportIndex = strmatch(airportsId(numVaAirports + i), airportsId);
%find the nonVaAirports in airportsId list
%
```

```
%      if(isempty(newAirportIndex))%
%       aaa = 999999
%     else
%        newAirport   = [allAirportsLat(newAirportIndex)
allAirportsLong(newAirportIndex)];
%         otherAirport = [allAirportsLat(j) allAirportsLong(j)];
%         dist         = round(calcDistance(orgAirportLatLong,
desAirportLatLong));
%         if(dist < radiusForSmallAirport) % radiusForSmallAirport = 30 miles,
for example
%        end
%     end
%   end
%end

fprintf(odFile,'%5d', dist(i,j));


fprintf(odFile,' <SATS Flights O-D>\n ');
printOut(odFile, odFlightsSats, allAirports);
fprintf(odFile,' <SATS Passenger O-D>\n');
printOut(odFile, odPassengersSats, allAirports);

fclose(odFile);

%-------------------------------------------------------------------
% generate TAAM data file for GA flights using "odFlightsGap" table
%-------------------------------------------------------------------
% cummulative demand vs. time function
demandTime    = [ 0.01 2; 0.01 4; 0.13 6; 0.15 8; 0.17 10; 0.17 12; 0.15 14;
0.13 16; 0.03 18; 0.02 20; .01 22; .01 24]; %pdf
demandTime(:,2) = demandTime(:,2) .* 60;
plot(demandTime(:,2), demandTime(:,1));
ylabel('Percentage of demand');
xlabel('Time (min)');
grid on;

cumDemandTime = zeros(size(demandTime,1) ,2);
cumDemandTime(1,1) = demandTime(1,1); %cdf
cumDemandTime(:,2) = demandTime(:,2);
for i = 2:size(demandTime,1)
   cumDemandTime(i,1) = cumDemandTime(i-1,1) + demandTime(i,1);%cdf
end

coeff= polyfit(cumDemandTime(:,1),cumDemandTime(:,2),9);
cumDemandTime(:,3) = polyval(coeff, cumDemandTime(:,1));%estimated by polyfit

plot(cumDemandTime(:,1),cumDemandTime(:,2),'b',cumDemandTime(:,1),cumDemandTim
e(:,3),'r');
xlabel('Percentage of demand');
ylabel('Time (min)');
axis([0 1 0 24*60]);
grid on;

for i = 1 : size(allAirports, 1)
   for j = 1 : size(allAirports, 1)
      if(odFlightsGap(i,j) > 0)
```

```
        for k = 1 : odFlightsGap(i,j)
              %totRoute          = totRoute + 1;
              totGaFlights      = totGaFlights + 1;

              etd      = polyval(coeff, rand(1));
              eta      = etd + 60;

              orgAirportName    = allAirports(i, 1:3);
              desAirportName    = allAirports(j, 1:3);
                 orgAirportLatLong = [allAirportsLat(i) allAirportsLong(i)];
              desAirportLatLong = [allAirportsLat(j) allAirportsLong(j)];
              distOrgDest       = dist(i,j);

                 % flight direction (E->W or W->E)
              if (allAirportsLong(i) > allAirportsLong(j))
                    flightDirection = 'W';
                 else
                 flightDirection = 'E';
                 end


              flightDataNew = generateFlightDataNew(orgAirportName,
desAirportName, orgAirportLatLong, desAirportLatLong, etd, eta);
              flightDataNew.fname  = ['GA', num2str(totGaFlights)];
              gaAircraftTypeIndex  = ceil(rand * size(gaAircraftType, 1));
              flightDataNew.fmodel = gaAircraftType(gaAircraftTypeIndex, :);



                %(cruise alt.)
                  altGap            = gaAircraftMaxAlt(gaAircraftTypeIndex)
- gaAircraftMinAlt(gaAircraftTypeIndex);
                totNumAltGap      = floor(altGap / 2000);
                distForEachAltGap = maxGaFlightDist / totNumAltGap;
                numAltGap         = ceil(distOrgDest / distForEachAltGap);

                if(flightDirection == 'E') % assign odd thousand
                            cruiseAlt =
(gaAircraftMinAlt(gaAircraftTypeIndex) + 2000 * numAltGap) / 100;
                else %(flightdiection == 'W') % assign even thousand
                            cruiseAlt =
(gaAircraftMinAlt(gaAircraftTypeIndex) + 1000 + 2000 * (numAltGap - 1)) / 100;
                end


                printTaamData_2(routeFile, timeStampFile, wayPointsFile,
flightDataNew, cruiseAlt);
        end

      end
   end
end


%-----------------------------------------------------------------------------
% File close
%-----------------------------------------------------------------------------
```

```
fclose(wayPointsFile);
fclose(routeFile);
fclose(timeStampFile);
fclose(f1);
toc
```

Appendix B

Source Code:
Pre-processor Submodules

% This file finds airports that are within 1000 miles of all airports in

% Virginia

```
Virginia_airports=['DCA GAI HEF IAD JYO BWI FDK MTN W54 MRB OKV FCI OFP PTB
                    RIC BCB PSK ROA LYH FVX CPK ORF PHF OA9 TRI VJI DAN MTV
                    CHO SHD'];

tic

dataFile = fopen('distTest.txt')
airportsFile = fopen('airportsIn1500','w');

totFlight = 0;

while(feof(dataFile)==0)

      totFlight  = totFlight + 1;


   % read data
   fname = fscanf(dataFile,'%s',1);             % flight name
      %move=fscanf(dataFile,'%s',1);   clear move;
   fmodel = fscanf(dataFile,'%s',1); % flight model
   %move=fscanf(dataFile,'%s',[1 2]);clear move;
      origin=fscanf(dataFile,'%s',1);
   dest=fscanf(dataFile,'%s',1);

      num = fscanf(dataFile,'%d',1); % number of way points
   Fp(totFlight).n = num;

   for(i = 1 : num)

                  %move = fscanf(dataFile,'%s',1);
                  %clear move;
         temp_wp(i, 1:3) = fscanf(dataFile,'%f',[1 3]);
         %temp_wp(i, 1) = longitude
         %temp_wp(i, 2) = latitude
         %temp_wp(i, 3) = altitude
      end

      check1 = length( findstr(origin,Virginia_airports));
      check2 = length( findstr(dest,Virginia_airports));
      check = check1 + check2;

      if(check > 0) % check if any of these two airports is in VA

      totFlight  = totFlight + 1;

            Fp(totFlight).fname  = fname;
            Fp(totFlight).fmodel = fmodel;
            Fp(totFlight).origin = origin;
            Fp(totFlight).dest  = dest;
```

```
      orgAirport  = [temp_wp(1, 2) -temp_wp(1, 1)];  % Lat/Long for
                                                     % origin airports
      destAirport = [temp_wp(num, 2) -temp_wp(num, 1)];% Lat/Long for
                                                       % destination airports

            distanceMile = calcDistance(orgAirport, destAirport);

            if(distanceMile > 1500) % mile
         % do nothing
            else
         fprintf(airportsFile,'%s -> %s: %s, %6.1f miles\n',origin, dest,
fmodel, distanceMile);
      end


      end %if

end % while

fclose(dataFile);
fclose(airportsFile);

toc
```

```
% Enter dummy data


city1=[2.580000e+01 8.028300e+01 ]; %MIA
city2=[3.885000e+01 7.703300e+01 ]; %DCA


    phi1 = city1(1) * pi / 180; % radian
    tht1 = (city1(2) + 135) * pi / 180 + pi / 4;
    [xp1,yp1,zp1] = sph2cart(tht1, phi1, 1);

    phi2 = city2(1) * pi / 180;
    tht2 = (city2(2) + 135) * pi / 180 + pi / 4;
    [xp2,yp2,zp2] = sph2cart(tht2, phi2, 1);


    out = cross([xp2 yp2 zp2], [xp1 yp1 zp1]);
    [tht3, phi3,r] = cart2sph(out(1), out(2), out(3));


    % Following calculation uses Napier's Spherical
    % Trigonometry Cosine Rule for Sides
    % Ref: VNR Encyclopedia of Mathematics


    angularDistCos = sin(phi1) * sin(phi2) + cos(phi1) * cos(phi2) * cos(tht1
                     - tht2);
    angularDist = acos(angularDistCos) * 180 / pi;

    % Earth radius in miles: 3963

    earthRadius = 3963;  % mile
    distance=(angularDist * pi / 180) * earthRadius


%    for count=1:2:angularDist,
%       rotate(h,[tht3*180/pi phi3*180/pi],-2,[0 0 0]);
%       drawnow;
%    end;
```

```
function distance = calcDistance(airport1, airport2)

%ex, airport1 = [25.2310 -80]; airport2 = [36 -85.1234]; [North(+)  West(-)];


    phi1 = airport1(1) * pi / 180; % radian
    tht1 = (airport1(2) + 135) * pi / 180 + pi / 4;
    [xp1,yp1,zp1] = sph2cart(tht1, phi1, 1);

    phi2 = airport2(1) * pi / 180;
    tht2 = (airport2(2) + 135) * pi / 180 + pi / 4;
    [xp2,yp2,zp2] = sph2cart(tht2, phi2, 1);


    out = cross([xp2 yp2 zp2], [xp1 yp1 zp1]);
    [tht3, phi3,r] = cart2sph(out(1), out(2), out(3));


    % Following calculation uses Napier's Spherical
    % Trigonometry Cosine Rule for Sides
    % Ref: VNR Encyclopedia of Mathematics


    angularDistCos = sin(phi1) * sin(phi2) + cos(phi1) * cos(phi2) * cos(tht1
                     - tht2);
    angularDist = acos(angularDistCos) * 180 / pi;

    % Earth radius in miles: 3963

    earthRadius = 3963;  % mile

    distance=(angularDist * pi / 180) * earthRadius;
```

```
function coordinateDegree = convertDecimal2Degree(coordinateDecimal)

coordinateDegree(1) = floor(coordinateDecimal); % degree

coordinateDegree(2) = floor((coordinateDecimal - coordinateDegree(1)) .* 60);
% min

coordinateDegree(3) = ((coordinateDecimal - coordinateDegree(1)) .* 60 -
coordinateDegree(2) ) * 60; % sec

return
```

```
% THIS FUNCTION READS THE ETMS DATA FROM THE INPUT FILE.

function Fp=O_D_acft(filename)

RLV_airports=['BWI KBWI DCA KDCA IAD KIAD ORF KORF PHF KPHF RIC KRIC, ...
              ROA KROA CHO KCHO HEF KHEF LYH KLYH MTN KMTN MRB KMRB, ...
              SHD KSHD TRI KTRI BCB KBCB DAN KDAN FCI KFCI FDK KFDK, ...
              GAI KGAI JYO KJYO W32 KW32 CPK KCPK OFP KOFP OKV KOKV, ...
              PTB KPTB PVG KPVG VJI KVJI W54 KW54 0A9 K0A9 FVX KFVX, ...
              MTV KMTV PSK KPSK'];

tic

f1=fopen(filename,'r')

f=0;

fname=fscanf(f1,'%s',1);

while(feof(f1)==0)

        fname=fname;


        fmodel=fscanf(f1,'%s',1);



      origin=fscanf(f1,'%s',1);
      dest=fscanf(f1,'%s',1);

      check1=length( findstr(origin,RLV_airports));

      check2=length( findstr(dest,RLV_airports));

      check=check1 + check2;

      if(check>0)


            f=f+1;
            Fp(f).fname=fname;
            Fp(f).fmodel=fmodel;
            Fp(f).origin=origin;
            Fp(f).dest=dest;


            num=fscanf(f1,'%d',1);
            Fp(f).n=num;

            for(i=1:num)


                  temp_wp(i, 1:3)=fscanf(f1,'%f',[1 3]);

            end
```

```
                Fp(f).wp(:,1:3)=temp_wp(:, 1:3);


      end

      fname=fscanf(f1,'%s',1);

 end

 fff = fopen('acft_sort_newest1','w');

 for (i=1:length(Fp))
    fprintf(fff,'\n');
    fprintf(fff,'%s ',Fp(i).fname);
    fprintf(fff,'%s ',Fp(i).fmodel);
    fprintf(fff,'%s ',Fp(i).origin);
    fprintf(fff,'%s\n',Fp(i).dest);
    %fprintf(fff,'%d\n',Fp(i).n);

    %for (j=1:Fp(i).n)
     %fprintf(fff,'%d %d %d \n', ...
      % Fp(i).wp(j,1), Fp(i).wp(j,2) );
    %end

 end
  fprintf(fff,'\n\n');

%fclose(fff);


fclose(f1);
fclose(fff);

toc
```

```
function flightDataNew = generateFlightDataNew(orgAirportName,
desAirportName, orgAirport, desAirport, etd, eta)

flightDataNew.origin = orgAirportName;
flightDataNew.dest   = desAirportName;
%flightDataNew.fmodel = 'C500';
flightDataNew.n      = 2;  % only two way points


% Origin Airport
coordinateDegree = convertDecimal2Degree(orgAirport(1,1)); %latitude
flightDataNew.wp(1,1) = coordinateDegree(1); % deg.
flightDataNew.wp(1,2) = coordinateDegree(2); % min.
flightDataNew.wp(1,3) = coordinateDegree(3); % sec.

coordinateDegree = convertDecimal2Degree(orgAirport(1,2)); %longitude
flightDataNew.wp(1,4) = coordinateDegree(1); % deg.
flightDataNew.wp(1,5) = coordinateDegree(2); % min.
flightDataNew.wp(1,6) = coordinateDegree(3); % sec.

% Destination Airport
coordinateDegree = convertDecimal2Degree(desAirport(1,1)); %latitude
flightDataNew.wp(2,1) = coordinateDegree(1); % deg.
flightDataNew.wp(2,2) = coordinateDegree(2); % min.
flightDataNew.wp(2,3) = coordinateDegree(3); % sec.

coordinateDegree = convertDecimal2Degree(desAirport(1,2)); %longitude
flightDataNew.wp(2,4) = coordinateDegree(1); % deg.
flightDataNew.wp(2,5) = coordinateDegree(2); % min.
flightDataNew.wp(2,6) = coordinateDegree(3); % sec.


%flightDataNew.wp(:,7) = zeros0;% altitude
flightDataNew.wp(1,8) = etd;% time stamp
flightDataNew.wp(2,8) = eta;% time stamp

return
```

```
function print_1 = printOut(odFile, odTable, allAirports)

fprintf(odFile,'       ');
for  i = 1 : size(allAirports, 1)
   fprintf(odFile,'  %s', allAirports(i,:));
end
fprintf(odFile,'  tot \n');

for i = 1 : size(allAirports, 1)
   fprintf(odFile,' %s', allAirports(i,:));
   for j = 1 : size(allAirports, 1)
       fprintf(odFile,'%6d', round(odTable(i,j)));
   end
   fprintf(odFile,'%6d\n', round(sum(odTable(i,:))));
end
fprintf(odFile,' tot ');
for  i = 1 : size(allAirports, 1)
   fprintf(odFile,'%6d', round(sum(odTable(:,i))));
end
   fprintf(odFile,'%6d\n', round(sum(odTable(:))));
fprintf(odFile,'\n\n\n');

return;
```

```
% Produces the TAAM file for ETMS flights with cruise altitudes


function printTaamData(routeFile, timeStampFile, wayPointsFile, flightData)


global totNum totRoute
global aircraftSubstitute

%Route file
       totRoute = totRoute + 1;
       fprintf(routeFile,'K%sK%s%d',flightData.origin, flightData.dest,
totRoute); %route naming
       fprintf(routeFile,' K%s',flightData.origin);

    %TimeTable
    fprintf(timeStampFile,'{\n');
    fprintf(timeStampFile,'%s ',flightData.fname);       % Flt_name

    %check if this aircraft type is in TAAM or not
    findSubstitute = [];
    for ii = 1 : size(aircraftSubstitute, 2)
       findSubstitute = strmatch(flightData.fmodel,
aircraftSubstitute(ii).sub);
       if(~isempty(findSubstitute)) % found that this aircraft is not in the
TAAM, so should be substitute
          break;
       end
    end

    if(~isempty(findSubstitute)) %aircraft is not in the TAAM, so should be
substitute
        fprintf(timeStampFile,'%s ', aircraftSubstitute(ii).main);
    else %
        fprintf(timeStampFile,'%s ',flightData.fmodel);
    end

    fprintf(timeStampFile,'1 ');   % MkSeg

    fprintf(timeStampFile,'K%sK%s%d ',flightData.origin, flightData.dest,
           totRoute); % Rt

    mid = floor(flightData.n / 2) + 1;

    if(mid > 2) % for Altitude
       fprintf(timeStampFile,'%6d ', round(flightData.wp(mid, 7)));
    else
       fprintf(timeStampFile,' ? ');
    end

    etdDay  = floor(flightData.wp(1, 8) / 1440);  % 1 day = 1440 minutes
    etdHour = floor((flightData.wp(1, 8) - etdDay * 1440) / 60);
    etdMin  = floor(flightData.wp(1, 8) - etdDay * 1440 - etdHour * 60);

    fprintf(timeStampFile,'0%d,', etdDay + 1);
```

```
if(etdHour < 10 & etdMin < 10 )
   fprintf(timeStampFile,'0%d:0%d ',etdHour, etdMin);   % Etd: departure
elseif(etdHour > 10 & etdMin < 10 )
   fprintf(timeStampFile,'%d:0%d ',etdHour, etdMin);
elseif(etdHour < 10 & etdMin > 10 )
   fprintf(timeStampFile,'0%d:%d ',etdHour, etdMin);

else
   fprintf(timeStampFile,'%d:%d ',etdHour, etdMin);

end



%if(mid > 2)
      etaDay  = floor(flightData.wp(flightData.n, 8) / 1440);
                                                    % 1 day = 1440 minutes
      etaHour = floor((flightData.wp(flightData.n, 8) - etaDay *
                1440)/60);
      etaMin  = round(flightData.wp(flightData.n, 8) - etaDay * 1440 -
                etaHour * 60);

      fprintf(timeStampFile,'0%d,', etaDay + 1);


      if(etaHour < 10 & etaMin < 10 )
         fprintf(timeStampFile,'0%d:0%d ',etaHour, etaMin); % Eta:Arrival
      elseif(etaHour > 10 & etaMin < 10 )
         fprintf(timeStampFile,'%d:0%d ',etaHour, etaMin);

      elseif(etaHour < 10 & etaMin > 10 )
         fprintf(timeStampFile,'0%d:%d ',etaHour, etaMin);

      else
         fprintf(timeStampFile,'%d:%d ',etaHour, etaMin);

      end
%else
%   fprintf(timeStampFile,' ? ');
%end


fprintf(timeStampFile,'0 ');%P/Rnav
fprintf(timeStampFile,'0 ');%Ads
fprintf(timeStampFile,'S\n');%Haul
fprintf(timeStampFile,'@SID  ? ?\n');
fprintf(timeStampFile,'@STAR ? ?\n');
fprintf(timeStampFile,'@R K%sK%s%d \n',flightData.origin,
        flightData.dest, totRoute);

fprintf(timeStampFile,' K%s    ',flightData.origin);
fprintf(timeStampFile,' ?'); % Alt.
fprintf(timeStampFile,' 0 0 0\n'); % all else.


fprintf(wayPointsFile,'\n');
```

```
% data for all waypoints except departing and ending airports

for (j = 2 : (flightData.n - 1))

   totNum = totNum + 1;
   fprintf(wayPointsFile,'%4d' ,totNum);

   %Way point
   fprintf(wayPointsFile,'  AZ');
   fprintf(wayPointsFile,'%-04d' ,totNum);

   %Route file
   fprintf(routeFile,'  AZ');
   fprintf(routeFile,'%-04d' ,totNum);

   %Time Table
   fprintf(timeStampFile,'  AZ');
                    %way point
   fprintf(timeStampFile,'%-04d ' ,totNum);
         fprintf(timeStampFile,' %5.2f ',flightData.wp(j, 7)); % Alt.
      fprintf(timeStampFile,' 0 0 0\n',flightData.wp(j, 7)); % all else



   % Print out Lat.
         fprintf(wayPointsFile,' N'); % Lat. hr.
   fprintf(wayPointsFile,'%d ', flightData.wp(j,1));

   if(flightData.wp(j,2) < 10.0)      % Lat. min.
      fprintf(wayPointsFile,'0%d ', flightData.wp(j,2));
         else
               fprintf(wayPointsFile,'%d ', flightData.wp(j,2));
         end

   if(flightData.wp(j,3) < 10.0)  % Lat. sec.
      fprintf(wayPointsFile,'0%4.2f', flightData.wp(j,3));
         else
               fprintf(wayPointsFile,'%4.2f', flightData.wp(j,3));
         end


   % Print out Long.
   fprintf(wayPointsFile,'  W');
   if(flightData.wp(j,4) < 100)
      fprintf(wayPointsFile,'0%d ', flightData.wp(j,4));
   else
      fprintf(wayPointsFile,'%d ', flightData.wp(j,4));
   end

   if(flightData.wp(j,5) < 10.0)
      fprintf(wayPointsFile,'0%d ', flightData.wp(j,5));
         else
               fprintf(wayPointsFile,'%d ', flightData.wp(j,5));
         end
```

```
        if(flightData.wp(j,6) < 10.0)
           fprintf(wayPointsFile,'0%4.2f', flightData.wp(j,6));
              else
                    fprintf(wayPointsFile,'%4.2f', flightData.wp(j,6));
              end

        fprintf(wayPointsFile,'      000      0000');
        fprintf(wayPointsFile,'\n');

     end%for (j = 1:flightData.n)


     %route file
     fprintf(routeFile,' K%s\n',flightData.dest);


     %time table
     fprintf(timeStampFile,' K%s    ',flightData.dest);
     fprintf(timeStampFile,' ?');  % Alt.
     fprintf(timeStampFile,' 0 0 0\n'); % etc.
     fprintf(timeStampFile,'}\n');


fprintf(wayPointsFile,'\n\n');
```

```
% Produces the TAAM file for SATS and GA flights without cruise altitudes


function printTaamData(routeFile, timeStampFile, wayPointsFile, flightData,
cruiseAlt)

global totNum totRoute

    %Route file
       totRoute = totRoute + 1;
       fprintf(routeFile,'K%sK%s%d',flightData.origin, flightData.dest,
totRoute); %route naming
       fprintf(routeFile,' K%s',flightData.origin);

    %TimeTable
    fprintf(timeStampFile,'{\n');
    fprintf(timeStampFile,'%s ',flightData.fname);     % Flt_name
    fprintf(timeStampFile,'%s ',flightData.fmodel);

    fprintf(timeStampFile,'1 ');                       % MkSeg
    fprintf(timeStampFile,'K%sK%s%d ',flightData.origin, flightData.dest,
totRoute); % Rt
    fprintf(timeStampFile, '%6d ', cruiseAlt);         % Cruise Altitude

    etdDay  = floor(flightData.wp(1, 8) / 1440);       % 1 day = 1440 minutes
    etdHour = floor((flightData.wp(1, 8) - etdDay * 1440) / 60);
    etdMin  = floor(flightData.wp(1, 8) - etdDay * 1440 - etdHour * 60);

    fprintf(timeStampFile,'0%d,', etdDay + 1);


    if(etdHour < 10 & etdMin < 10 )
       fprintf(timeStampFile,'0%d:0%d ',etdHour, etdMin);  % Etd: departure
    elseif(etdHour > 10 & etdMin < 10 )
       fprintf(timeStampFile,'%d:0%d ',etdHour, etdMin);
    elseif(etdHour < 10 & etdMin > 10 )
       fprintf(timeStampFile,'0%d:%d ',etdHour, etdMin);

    else
       fprintf(timeStampFile,'%d:%d ',etdHour, etdMin);

    end



%if(mid > 2)
          etaDay  = floor(flightData.wp(flightData.n, 8) / 1440);
                                                       % 1 day = 1440 minutes
          etaHour = floor((flightData.wp(flightData.n, 8) - etaDay *
                    1440)/60);
          etaMin  = round(flightData.wp(flightData.n, 8) - etaDay * 1440 –
                    etaHour * 60);

          fprintf(timeStampFile,'0%d,', etaDay + 1);


          if(etaHour < 10 & etaMin < 10 )
```

```
    fprintf(timeStampFile,'0%d:0%d ',etaHour, etaMin);  % Eta: Arrival

    elseif(etaHour > 10 & etaMin < 10 )

    fprintf(timeStampFile,'%d:0%d ',etaHour, etaMin);

    elseif(etaHour < 10 & etaMin > 10 )

    fprintf(timeStampFile,'0%d:%d ',etaHour, etaMin);

    else

    fprintf(timeStampFile,'%d:%d ',etaHour, etaMin);

    end

%else
%   fprintf(timeStampFile,' ? ');
%end


fprintf(timeStampFile,'0 ');%P/Rnav
fprintf(timeStampFile,'0 ');%Ads
fprintf(timeStampFile,'S\n');%Haul
fprintf(timeStampFile,'@SID  ? ?\n');
fprintf(timeStampFile,'@STAR ? ?\n');
fprintf(timeStampFile,'@R K%sK%s%d \n',flightData.origin,
        flightData.dest, totRoute);

fprintf(timeStampFile,' K%s    ',flightData.origin);
fprintf(timeStampFile,' ?');                                % Alt.
fprintf(timeStampFile,' 0 0 0\n');                          % all else


fprintf(wayPointsFile,'\n');


% data for all waypoints except departing and ending airports

for (j = 2 : (flightData.n - 1))

   totNum = totNum + 1;
   fprintf(wayPointsFile,'%4d' ,totNum);

   %Waypoints
   fprintf(wayPointsFile,'  AZ');
   fprintf(wayPointsFile,'%-04d' ,totNum);

   %Route file
   fprintf(routeFile,'  AZ');
   fprintf(routeFile,'%-04d' ,totNum);

   %Time Table
   fprintf(timeStampFile,'  AZ');
                    %way point
   fprintf(timeStampFile,'%-04d ' ,totNum);
```

```
    fprintf(timeStampFile,' %5.2f ',flightData.wp(j, 7));  % Alt.

    fprintf(timeStampFile,' 0 0 0\n',flightData.wp(j, 7)); % all else

    % Print out Lat.
         fprintf(wayPointsFile,' N');                          % Lat. hr.
   fprintf(wayPointsFile,'%d ', flightData.wp(j,1));

   if(flightData.wp(j,2) < 10.0)      % Lat. min.
      fprintf(wayPointsFile,'0%d ', flightData.wp(j,2));
         else
               fprintf(wayPointsFile,'%d ', flightData.wp(j,2));
         end

   if(flightData.wp(j,3) < 10.0)  % Lat. sec.
      fprintf(wayPointsFile,'0%4.2f', flightData.wp(j,3));
         else
               fprintf(wayPointsFile,'%4.2f', flightData.wp(j,3));
         end


   % Print out Long.
   fprintf(wayPointsFile,'  W');
   if(flightData.wp(j,4) < 100)
      fprintf(wayPointsFile,'0%d ', flightData.wp(j,4));
   else
      fprintf(wayPointsFile,'%d ', flightData.wp(j,4));
   end

   if(flightData.wp(j,5) < 10.0)
      fprintf(wayPointsFile,'0%d ', flightData.wp(j,5));
         else
               fprintf(wayPointsFile,'%d ', flightData.wp(j,5));
         end

   if(flightData.wp(j,6) < 10.0)
      fprintf(wayPointsFile,'0%4.2f', flightData.wp(j,6));
         else
               fprintf(wayPointsFile,'%4.2f', flightData.wp(j,6));
         end

   fprintf(wayPointsFile,'      000      0000');
   fprintf(wayPointsFile,'\n');
   end                              %for (j = 1:flightData.n)


%route file
fprintf(routeFile,' K%s\n',flightData.dest);

%time table
fprintf(timeStampFile,' K%s    ',flightData.dest);
fprintf(timeStampFile,' ?');                              % Alt.
fprintf(timeStampFile,' 0 0 0\n');                        % all else
fprintf(timeStampFile,'}\n');

fprintf(wayPointsFile,'\n\n');
```

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Appendix C

Simulation Airport Data

```
#              TABLE OF AIRPORTS

#       Last update by TAAM on Fri Dec 22 07:06:32 2000

# AIRPORT LOCATION    ID    Latitude          Longitude     Elevation   Bearing   TAR


ABERDEEN_FLD/SMITHFIELD_VA K31VA  N37 01 25.5 W076 35 18.8    33.000000   9.000000     0
ADAMS_FIELD/LITTLE_ROCK_AR KLIT    N34 43 45.8     W092 13 27.3    262.000000    -5.000000  1
ADDISON/DALLAS_TX     KADS    N32 58 6.8      W096 50 11.2    644.000000    -6.000000  1
AIKEN_MUNI/SC         KAIK    N33 38 58.4     W081 41 4.1     528.000000    4.000000  1
AIRBORNE_AIRPARK/WILMINGTON_OH KILN    N39 25 40.5     W083 47 31.6    1077.000000    4.000000  1
AIRGLADES_ARPT/CLEWISTON_FL K2IS N26 43 58.8 W081 02 59.9  20  3  1
AKRON-CANTON_REGL/OH  KCAK    N40 54 58.7     W081 26 32.9    1228.000000    7.000000  1
ALBANY_INTL/NY        KALB    N42 44 53.2     W073 48 10.7    285.000000    13.000000  1
ALBERT_J_ELLIS/JACKSONVILLE_NC KOAJ    N34 49 45.0     W077 36 43.7    94.000000    8.000000  1
ALLAIRE_ARPT/BELMAR-FARMINGDALE_NJ KBLM N40 10 58.8 W074 07 01.2  159  12  1
ALLEGHENY_CO/PITTSBURGH_PA KAGC    N40 21 15.8     W079 55 48.6    1252.000000    9.000000  1
ALLEN_C_PERKINSON-BLACKSTONE_AAF/VA KBKT N37 04 58.8 W077 58 01.2  439  9  1
ALTOONA-BLAIR_CO/PA   KAOO    N40 17 46.9     W078 19 12.1    1504.000000    10.000000  1
AMSTERDAM-SCHIPHOL/NETHERLANDS   EHAM    N52 18 29.0     E004 45 51.0    -11.000000   2.600000  1
ANDERSON_AFB/MARIANA_ISLAND_GUAM KUAM N13 34 52.0 E144 55 28.0  612  -2  1
ANDERSON_REGL/SC KAND N34 30 00.0 W082 42 00.0  782  4  1
ANDREWS_AFB/CAMP_SPRINGS_MD KADW    N38 48 38.9     W076 52 1.3     280.000000    10.000000  1
ANDREWS-MURPHY_ARPT/NC K6A3    N35 11 40.3     W083 51 53.6    1700.000000    3.000000  0
ANGELINA_CO/LUFKIN_TX KLFK N31 13 58.8 W094 45 00.0  296  -5  1
ANNISTON_METROPOLITAN/AL KANB    N33 35 17.4     W085 51 29.2    612.000000    1.000000  1
ARNOLD_PALMER_REGL/LATROBE_PA KLBE    N40 16 33.4     W079 24 17.3    1185.000000    7.000000  0
ASHEVILLE_REGL/NC     KAVL    N35 26 10.3     W082 32 30.5    2165.000000    4.000000  1
ASHLAND-BOYD_CO/KY_(DWU) KI28    N38 33 16.2     W082 44 16.8    546.000000    5.000000  1
ATHENS-BEN_EPPS/GA    KAHN    N33 56 54.9     W083 19 34.8    808.000000    3.000000  0
ATLANTA-WILLIAM_B_HARTSFIELD_INT KATL    N33 38 25.6     W084 25 36.9    1026.000000  2.000000  1
ATLANTIC_CITY_INTL/NJ KACY    N39 27 27.3     W074 34 37.8    76.000000    10.000000  1
AUBURN-OPELIKA/ROBERT_G_PITTS/AL KAUO    N32 36 58.9     W085 26 0.8     776.000000   1.000000  1
AUGUSTA_REGL-BUSH_FLD/GA KAGS    N33 22 11.8     W081 57 52.2    145.000000    4.000000  1
AUGUSTA_STATE_ARPT/ME KAUG    N44 19 14.3     W069 47 50.3    352.000000    18.000000  1
AURORA_MUNI/CHICAGO-AURORA_IL KARR N41 46 01.2 W088 28 01.2  712  1  1
AUSTIN_STRAUBEL_INTL/GREEN_BAY_W KGRB    N44 29 6.3      W088 07 46.5    695.000000   2.000000  1
BALDWIN_CO/MILLEDGEVILLE_GA KMLJ    N33 09 15.1     W083 14 26.2    384.000000    3.000000  1
BALTIMORE-WASHINGTON_INTL/MD KBWI    N39 10 31.4     W076 40 5.5     146.000000    8.000000  1
BANGOR_INTL/ME        KBGR    N44 48 26.8     W068 49 41.3    192.000000    19.000000  1
BARNWELL_CO/SC KBNL N33 16 01.2 W081 22 58.8  246  4  1
BARTLESVILLE_MUNI/OK  KBVO    N36 45 44.9     W096 00 40.1    713.000000    -7.000000  1
BATON_ROUGE_METRO-RYAN_FLD/LA KBTR    N30 31 59.4     W091 08 58.7    70.000000    -3.000000  1
BEATRIX_INTL/ARUBA    TNCA    N12 30 15.0     W070 00 44.0    60.000000    8.000000  1
BEAUFORT_CO/SC        K73J    N32 24 43.7     W080 38 4.4     10.000000    5.000000  1
BEAUFORT_MCAS-MERRITT_FLD/SC KNBC N32 28 58.8 W080 43 01.2  36  5  1
BEAVER_CO/BEAVER_FALLS_PA KBVI    N40 46 20.9     W080 23 29.1    1253.000000    7.000000  0
BEDFORD_CO/PA_(HMZ)   KB17    N40 05 7.3      W078 30 44.0    1161.000000    9.000000  0
BEECH_FACTORY/WICHITA_KS KBEC    N37 41 40.1     W097 12 54.0    1408.000000    -6.000000  1
BELLINGHAM_INTL/WA    KBLI    N48 47 33.9     W122 32 15.1    170.000000    -21.000000  1
BENEDUM/CLARKSBURG_WV KCKB    N39 17 47.9     W080 13 41.1    1217.000000    8.000000  1
BERMUDA_NAS           TXKF    N32 21 48.0     W064 40 42.0    12.000000    15.000000  1
BIDDEFORD_MUNI/MAINE KB19 N43 28 01.2 W070 28 01.2  157  17  1
BIG_SANDY_REGL/PRESTONBURG_KY KK22    N37 45 3.7      W082 38 12.1    1221.000000    5.000000  1
BINGHAMTON_REGL-EDWIN_A._LINK_FLD/NY KBGM    N42 12 30.5  W075 58 46.6  1636.000000 12.000000  1
BIRMINGHAM_INTL/AL    KBHM    N33 33 46.6     W086 45 12.8    644.000000    1.000000  1
BLUE_GRASS_ARPT/LEXINGTON_KY KLEX    N38 02 13.1     W084 36 19.4    979.000000    4.000000  1
BLUE_RIDGE_ARPT/MARTINSVILLE_VA KMTV    N36 37 50.7     W080 01 6.1     941.000000    7.000000  1
BLUFFTON_ARPT/OH      K5G7    N40 53 7.6      W083 52 7.1     851.000000    5.000000  1
BOB_SIKES_ARPT/CRESTVIEW_FL KCEW    N30 46 43.8     W086 31 19.6    213.000000    0.000000  1
BOCA_RATON_ARPT/FL    KBCT    N26 22 42.6     W080 06 27.7    13.000000    5.000000  1
BOEING_FLD-KING_CO_INTL/SEATTLE_WA KBFI    N47 31 48.0  W122 18 7.0    18.000000    -20.000000  1
BOWMAN_FIELD/LOUISVILLE_KY KLOU    N38 13 40.8     W085 39 49.4    546.000000    2.000000  1
BRADLEY_INTL/WINDSOR_LOCKS_CT KBDL    N41 56 19.9     W072 40 59.7    174.000000    14.000000  1
BRANDYWINE/WEST_CHESTER_PA KN99 N40 00 00.0 W075 34 58.8  466  12  1
BRASILIA_INTL/BRAZIL  SBBR    S15 51 44.0     W047 54 44.0    3473.000000    19.000000  1
BRUNSWICK_CO/SOUTHPORT_NC KSUT    N33 55 45.3     W078 04 30.0    25.000000    8.000000  1
BRUSSELS-AIR_TERMINUS/BELGIUM    EBBV    N50 00 0.0      E004 00 0.0     36.000000    2.200000  1
BRUSSELS_NATIONAL/BELGIUM     EBBR    N50 54 8.0      E004 29 9.0     184.000000    3.000000  1
BUFFALO_AIRFIELD/NY   K9G0    N42 51 43.2     W078 42 59.7    670.000000    10.000000  1
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BUFFALO-NIAGARA_INTL/NY KBUF    N42 56 25.9     W078 43 55.8    724.000000    10.000000  1
BUNDORAN/CHARLOTTESVILLE_VA KVA18   N37 58 6.5      W078 40 56.1    840.000000    8.000000  0
BURBANK-GLENDALE-PASADENA_ARPT/CA KBUR    N34 12 2.2 W118 21 30.6    775.000000    -14.000000  1
BURKE_LAKEFRONT_ARPT/CLEVELAND_OH KBKL    N41 31 3.0      W081 41 0.0    583.000000   7.000000  1
BURLINGTON_INTL/VT    KBTV    N44 28 22.8     W073 09 1.1     334.000000    15.000000  1
BURLINGTON_MUNI/WI    KC52    N42 41 26.0     W088 18 16.7    779.000000    1.000000  1
BURLINGTON-ALAMANCE_REGL/NC KBUY    N36 02 54.8     W079 28 29.6    617.000000    8.000000  1
BUTLER_CO-K_W_SCHOLTER_FLD/PA KBTP N40 46 58.8 W079 57 00.0  1248  8  1
CAIRNS_AAF/FT_RUCKER_AL KOZR N31 16 58.8 W085 43 01.2  298  0  1
CAMBRIDGE-DORCHESTER_ARPT/MD KCGE    N38 32 21.5     W076 01 49.3    19.000000    10.000000  1
CAMDEN_CO/BERLIN_NJ   K19N    N39 46 42.3     W074 56 52.1    150.000000    12.000000  1
CAMILLA-MITCHELL_CO/GA KCXU    N31 12 46.5     W084 14 12.5    175.000000    2.000000  1
CAMPBELL_AAF/FT_CAMPBELL_KY KHOP N36 40 58.8 W087 28 58.8  573  1  1
CAMPBELL_CO/JACKSBORO_TN KJAU    N36 20 4.5      W084 09 44.4    1180.000000    3.000000  1
CANCUN_INTL/MEXICO    MMUN    N21 02 15.0     W086 53 1.0     23.000000    -3.000000  1
CAPITAL_ARPT/SPRINGFIELD_IL KSPI    N39 50 38.2     W089 40 39.4    597.000000    -1.000000  1
CAPITAL_CITY_ARPT/FRANKFORT_KY KFFT    N38 10 57.0     W084 54 16.9    804.000000    3.000000  1
CAPITAL_CITY_ARPT/HARRISBURG_PA KCXY    N40 13 1.7      W076 51 5.3     347.000000    11.000000  1
CAPITAL_CITY_ARPT/LANSING_MI KLAN    N42 46 43.3     W084 35 14.5    861.000000    5.000000  1
CAPT_W_F_DUKE_REGL/LEONARDTOWN_MD K2W6 N38 19 01.2 W076 32 59.9  142  10  1
CARROLL_CO_REGL-JACK_B_POAGE_FLD/MD KW54    N39 36 29.8   W077 00 27.6  789.000000   10.000000  1
CARTERSVILLE/GA KVPC N34 07 58.8 W084 50 59.9  759  2  1
CATTARAUGAS_CO-OLEAN_ARPT/NY KOLE    N42 14 24.2     W078 22 18.1    2135.000000    10.000000  1
CECIL_FIELD/NAS_JAX_FL_(VQQ) KNZC N30 13 01.2 W081 52 58.8  81  3  1
CENTENNIAL_ARPT/DENVER_CO KAPA    N39 34 12.5     W104 50 57.5    5883.000000    -11.000000  1
CENTRAL_IL_REGL_AT_BLOOMINGTON-NORMAL KBMI    N40 28 40.7  W088 54 57.4  871.000000   0.000000  1
CHARLESTON_AFB_&_INTL_ARPT/SC KCHS    N32 53 55.1     W080 02 25.8    46.000000    5.000000  1
CHARLESTON_EXECUTIVE/SC KJZI N32 42 00.0 W080 00 00.0  17  5  1
CHARLOTTE_CO/PUNTA_GORDA_FL KPGD    N26 55 12.7     W081 59 25.9    25.000000    3.000000  1
CHARLOTTE-DOUGLAS_INTL/NC KCLT    N35 12 50.7     W080 56 35.1    748.000000    7.000000  1
CHARLOTTESVILLE-ALBEMARLE_ARPT/VA KCHO    N38 08 19.1     W078 27 10.3    639.000000  8.000000  1
CHAUTAUQUA_CO-DUNKIRK_ARPT/NY KDKK N42 28 58.8 W079 16 01.2  693  7  1
CHAUTAUQUA_CO-JAMESTOWN_ARPT/NY KJHW N42 08 59.9 W079 15 00.0  1724  9  1
CHENNAULT_INTL/LAKE_CHARLES_LA KCWF    N30 12 38.1     W093 08 35.5    17.000000    -5.000000  1
CHERRY_POINT_MCAS-CUNNINGHAM_FLD/NC KNKT N34 53 59.9 W076 52 58.8  28  9  1
CHESAPEAKE_REGL/VA    KCPK    N36 39 56.2     W076 19 14.4    20.000000    9.000000  1
CHESTER_CO/G.O._CARLSON_ARPT/PA K40N    N39 58 44.3     W075 51 55.7    660.000000   11.000000  1
CHESTER_MUNI/SC K9A6 N34 46 58.8 W081 12 00.0  656  5  1
CHESTERFIELD_CO/RICHMOND_VA KFCI    N37 24 23.5     W077 31 30.0    237.000000    9.000000  1
CHICAGO-MIDWAY/IL     KMDW    N41 47 9.5      W087 45 8.7     620.000000    1.000000  1
CHICAGO-O'HARE_INTL/IL KORD    N41 58 46.5     W087 54 16.1    668.000000    0.000000  1
CHIPPEWA_CO_INTL/SAULT_STE_MARIE_MI KCIU    N46 15 2.7   W084 28 20.6  799.000000    6.000000  0
CINCINNATI-N_KENTUCKY_INTL/COVINGTON_KY KCVG    N39 02 46.1  W084 39 43.8 897.000000  4.000000  1
CINCINNATI_MUNI-LUNKEN_FLD/OH KLUK    N39 06 12.0     W084 25 7.0     483.000000    4.000000  1
CINCINNATI-BLUE_ASH_ARPT/OH KISZ    N39 14 48.1     W084 23 20.3    856.000000    4.000000  1
CLARK_CO/JEFFERSONVILLE_IN KJVY    N38 21 56.2     W085 44 17.9    474.000000    2.000000  1
CLAYTON_CO-TARA_FLD/HAMPTON_GA K4A7    N33 23 20.8     W084 19 56.5    874.000000    3.000000  1
CLERMONT_CO/BATAVIA_OH KI69    N39 04 42.2     W084 12 36.7    844.000000    4.000000  1
CLEVELAND-HOPKINS_INTL/OH KCLE    N41 24 39.2     W081 50 57.8    792.000000    6.000000  1
COBB_CO-MCCOLLUM_FLD/MARIETTA_GA KRYY    N34 00 47.4     W084 35 54.8    1040.000000  3.000000  1
COINTRIN/GENEVA_SWITZERLAND    LSGG    N46 14 23.0     E006 06 37.0    1411.000000    1.100000  1
COLOGNE-BONN/GERMANY     EDDK    N50 52 2.0      E007 08 37.0    300.000000    2.000000  1
COLORADO_SPRINGS_MUNI/CO KCOS    N38 48 20.9     W104 42 0.9     6184.000000    -11.000000  1
COLUMBIA_METROPOLITAN/SC KCAE    N33 56 19.8     W081 07 10.3    236.000000    5.000000  1
COLUMBIA_OWENS_DOWNTOWN/SC KCUB    N33 58 13.7     W080 59 42.9    193.000000    5.000000  1
COLUMBUS_CO_MUNI/WHITEVILLE_NC KCPC    N34 16 22.3     W078 42 54.0    98.000000    7.000000  1
COLUMBUS_METROPOLITAN/GA KCSG    N32 30 58.8     W084 56 19.9    397.000000    2.000000  1
COLUMBUS_MUNI/IN KBAK N39 16 01.2 W085 54 00.0  656  3  1
CONWAY-HORRY_CO/SC    KHYW    N33 49 42.6     W079 07 19.8    34.000000    6.000000  1
CORPUS_CHRISTI_INTL/TX KCRP    N27 46 13.3     W097 30 4.4     43.000000    -7.000000  1
COVINGTON_MUNI/GA     K9A1    N33 37 56.9     W083 50 58.4    795.000000    2.000000  1
CRAIG_MUNI/JACKSONVILLE_FL KCRG    N30 20 10.8     W081 30 52.0    41.000000    4.000000  1
CRAVEN_CO_REGL/NEW_BERN_NC KEWN    N35 04 22.7     W077 02 34.6    18.000000    8.000000  1
CROSSVILLE_MEMORIAL-WHITSON_FLD/TN KCSV N35 57 00.0 W085 04 58.8  1881  2  1
CUSTER_ARPT/MONROE_MI_(TTF) KD92    N41 56 23.7     W083 26 4.9     616.000000    5.000000  1
CUYAHOGA_CO/CLEVELAND_OH KCGF    N41 33 54.4     W081 29 10.9    879.000000    8.000000  1
CYRIL_E_KING/ST_THOMAS    TIST    N18 20 14.2     W064 58 24.0    24.000000    12.300000  1
DADE_CO-HOMESTEAD_REGL/FL KHST N25 28 58.8 W080 22 58.8  7  3  1
DALLAS-LOVE_FIELD/TX  KDAL    N32 50 49.6     W096 51 6.4     487.000000    -6.000000  1
DALLAS-FT_WORTH_INTL/TX KDFW    N32 53 45.4     W097 02 13.9    603.000000    -6.000000  1
DANBURY_MUNI/CT       KDXR    N41 22 17.5     W073 28 55.9    458.000000    14.000000  1
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DANE_CO_REGL-TRUAX_FLD/MADISON_WI KMSN    N43 08 23.5     W089 20 15.0    887.000000  0.000000  1
DANVILLE_REGL/VA       KDAN    N36 34 22.3     W079 20 10.0    571.000000    6.000000  0
DARE_CO_REGL/MANTEO_NC KMQI    N35 55 8.4      W075 41 43.9    14.000000    9.000000  0
DARLINGTON_CO_JETPORT/SC_(UDG) K04J    N34 26 57.1     W079 53 25.3    192.000000    6.000000  1
DAVISON_AAF/FT_BELVOIR_VA KDAA    N38 42 55.4     W077 10 53.9    69.000000    9.000000  1
DAYTONA_BEACH_INTL/FL KDAB    N29 10 47.7     W081 03 29.0    34.000000    3.000000  1
DAYTON-WRIGHT_BROTHERS_ARPT/OH KMGY    N39 35 20.3     W084 13 29.5    957.000000    4.000000  1
DECATUR_ARPT/IL        KDEC    N39 50 4.4      W088 51 56.5    682.000000    1.000000  1
DEFIANCE_MEMORIAL/OH  KDFI    N41 20 15.0     W084 25 43.7    707.000000    5.000000  1
DEKALB-PEACHTREE/ATLANTA_GA KPDK    N33 52 32.2     W084 18 7.1     1002.000000    2.000000  1
DEL_RIO_INTL/TX        KDRT    N29 22 18.5     W100 55 23.6    999.000000    -8.000000  1
DELAWARE_CO-JOHNSON_FLD/MUNCIE_IN KMIE    N40 14 32.5     W085 23 45.1    937.000000  3.000000  1
DENTON_MUNI/TX         KDTO    N33 12 2.6      W097 11 52.7    642.000000    -7.000000  1
DENVER_INTL/CO         KDEN    N39 51 30.3     W104 40 1.2     5431.000000    -11.000000  1
DES_MOINES_INTL/IA     KDSM    N41 32 5.8      W093 39 38.5    957.000000    -4.000000  1
DETROIT_CITY_ARPT/MI  KDET    N42 24 33.1     W083 00 35.5    626.000000    6.000000  1
DETROIT_METRO-WAYNE_CO/MI KDTW    N42 12 43.4     W083 20 55.8    640.000000    6.000000  1
DILLANT-HOPKINS/KEENE_NH KEEN    N42 53 54.2     W072 16 14.8    488.000000    15.000000  0
DOBBINS_ARB/MARIETTA_GA KMGE    N33 54 55.4     W084 30 58.8    1068.000000    2.000000  1
DODGE_CO/JUNEAU_WI     KUNU    N43 25 35.7     W088 42 11.6    936.000000    1.000000  1
DONALDSON_CENTER/GREENVILLE_SC K7A1    N34 45 29.9     W082 22 35.1    955.000000    4.000000  1
DOTHAN_REGL/AL KDHN N31 19 15.6 W085 27 00.0  401  1  1
DOVER_AFB/DE           KDOV    N39 07 48.4     W075 27 58.7    30.000000    11.000000  1
DUBOIS-JEFFERSON_CO/PA KDUJ    N41 10 41.8     W078 53 55.3    1817.000000    9.000000  1
DULUTH_INTL/MN         KDLH    N46 50 31.5     W092 11 37.1    1428.000000    -2.000000  1
DUPAGE_ARPT/WEST_CHICAGO_IL KDPA    N41 54 24.8     W088 14 54.3    758.000000    1.000000  1
DUPLIN_CO/KENANSVILLE_NC KDPL    N35 00 0.2      W077 58 54.1    137.000000    7.000000  1
DUTCHESS_CO/POUGHKEEPSIE_NY KPOU    N41 37 35.8     W073 53 2.8     165.000000    13.000000  1
EAST_COOPER_ARPT/MOUNT_PLEASANT_SC K8S5    N32 53 52.2     W079 46 58.3    12.000000  5.000000  1
EASTERN_SLOPES_REGL/FRYEBURG_ME KB20    N43 59 28.1     W070 56 52.3    454.000000  17.000000  1
EASTERN_WV_REGL-SHEPHERD/MARTINSBURG KMRB    N39 24 7.0     W077 59 4.5   557.000000    9.000000  1
EASTON-NEWMAN_FIELD/MD KESN    N38 48 15.0     W076 04 8.4     72.000000    10.000000  1
EGLIN_AFB/VALPARAISO_FL KVPS N30 28 58.8 W086 31 58.8  85  -0  1
EGLIN_AUX_#3-DUKE_FLD/VALPARAISO_FL KEGI N30 38 59.9 W086 31 01.2  193  -0  1
ELKIN_MUNI/NC KZEF N36 16 58.8 W080 46 58.8  1068  5  1
ELKINS-RANDOLPH_CO/WV KEKN N38 52 58.8 W079 52 01.2  1987  7  1
ELLINGTON_FLD/HOUSTON_TX KEFD N29 36 00.0 W095 09 00.0  32  -6  1
EL_PASO_INTL/TX        KELP    N31 48 24.0     W106 22 40.1    3958.000000    -11.000000  1
ELIZABETH_CITY_CGAS_&_REGL_ARPT/NC KECG    N36 15 38.1     W076 10 28.6    12.000000  9.000000  1
ELIZABETHTON_MUNI/TN  K0A9    N36 22 15.4     W082 10 25.5    1585.000000    4.000000  0
ELIZABETHTOWN_ARPT/NC K4W1    N34 36 6.6      W078 34 47.0    133.000000    8.000000  1
ELMIRA-CORNING_REGL/NY KELM    N42 09 35.7     W076 53 29.2    955.000000    12.000000  1
EPPLEY_AIRFIELD/OMAHA_NE KOMA    N41 18 9.1      W095 53 39.0    984.000000    -6.000000  1
ERIE_INTL/PA           KERI    N42 04 55.3     W080 10 34.4    733.000000    8.000000  1
ESSEX_CO/CALDWELL_NJ  KCDW    N40 52 30.8     W074 16 52.9    173.000000    13.000000  1
EXECUTIVE_ARPT/ORLANDO_FL KORL    N28 32 43.7     W081 19 58.6    113.000000    3.000000  1
FAIRHOPE_MUNI/AL       K4R4    N30 27 43.6     W087 52 40.9    95.000000    -2.000000  0
FAIRMONT_MUNI-FRANKMAN_FLD/WV K4G7    N39 26 53.4     W080 10 1.3     1029.000000    8.000000  1
FALWELL_ARPT/LYNCHBURG_VA KW24 N37 22 58.8 W079 07 01.2  939  7  1
FARMVILLE_REGL/VA      KFVX    N37 21 27.1     W078 26 16.1    417.000000    8.000000  0
FAYETTE_CO/SOMERVILLE_TN KFYE    N35 12 21.3     W089 23 39.9    436.000000    0.000000  1
FAYETTEVILLE_REGL-GRANNIS_FLD/NC KFAY    N34 59 29.3     W078 52 48.0    189.000000    7.000000  1
FELKER_AAF/FT_EUSTIS_VA KFAF    N37 07 57.5     W076 36 31.8    12.000000    9.000000  1
FINDLAY_ARPT/OH        KFDY    N41 00 48.7     W083 40 7.3     813.000000    5.000000  1
FITCHBURG_MUNI/MA      KFIT    N42 33 14.8     W071 45 32.2    348.000000    15.000000  1
FLORENCE_REGL/SC       KFLO    N34 11 7.3      W079 43 26.0    146.000000    6.000000  1
FLYING_CLOUD/MINNEAPOLIS_MN KFCM    N44 49 38.1     W093 27 25.7    906.000000    -3.000000  1
FLYING_W/LUMBERTON_NJ KN14 N39 55 58.8 W074 47 59.9  49  13  1
FOREST_HILL/MD         MD31 N39 34 58.8 W076 22 58.8  476  10  1
FORT_SMITH_REGL/AR     KFSM    N35 20 11.7     W094 22 2.8     469.000000    -5.000000  1
FORT_WORTH-MEACHAM_INTL/TX KFTW    N32 49 11.2     W097 21 44.8    710.000000    -8.000000  1
FRANKFURT_INTL-RHEIN_MAIN_AB/FRG EDDF    N50 02 4.0      E008 34 17.0    364.000000    1.000000  1
FRANKLIN_CO/LOUISBURG_NC_(LHZ) K2N9    N36 01 24.0     W078 19 49.0    369.000000    8.000000  1
FRANKLIN_MUNI-JOHN_BEVERLY_ROSE/VA KFKN    N36 41 53.4     W076 54 11.3    41.000000  9.000000  1
FREDERICK_MUNI/MD      KFDK    N39 25 3.3      W077 22 27.5    303.000000    9.000000  1
FREEPORT_INTL/BAHAMAS MYGF    N26 33 19.0     W078 41 54.0    7.000000    4.000000  1
FREMONT_MUNI/MI        K3FM    N43 26 20.1     W085 59 41.2    772.000000    4.000000  1
FRONT_RANGE/DENVER_CO KFTG    N39 47 6.9      W104 32 35.3    5512.000000    -11.000000  1
FT_LAUDERDALE_EXECUTIVE/FL KFXE    N26 11 50.2     W080 10 14.6    14.000000    3.000000  1
FT_LAUDERDALE-HOLLYWOOD_INTL/FL KFLL    N26 04 21.3     W080 09 9.9     9.000000    4.000000  1
FT_WORTH_NAS/JRB-CARSWELL_FLD/TX KNFW    N32 46 9.0      W097 26 29.5    650.000000  -7.000000  1
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FULTON_CO/JOHNSTOWN_NY_(NY0) KNY27   N42 59 53.6     W074 19 46.4    881.000000    14.000000  1
FULTON_CO-BROWN_FLD/ATLANTA_GA KFTY    N33 46 44.9     W084 31 16.9    841.000000    2.000000  1
GAINESVILLE_REGL/FL   KGNV    N29 41 24.2     W082 16 18.4    152.000000    3.000000  1
GALLATIN_FIELD/BOZEMAN_MT KBZN    N45 46 36.8     W111 09 10.8    4474.000000    -16.000000  1
GANDER_INTL/NEWFOUNDLAND_CANADA CYQX    N48 56 24.0     W054 34 7.0     496.000000   25.000000  1
GARRETT_CO/OAKLAND_MD K2G4    N39 34 49.0     W079 20 21.9    2933.000000    8.000000  1
GATLINBURG-PIGEON_FORGE/SEVIERVILLE_TN KGKT    N35 51 27.9  W083 31 43.3 1014.000000  3.000000  1
GATWICK_INTL/LONDON_UK  EGKK    N51 08 52.0     W000 11 19.0    202.000000    4.400000  1
GEN_E_L_LOGAN_INTL/BOSTON_MA KBOS    N42 21 51.7     W071 00 18.6    20.000000    16.000000  1
GEN_MARIANO_ESCOBEDO/MONTERREY_MEXICO  MMMY    N25 46 42.0  W100 06 24.0 1270.000000  -9.00000  1
GEN_MITCHELL_INTL/MILWAUKEE_WI KMKE    N42 56 48.4     W087 53 49.2    723.000000    2.000000  1
GEORGE_BUSH_INTERCONTINENTAL/HOUSTON_TX KIAH    N29 58 49.7  W095 20 23.0 97.000000  -5.000000  1
GEORGE_M._BRYAN/STARKVILLE_MS KSTF    N33 26 1.7      W088 50 55.1    333.000000    -2.000000  1
GEORGETOWN_CO/SC KGGE N33 19 01.2 W079 19 01.2  39  6  1
GEORGETOWN_SCOTT_CO-MARSHALL_FLD/KY K27K    N38 14 3.9    W084 26 4.9   947.000000    3.000000  1
GERALD_R._FORD_INTL/GRAND_RAPIDS_MI KGRR    N42 52 51.0   W085 31 22.0  794.000000    4.000000  1
GOHEEN_ARPT/BATTLE_GROUND_WA KW52    N45 49 39.4     W122 34 34.4    285.000000    -20.000000  0
GOSHEN_MUNI/IN         KGSH    N41 31 37.8     W085 47 31.6    827.000000    2.000000  1
GRAND_STRAND/N_MYRTLE_BEACH_SC KCRE    N33 48 42.3     W078 43 26.2    32.000000    6.000000  1
GRANT_CO/PETERSBURG_WV KW99    N38 59 39.1     W079 08 39.8    960.000000    8.000000  1
GRANVILLE/NY     KB01    N43 25 30.3     W073 15 43.4    420.000000    15.000000  0
GREAT_BARRINGTON/MA KGBR    N42 11 3.2      W073 24 11.7    739.000000    14.000000  1
GREATER_CUMBERLAND_REGL/MD KCBE    N39 36 55.5     W078 45 39.1    775.000000    7.000000  1
GREATER_KANKAKEE/IL KIKK    N41 04 17.1     W087 50 46.6    629.000000    0.000000  0
GREATER_PEORIA_REGL/IL KPIA    N40 39 51.3     W089 41 35.9    660.000000    -1.000000  1
GREATER_PORTSMOUTH_REGL/OH KPMH    N38 50 25.7     W082 50 50.3    663.000000    5.000000  1
GREATER_ROCHESTER_INTL/NY KROC    N43 07 7.9      W077 40 20.6    560.000000    11.000000  1
GREATER_ROCKFORD/IL KRFD    N42 11 43.3     W089 05 50.0    742.000000    0.000000  1
GREENBRIER_VALLEY/LEWISBURG_WV KLWB    N37 51 29.9     W080 23 58.1    2302.000000    8.000000  0
GREENEVILLE-GREENE_CO_MUNI/TN KGCY    N36 11 34.8     W082 48 54.3    1608.000000    4.000000  1
GREENVILLE_DOWNTOWN/SC KGMU    N34 50 52.6     W082 21 0.0     1048.000000    5.000000  1
GREENVILLE-SPARTANBURG_INTL/SC KGSP    N34 53 44.4     W082 13 7.9     964.000000    6.000000  1
GREENWOOD_CO/SC        KGRD    N34 14 55.4     W082 09 32.7    631.000000    4.000000  1
GREENWOOD_MUNI/INDIANAPOLIS_IN KHFY N39 37 42.3 W086 05 16.4  822  2  1
GREGG_CO/LONGVIEW_TX  KGGG    N32 23 5.5      W094 42 42.2    365.000000    -5.000000  1
GRIFFIN-SPALDING_CO/GA K6A2    N33 13 37.1     W084 16 29.8    958.000000    4.000000  1
GROTON-NEW_LONDON/CT KGON    N41 19 48.2     W072 02 42.5    10.000000    15.000000  1
GULFPORT-BILOXI_REGL/MS KGPT    N30 24 26.2     W089 04 12.3    28.000000    -2.000000  1
GWINNETT_CO-BRISCOE_FLD/LAWRENCEVILLE_GA KLZU  N33 58 41.1  W083 57 44.6 1061.000000  2.000000  1
HAGERSTOWN_REGL-RICHARD_A._HENSON_FLD/MD KHGR    N39 42 28.6  W077 43 46.2 703.000000 9.000000  0
HENRY_E_ROHLSEN/ST_CROIX     TISX    N17 42 6.7      W064 47 54.8    61.000000    11.800000  1
HAMPTON_ROADS/PORTSMOUTH_VA KPVG    N36 46 48.5     W076 26 55.8    23.000000    10.000000  1
HANOVER_CO_MUNI/ASHLAND_VA KOFP    N37 42 28.9     W077 26 9.6     205.000000    9.000000  1
HARDWICK_FLD/CLEVELAND_TN KHDI    N35 13 12.3     W084 49 56.8    874.000000    2.000000  1
HARRISBURG_INTL/PA    KMDT    N40 11 36.6     W076 45 48.3    310.000000    11.000000  1
HARRISON_CO/CADIZ_OH K8G6 N40 13 58.8 W081 01 01.2  1174  8  1
HARTFORD-BRAINARD/CT  KHFD    N41 44 10.6     W072 39 0.8     19.000000    15.000000  1
HARTSVILLE_REGL/SC    KHVS    N34 24 11.1     W080 07 9.2     364.000000    7.000000  1
HAWKINS_CO/ROGERSVILLE_TN KRVN N36 27 00.0 W082 52 58.8  1255  4  1
HAWKINS_FIELD/JACKSON_MS KHKS    N32 20 5.2      W090 13 21.1    342.000000    -2.000000  1
HENDERSON_FLD/WALLACE_NC KACZ N34 43 01.2 W078 00 00.0  39  9  1
HENDERSON-OXFORD/NC KHNZ    N36 21 41.6     W078 31 45.0    527.000000    7.000000  1
HERLONG/JACKSONVILLE_FL K23J    N30 16 40.0     W081 48 21.4    87.000000    3.000000  1
HERNANDO_CO/BROOKSVILLE_FL KBKV    N28 28 24.9     W082 27 19.5    77.000000    4.000000  1
HICKORY_REGL/NC        KHKY    N35 44 28.1     W081 23 22.4    1189.000000    6.000000  1
HILLENBRAND_INDUSTRIES/BATESVILLE_IN KHLB    N39 20 40.2   W085 15 29.9  973.000000  3.000000  0
HILTON_HEAD/HILTON_HEAD_ISLAND_SC K49J    N32 13 27.7   W080 41 50.9    19.000000    5.000000  1
HOLMES_CO/MILLERSBURG_OH K10G N40 31 58.8 W081 57 00.0  1218  6  1
HONOLULU_INTL-HICKAM_AFB/HI KHNL N21 19 01.2 W157 55 01.2  13  -11  1
HOOK_FIELD_MUNI/MIDDLETOWN_OH KMWO    N39 31 51.7     W084 23 43.0    650.000000    4.000000  1
HOUSTON-SOUTHWEST/TX KAXH    N29 30 22.1     W095 28 36.9    68.000000    -6.000000  1
HUNTINGBURG/IN   KHNB    N38 14 56.5     W086 57 13.4    529.000000    0.000000  1
HUNTINGTON_MUNI/IN    KHHG    N40 51 10.8     W085 27 33.9    806.000000    3.000000  1
HUNTSVILLE_INTL-CARL_T._JONES_FLD/AL KHSV    N34 38 25.6  W086 46 23.2  629.000000    1.000000  1
IGOR_I._SIKORSKY_MEMORIAL/BRIDGEPORT_CT KBDR    N41 09 48.5 W073 07 34.2  10.000000  14.000000  1
INDIANAPOLIS_INTL/IN  KIND    N39 43 2.4      W086 17 39.8    797.000000    2.000000  1
INDIANAPOLIS_METROPOLITAN/IN KUMP    N39 56 6.7      W086 02 41.8    811.000000    3.000000  1
INGALLS_FIELD/HOT_SPRINGS_VA KHSP    N37 57 5.2      W079 50 2.0     3792.000000    6.000000  0
J0HN_H._BATTEN/RACINE_WI KRAC    N42 45 40.3     W087 48 50.0    674.000000    2.000000  0
JAARS-TOWNSEND/WAXHAW_NC KN52    N34 51 49.7     W080 44 52.7    602.000000    5.000000  1
JACK_BARSTOW/MIDLAND_MI K3BS    N43 39 46.5     W084 15 40.8    636.000000    5.000000  1
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JACKSON_CO/RAVENSWOOD_WV KI18 N38 55 47.2 W081 49 10.1 758.000000 6.000000 1
JACKSON_CO-REYNOLDS_FLD/MI KJXN N42 15 35.2 W084 27 33.9 1001.000000 5.000000 1
JACKSON_INTL/MS KJAN N32 18 40.2 W090 04 33.2 346.000000 -3.000000 1
JACKSONVILLE_INTL/FL KJAX N30 29 38.6 W081 41 16.3 30.000000 3.000000 1
JAMES_M_COX_DAYTON_INTL/OH KDAY N39 54 8.6 W084 13 9.8 1010.000000 4.000000 1
JEFFCO/DENVER_CO KBJC N39 54 31.6 W105 07 2.0 5670.000000 -11.000000 1
JOE_FOSS_FLD/SIOUX_FALLS_SD KFSD N43 34 52.9 W096 44 30.1 1429.000000 -6.000000 1
JOHN_C._TUNE/NASHVILLE_TN KJWN N36 10 56.5 W086 53 12.2 495.000000 1.000000 1
JOHN_F._KENNEDY_INTL/NY KJFK N40 38 23.1 W073 46 44.1 13.000000 13.000000 1
JOHN_WAYNE-ORANGE_CO/SANTA_ANA_CA KSNA N33 40 32.4 W117 52 5.6 54.000000 -14.000000 1
JOHNSTON_CO/SMITHFIELD_NC KJNX N35 32 27.4 W078 23 25.2 165.000000 7.000000 1
JOHNSTOWN-CAMBRIA_CO/PA KJST N40 18 58.0 W078 50 2.2 2284.000000 8.000000 1
JOPLIN_REGL/MO KJLN N37 09 6.5 W094 29 53.8 981.000000 -4.000000 1
JOSE_MARTI_INTL/HAVANA_CUBA MUHA N22 58 58.8 W082 24 00.0 210 1 1
KALAMAZOO-BATTLE_CREEK_INTL/MI KAZO N42 13 58.8 W085 32 59.9 874 3 1
KANSAS_CITY_DOWNTOWN/MO KMKC N39 07 23.7 W094 35 33.8 759.000000 -5.000000 1
KANSAS_CITY_INTL/MO KMCI N39 17 51.4 W094 42 50.1 1026.000000 -5.000000 1
KAY_LARKIN/PALATKA_FL K28J N29 39 31.1 W081 41 18.8 49.000000 3.000000 1
KEESLER_AFB/BILOXI_MS KBIX N30 25 01.2 W088 55 01.2 34 -1 1
KEFLAVIK_INTL/ICELAND BIKF N63 59 7.0 W022 36 21.0 171.000000 21.000000 1
KENDALL-MIAMI_EXECUTIVE/FL KTMB N25 38 59.9 W080 25 58.8 8 3 1
KENOSHA_REGL/WI KENW N42 35 44.5 W087 55 40.1 743.000000 2.000000 1
KEWANEE_MUNI/IL KEZI N41 12 18.7 W089 57 49.9 858.000000 -1.000000 1
KEY_FIELD/MERIDIAN_MS KMEI N32 19 59.3 W088 45 4.3 297.000000 -1.000000 1
KEY_WEST_INTL/FL KEYW N24 33 22.0 W081 45 34.4 3.000000 4.000000 1
KIMPO_INTL/SEOUL_ROK RKSS N37 33 24.0 E126 47 54.0 58 5 1
KINSTON_REGL_JETPORT_AT_STALLINGS_FLD/NC KISO N35 19 41.1 W077 36 55.9 94.000000 9.000000 1
KIRSCH_MUNI/STURGIS_MI KIRS N41 49 01.2 W085 25 58.8 925 4 1
KISSIMMEE_MUNI/ORLANDO_FL KISM N28 17 23.3 W081 26 13.5 82.000000 5.000000 1
KNOXVILLE_DOWNTOWN_ISLAND/TN KDKX N35 57 49.8 W083 52 25.2 833.000000 3.000000 1
KOKOMO_MUNI/IN KOKK N40 31 41.4 W086 03 32.4 830.000000 2.000000 1
LA_AURORA_INTL/GUATEMALA_CITY MGGT N14 34 55.0 W090 31 39.0 4952.000000 -5.000000 1
LACROSSE_MUNI/WI KLSE N43 52 58.8 W091 15 00.0 654 -2 1
LAFAYETTE_REGL/LA KLFT N30 12 19.0 W091 59 15.6 42.000000 -3.000000 1
LAGRANGE-CALLAWAY/GA KLGC N33 00 31.8 W085 04 21.4 693.000000 1.000000 1
LAGUARDIA/NEW_YORK_NY KLGA N40 46 38.1 W073 52 21.4 22.000000 13.000000 1
LAKE_CHARLES_REGL/LA KLCH N30 07 34.0 W093 13 24.3 15.000000 -5.000000 1
LAKE_CITY_MUNI-C_J_EVANS_FLD/SC K51J N33 51 00.0 W079 46 01.2 80 6 1
LAKEFRONT_ARPT/NEW_ORLEANS_LA KNEW N30 01 58.8 W090 01 58.8 9 -2 1
LAKE_IN_THE_HILLS/CHICAGO_IL K3CK N42 12 24.5 W088 19 22.9 888.000000 2.000000 1
LAKE_LAWN/DELAVAN_WI KC59 N42 38 2.9 W088 36 4.1 981.000000 0.000000 1
LAKELAND-LINDER_REGL/FL KLAL N27 59 20.1 W082 01 6.8 142.000000 4.000000 1
LAKE_NORMAN_AIRPARK/MOORESVILLE_NC K14A N35 37 01.2 W080 54 00.0 838 5 0
LAKEWOOD_ARPT/NJ KN12 N40 04 01.2 W074 10 58.8 32 13 1
LANCASTER/PA KLNS N40 07 18.2 W076 17 46.0 403.000000 11.000000 1
LANEYS_ARPT/MAIDEN_NC KN92 N39 31 01.2 W075 43 01.2 1025 5 1
LANGLEY_AFB/HAMPTON_VA KLFI N37 04 58.5 W076 21 37.8 11.000000 10.000000 1
LAREDO_INTL/TX KLRD N27 32 37.5 W099 27 41.6 508.000000 -8.000000 0
LAURENCE_G._HANSCOM_FLD/BEDFORD_MA KBED N42 28 11.8 W071 17 20.5 133.000000 16.000000 1
LAURENS_CO/SC K34A N34 30 25.4 W081 56 49.9 697.000000 4.000000 1
LAURINBURG-MAXTON/NC KMEB N34 47 31.0 W079 21 57.1 220.000000 6.000000 1
LAWRENCEVILLE-BRUNSWICK_MUNI/VA KLVL N36 46 01.2 W077 47 59.9 329 8 0
LAWSON_AAF/FT_BENNING_GA KLSF N32 19 58.8 W085 00 00.0 232 2 1
LEBANON_MUNI/NH KLEB N43 37 34.9 W072 18 15.4 604.000000 16.000000 1
LEBANON_MUNI/TN KM54 N36 11 25.5 W086 18 56.5 576.000000 2.000000 1
LEE_ARPT/ANNAPOLIS_MD KANP N38 56 34.4 W076 34 6.2 34.000000 10.000000 0
LEE_CO-BRICK_FLD/SANFORD_NC KW77 N35 26 02.4 W079 10 58.8 430 7 1
LEE_GILMER_MEMORIAL/GAINESVILLE_FL KGVL N34 16 22.5 W083 49 36.5 1275.000000 3.000000 1
LEESBURG_EXECUTIVE-GODFREY_FLD/VA KJYO N39 04 40.7 W077 33 27.0 389.000000 10.000000 1
LEESBURG_REGL/FL KLEE N28 49 21.9 W081 48 32.4 77.000000 4.000000 1
LEHIGH_VALLEY_INTL/ALLENTOWN_PA KABE N40 39 8.5 W075 26 25.4 394.000000 10.000000 1
LIC_BENITO_JUAREZ_INTL/MEXICO_CITY MMMX N19 26 7.0 W099 04 20.0 7341.000000 -8.000000 1
LIMA-ALLEN_CO/OH KAOH N40 42 25.0 W084 01 36.0 975.000000 4.000000 1
LINCOLN_MUNI/NE KLNK N40 51 3.5 W096 45 33.3 1219.000000 -6.000000 1
LITTLE_ROCK_AFB/JACKSONVILLE_AR KLRF N34 55 01.2 W092 09 00.0 311 -4 1
LONDON-CORBIN/MAGEE_FLD/KY KLOZ N37 05 14.2 W084 04 36.4 1212.000000 3.000000 1
LONDON-HEATHROW_INTL/UK EGLL N51 28 37.0 W000 27 35.0 80.000000 4.400000 1
LONDON-STANSTED/UK EGSS N51 53 5.0 E000 14 12.0 347.000000 4.100000 1
LONESOME_PINE/WISE_VA KLNP N36 59 14.8 W082 31 48.6 2685.000000 6.000000 0
LONG_ISLAND_MACARTHUR/ISLIP_NY KISP N40 47 42.9 W073 06 0.8 99.000000 13.000000 1
LORAIN_CO_REGL/ELYRIA_OH_(LPR) K22G N41 20 39.4 W082 10 39.5 793.000000 6.000000 1

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LOS_ANGELES_INTL/CA    KLAX    N33 56 33.1     W118 24 29.1    126.000000    -14.000000  1
LOS_CABOS_INTL/MEXICO MMSD N23 09 18.0 W109 43 15.6  358  -10  1
LOUISA_CO-FREEMAN_FLD/VA KLKU N38 01 01.2 W077 58 01.2  493  9  1
LOUISVILLE_INTL-STANDIFORD_FLD/KY KSDF    N38 10 27.8     W085 44 9.6  501.000000    3.000000  1
LOVELL_FIELD/CHATTANOOGA_TN KCHA    N35 02 7.0      W085 12 13.6    682.000000    2.000000  1
LOWCOUNTRY_REGL/WALTERBORO_SC KRBW N32 55 01.2 W080 39 00.0  98  5  1
LUIS_MUNOZ_MARIN_INTL/SAN_JUAN_PR TJSJ    N18 26 21.8     W066 00 6.6   10.000000    10.800000  1
LUMPKIN_CO-WIMPYS/DAHLONEGA_GA K9A0    N34 34 45.3     W084 01 14.7    1311.000000    3.000000  0
LUTON/LONDON_UK        EGGW    N51 52 27.0     W000 22 1.0     525.000000    4.400000  1
LYNCHBURG_REGL-PRESTON_GLENN_FLD/VA KLYH    N37 19 36.7   W079 12 1.2   938.000000    8.000000  1
MACDILL_AFB/TAMPA_FL  KMCF    N27 50 57.1     W082 31 17.3    14.000000    2.000000  1
MADISON_MUNI/GA        K52A    N33 36 43.7     W083 27 37.6    694.000000    4.000000  1
MADISONVILLE_MUNI/KY  K2I0    N37 21 18.1     W087 23 58.7    439.000000    0.000000  1
MAHNOMEN_CO/MN         K3N8    N47 15 35.9     W095 55 41.2    1244.000000    -5.000000  0
MALCOLM_MCKINNON/BRUNSWICK_GA KSSI    N31 09 5.7      W081 23 28.8    20.000000    4.000000  0
MALPENSA/MILAN_ITALY    LIMC    N45 38 1.0      E008 43 51.0    768.000000    1.000000  1
MANASSAS_REGL/HARRY_P._DAVIS_FLD/VA KHEF    N38 43 17.1   W077 30 55.6  192.000000  10.000000  1
MANCHESTER/NH                KMHT    N42 56 0.7      W071 26 15.8    234.000000    16.000000  1
MANKATO_REGL/MN       KMKT    N44 13 17.9     W093 55 7.5     1020.000000    -4.000000  1
MARION_CO/HAMILTON_AL KHAB    N34 07 3.3      W087 59 53.5    442.000000    -1.000000  1
MARION_MUNI/IN         KMZZ    N40 29 25.3     W085 40 44.9    859.000000    3.000000  1
MARION_MUNI/OH         KMNN    N40 36 58.5     W083 03 48.5    993.000000    5.000000  1
MARLBORO_CO_JETPORT/BENNETTSVILLE_SC KBBP N34 37 01.2 W079 43 58.8  146  6 1
MARSHALL_MEMORIAL_MUNI/MO KMHL    N39 05 44.7     W093 12 10.4    779.000000    -3.000000  1
MARTHA'S_VINEYARD/VINEYARD_HAVEN_MA KMVY    N41 23 34.9   W070 36 51.6  68.000000    16.000000  1
MARTIN_STATE/BALTIMORE_MD KMTN    N39 19 32.4     W076 24 49.6    22.000000    11.000000  1
MASSENA_INTL-RICHARDS_FLD/NY KMSS    N44 56 9.0      W074 50 44.0    215.000000    14.000000  1
MAURY_CO/MOUNT_PLEASANT_TN KMRC    N35 33 14.9     W087 10 44.1    681.000000    1.000000  1
MAXWELL_AFB/MONTGOMERY_AL KMXF N32 22 58.8 W086 22 01.2  172  0  1
MCCARRAN_INTL/LAS_VEGAS_NV KLAS    N36 04 49.3     W115 09 8.4     2181.000000    -14.000000  1
MCCONNELL_AFB/WICHITA_KS KIAB    N37 37 23.1     W097 16 3.2     1371.000000    -7.000000  1
MCENTIRE_ANGB/EASTOVER_SC KMMT N33 55 01.2 W080 47 59.9  252  5  1
MCGHEE_TYSON/KNOXVILLE_TN KTYS    N35 48 45.0     W083 59 34.3    981.000000    3.000000  1
MCGUIRE_AFB/WRIGHTSTOWN_NJ KWRI N40 01 01.2 W074 35 59.9  133  12  1
MCKELLAR-SIPES_REGL/JACKSON_TN KMKL    N35 35 59.6     W088 54 56.2    434.000000    -2.000000  1
MECKLENBURG-BRUNSWICK_REGL/SOUTH_HILL_VA KAVC  N36 41 17.8  W078 03 16.1  442.000000  8.000000  1
MELBOURNE_INTL/FL      KMLB    N28 06 9.9      W080 38 44.9    33.000000    3.000000  1
MEMPHIS_INTL/TN        KMEM    N35 02 36.7     W089 58 36.4    335.000000    -1.000000  1
MENA_INTERMOUNTAIN_MUNI/AR KM39    N34 32 43.4     W094 12 9.6     1079.000000    -4.000000  1
MERCEDITA/PONCE_PR     TJPS    N18 00 30.0     W066 33 46.8    29.000000    10.800000  1
MERCER_CO/BLUEFIELD_WV KBLF    N37 17 44.9     W081 12 27.7    2857.000000    5.000000  0
MERRILL_C_MEIGS/CHICAGO_IL KCGX    N41 51 31.8     W087 36 28.5    593.000000    3.000000  1
METROPOLITAN_OAKLAND_INTL/CA KOAK    N37 43 16.6     W122 13 14.6    6.000000    -16.000000  1
MIAMI_INTL/FL          KMIA    N25 47 35.7     W080 17 26.0    8.000000    5.000000  1
MICHAEL_J._SMITH_FLD/BEAUFORT_NC KMRH    N34 44 0.8      W076 39 38.1    11.000000    8.000000  1
MIDDLE_GEORGIA_REGL/MACON_GA KMCN    N32 41 34.3     W083 38 57.2    354.000000    3.000000  1
MIDDLE_PENINSULA_REGL/WEST_POINT_VA KW97 N37 31 01.2 W076 46 01.2  24  9  1
MILFORD_MUNI/UT        KMLF    N38 25 35.9     W113 00 44.8    5039.000000    -14.000000  0
MILLENNIUM_DALLAS/TX_(7TX2) KNBE N32 43 58.8 W096 58 01.2  491  -6  1
MILLVILLE_MUNI/NJ      KMIV    N39 22 4.1      W075 04 20.0    85.000000    11.000000  1
MINGO_CO/WILLIAMSON_WV K4I0    N37 41 15.4     W082 15 39.5    1575.000000    5.000000  0
MINNEAPOLIS-ST_PAUL_INTL/MN KMSP    N44 52 50.0     W093 13 0.9     841.000000    -2.000000  1
MOBILE_DOWNTOWN/AL     KBFM    N30 37 35.3     W088 04 4.8     26.000000    -2.000000  1
MOBILE_REGL/AL         KMOB    N30 41 29.1     W088 14 34.2    219.000000    -2.000000  1
MONETT_MUNI/MO         KM58    N36 54 22.4     W094 00 45.9    1315.000000    -3.000000  1
MONROE_ARPT/NC         KEQY    N35 01 7.8      W080 37 12.8    679.000000    6.000000  1
MONTGOMERY_CO/CONROE_TX KCXO    N30 21 6.6      W095 24 52.1    245.000000    -6.000000  1
MONTGOMERY_CO_AIRPARK/GAITHERSBURG_MD KGAI   N39 10 6.0   W077 09 57.6  538.000000    9.000000  1
MONTGOMERY_REGL-DANNELLY_FIELD/AL KMGM    N32 18 2.3   W086 23 38.3    221.000000    1.000000  1
MONTREAL-DORVAL_INTL/PQ CYUL    N45 28 5.0      W073 44 29.0    117.000000    16.000000  1
MONTREAL_INTL/PQ             CYMX N45 40 58.8 W074 01 58.8  270  16  1
MONTREAL-ST-HUBERT/PQ CYHU    N45 31 3.0      W073 25 1.0     90.000000    16.000000  1
MOORE_CO/PINEHURST-SOUTHERN_PINES_NC KSOP    N35 14 14.5   W079 23 28.2  461.000000    6.000000  1
MOORE-MURRELL/MORRISTOWN_TN KMOR    N36 10 45.8     W083 22 31.6    1313.000000    3.000000  1
MORGANTON-LENOIR_ARPT/NC KMRN N35 49 01.2 W081 37 01.2  1270  5  1
MORGANTOWN_MUNI-W_L_BILL_HART_FLD/WV KMGW    N39 38 34.5  W079 54 58.7  1248.000000    9.000000  1
MORRISTOWN_MUNI/NJ    KMMU    N40 47 57.7     W074 24 53.5    187.000000    12.000000  1
MOUNT_AIRY-SURRY_CO/NC KMWK N36 27 00.0 W080 32 59.9  1247  7  1
MOUNT_PLEASANT_MUNI/TX KMSA    N33 07 45.7     W094 58 32.3    404.000000    -5.000000  0
MOUNT_STERLING-MONTGOMERY_CO/KY KIOB    N38 03 29.3     W083 58 46.5    1019.000000  4.000000  1
MOUNTAIN_EMPIRE/RURAL_RETREAT_VA KMKJ  N36 53 41.5     W081 20 59.8    2559.000000    1.000000  1
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MUIR_AAF/FT_INDIANTOWN_GAP-ANNVILLE_PA KMUI N40 26 5.3 W076 34 9.9 489.000000 11.000000 1
MURFREESBORO_MUNI/TN (SEB) KMBT N35 52 38.9 W086 22 39.1 615.000000 2.000000 1
MUSCATINE_MUNI/IA KMUT N41 21 59.0 W091 08 46.5 548.000000 -3.000000 1
MYRTLE_BEACH_INTL/SC KMYR N33 40 47.1 W078 55 42.0 25.000000 6.000000 1
NANTUCKET_MEMORIAL/MA KACK N41 15 11.0 W070 03 36.7 48.000000 16.000000 1
NAPLES_MUNI/FL KAPF N26 09 8.9 W081 46 31.6 9.000000 3.000000 1
NAS_BRUNSWICK/MAINE KNHZ N43 53 59.9 W069 55 58.8 75 18 1
NAS_JAX-TOWERS_FIELD/FL KNIP N30 13 58.8 W081 40 58.8 22 3 1
NAS_KEY_WEST-BOCA_CHICA_FIELD/FL KNQX N24 34 01.2 W081 40 58.8 6 2 1
NAS_NEW_ORLEANS-JRB/LA KNBG N29 49 01.2 W090 01 58.8 3 -3 1
NAS_OCEANA-SOUCEK_FLD/VIRGINIA_BEACH KNTU N36 49 14.5 W076 02 0.8 22.000000 10.000000 1
NAS_PATUXENT_RIVER-TRAPNELL_FIELD/MD KNHK N38 17 30.4 W076 24 58.8 40.000000 10.000000 1
NAS_GUANTANAMO_BAY/CUBA MUGM N19 53 59.9 W075 12 00.0 56 6 1
NAS_ROTA/SPAIN LERT N36 38 59.9 W006 20 59.9 86 5 1
NASHVILLE_INTL-BREYER_FIELD/TN KBNA N36 07 28.1 W086 40 41.5 599.000000 1.000000 1
NASSAU_INTL/BAHAMAS MYNN N25 02 25.0 W077 28 13.0 10.000000 5.000000 1
NEIL_ARMSTRONG/WAPAKONETA_OH KAXV N40 29 36.2 W084 17 56.2 912.000000 4.000000 1
NELLIS_AFB/LAS_VEGAS_NV KLSV N36 13 58.8 W115 01 58.8 1868 -14 1
NEW_CASTLE_CO/WILMINGTON_DE KILG N39 40 43.4 W075 36 23.5 79.000000 11.000000 1
NEW_CASTLE_MUNI/PA_(UCP) K2G7 N41 01 31.2 W080 24 48.1 1072.000000 7.000000 1
NEW_CENTURY_AIRCENTER/OLATHE_KS KIXD N38 49 51.3 W094 53 25.1 1087.000000 -4.000000 1
NEW_KENT_CO/QUINTON_VA KW96 N37 30 11.5 W077 07 31.9 123.000000 9.000000 1
NEW_ORLEANS_INTL-MOISANT_FIELD/LA KMSY N29 59 36.2 W090 15 28.9 4.000000 -2.000000 1
NEW_RIVER_MCAS/JACKSONVILLE_NC KNCA N34 42 38.6 W077 26 20.9 25.000000 8.000000 1
NEW_RIVER_VALLEY/DUBLIN_VA KPSK N37 08 14.4 W080 40 42.5 2105.000000 6.000000 1
NEWARK_INTL/NJ KEWR N40 41 34.0 W074 10 12.6 18.000000 13.000000 1
NEWPORT_NEWS-WILLIAMSBURG_INTL/VA KPHF N37 07 54.8 W076 29 34.8 43.000000 9.000000 1
NIAGARA_FALLS_INTL/NY KIAG N43 06 26.1 W078 56 43.4 590.000000 10.000000 1
NORFOLK_INTL/VA KORF N36 53 40.6 W076 12 4.4 26.000000 9.000000 1
NORMAN_MANLEY_INTL/KINGSTON_JAMAICA MKJP N17 55 58.8 W076 46 58.8 10 3 1
NORTHAMPTON/MA K7B2 N42 19 41.4 W072 36 41.5 122.000000 15.000000 1
NORTHEAST_PHILADELPHIA/PA KPNE N40 04 55.0 W075 00 38.1 121.000000 12.000000 1
NORTHEASTERN_REGL/EDENTON_NC KEDE N36 01 39.8 W076 34 1.5 20.000000 10.000000 0
NORWOOD_MEMORIAL/MA KOWD N42 11 26.9 W071 10 23.2 50.000000 15.000000 1
NS_MAYPORT-ADM_MCDONALD_FLD/FL KNRB N30 22 58.8 W081 25 01.2 17 3 1
NS_NORFOLK/VA KNGU N36 56 14.5 W076 17 24.8 15.000000 10.000000 1
NS_ROOSEVELT_ROADS/PR TJNR N18 14 52.8 W065 38 4.5 38.000000 11.000000 1
NW_ALABAMA_REGL/MUSCLE_SHOALS_AL KMSL N34 44 43.2 W087 36 36.8 550.000000 0.000000 1
OAKLAND_CO_INTL/PONTIAC_MI KPTK N42 39 54.7 W083 25 7.4 980.000000 6.000000 1
OCALA_REGL-JIM_TAYLOR_FLD/FL KOCF N29 10 21.4 W082 13 27.0 89.000000 4.000000 1
OCEAN_CITY_MUNI/MD_(OXB) KN80 N38 18 37.6 W075 07 26.3 11.000000 12.000000 1
OCEAN_REEF_CLUB/KEY_LARGO_FL KX09 N25 19 31.4 W080 16 29.2 8.000000 3.000000 0
OFFUTT_AFB/OMAHA_NE KOFF N41 07 01.2 W095 55 01.2 1048 -6 1
OGDENSBURG_INTL/NY KOGS N44 40 54.7 W075 27 55.8 297.000000 14.000000 1
OHIO_STATE_UNIV/COLUMBUS_OH KOSU N40 04 47.2 W083 04 22.9 905.000000 5.000000 1
OHIO_UNIV/ATHENS_OH KUNI N39 12 39.5 W082 13 53.1 766.000000 6.000000 1
ONEIDA_CO/UTICA_NY KUCA N43 08 42.4 W075 23 1.9 743.000000 13.000000 1
ONEONTA_MUNI/NY KN66 N42 31 29.2 W075 03 52.1 1764.000000 13.000000 0
ONTARIO_INTL/CALIFORNIA KONT N34 02 59.9 W117 37 01.2 944 -14 1
ORANGEBURG_MUNI/SC KOGB N33 28 01.2 W080 50 59.9 195 5 1
ORLANDO_SANFORD/FL KSFB N28 46 39.5 W081 14 15.0 55.000000 5.000000 1
ORLANDO_INTL/FL KMCO N28 25 44.0 W081 18 57.7 96.000000 5.000000 1
OTTAWA-CARTIER_INTL/ON CYOW N45 19 21.0 W075 40 9.0 374.000000 14.000000 1
OWEN_ROBERTS_INTL/GRAND_CAYMAN MWCR N19 17 30.0 W081 21 0.0 8.000000 0.000000 1
OWENSBORO-DAVIESS_CO/KY KOWB N37 44 24.4 W087 10 0.6 406.000000 1.000000 1
PAGE_FIELD/FORT_MYERS_FL KFMY N26 35 11.8 W081 51 47.7 17.000000 3.000000 1
PAGELAND/SC KPYG N34 44 31.7 W080 20 42.7 575.000000 6.000000 1
PALM_BEACH_INTL/WEST_PALM_BEACH_FL KPBI N26 40 59.6 W080 05 44.2 18.000000 3.000000 1
PALM_SPRINGS_INTL/CA KPSP N33 49 45.2 W116 30 22.5 474.000000 -13.000000 1
PALWAUKEE_MUNI/CHICAGO_IL KPWK N42 06 51.1 W087 54 5.3 647.000000 2.000000 1
PARIS-CHARLES_DE_GAULLE_INTL/FRANCE LFPG N49 00 35.0 E002 32 55.0 387.000000 3.000000 1
PARIS-ORLY/FRANCE LFPO N48 43 28.0 E002 22 53.0 292 3 1
PATRICK_AFB/COCOA_BEACH_FL KCOF N28 13 58.8 W080 37 01.2 9 3 1
PEACHTREE_CITY-FALCON_FLD/ATLANTA_GA KFFC N33 21 25.4 W084 34 19.7 808.000000 2.000000 1
PEASE_INTL_TRADEPORT/PORTSMOUTH_NH KPSM N43 04 40.7 W070 49 23.8 100.000000 16.000000 1
PENNRIDGE/PERKASIE_PA KN70 N40 23 21.1 W075 17 25.7 568.000000 12.000000 1
PENSACOLA_REGL/FL KPNS N30 28 23.9 W087 11 14.8 121.000000 -1.000000 1
PERSON_CO/ROXBORO_NC KTDF N36 17 5.6 W078 59 3.2 609.000000 8.000000 1
PETERSBURG_MUNI/VA KPTB N37 11 1.5 W077 30 26.6 193.000000 8.000000 1
PHILADELPHIA_INTL/PA KPHL N39 52 19.0 W075 14 28.1 38.000000 10.000000 1
PHILLIPS_AAF/ABERDEEN_PROVING_GRD_MD KAPG N39 27 58.4 W076 10 10.8 58.000000 10.000000 1

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PHOENIX-SKY_HARBOR_INTL/AZ KPHX    N33 26 10.0     W112 00 34.2    1135.000000    -12.000000  1
PIEDMONT_TRIAD_INTL/GREENSBORO_N KGSO    N36 05 51.9   W079 56 14.3    926.000000    6.000000  1
PIKE_CO-HATCHER_FIELD/PIKEVILLE_KY K7K0    N37 33 44.4   W082 33 55.5  1472.000000    6.000000  0
PINE_ISLAND/COROLLA_NC K7NC2   N36 15 12.6     W075 47 18.7    16.000000    9.000000  0
PIQUA_ARPT/OH         KI17    N40 09 52.9     W084 18 30.4    994.000000    4.000000  1
PITT-GREENVILLE/NC    KPGV    N35 38 6.9      W077 23 7.2     27.000000    9.000000  0
PITTSBURGH_INTL/PA    KPIT    N40 29 29.3     W080 13 58.3    1204.000000    7.000000  1
PITTSFIELD_MUNI/MA    KPSF    N42 25 36.6     W073 17 34.5    1194.000000    15.000000  1
P_K_AIRPARK/RAEFORD_NC K5W4 N35 01 01.2 W079 10 58.8  304  6  1
PLYMOUTH_MUNI/IN      KC65    N41 21 54.5     W086 18 1.8     800.000000    2.000000  1
POPE_AFB/FAYETTEVILLE_NC KPOB    N35 10 15.2     W079 00 52.1    218.000000    7.000000  1
PORT_COLUMBUS_INTL/OH KCMH    N39 59 52.7     W082 53 30.8    815.000000    5.000000  1
PORT_MEADVILLE/PA_(GKJ) K2G6    N41 37 35.5     W080 12 53.0    1400.000000    8.000000  1
PORTLAND_INTL/OR      KPDX    N45 35 19.4     W122 35 51.0    30.000000    -20.000000  1
PORTLAND_INTL_JETPORT/ME KPWM    N43 38 46.2     W070 18 31.5    74.000000    17.000000  1
POSEY_FIELD/HALEYVILLE_AL K1M4    N34 16 49.3     W087 36 1.6     930.000000    1.000000  1
POTTSTOWN_LIMERICK/PA KPTW N40 13 58.8 W075 32 59.9  309  12  1
POWELL_MUNI/WY        KPOY    N44 52 4.7      W108 47 34.8    5092.000000    -15.000000  0
PRINCESS_JULIANA_INTL/ST_MAARTEN TNCM N18 01 58.8 W063 07 01.2  13  12  1
PUERTO_PLATA_INTL/DOMINICAN_REP  MDPP    N19 45 32.0     W070 33 54.0    16.000000    7.000000  1
PULASKI_CO-WILSON_FLD/SOMERSET_KY KSME    N37 03 15.1     W084 36 53.8    927.000000  3.000000  1
PURDUE_UNIVERSITY/LAFAYETTE KLAF    N40 24 44.3     W086 56 12.8    606.000000    1.000000  0
QUAD_CITY_INTL/MOLINE_IL KMLI    N41 26 54.7     W090 30 27.1    590.000000    -1.000000  1
QUONSET_STATE_ARPT/N_KINGSTOWN_RI KOQU N41 36 00.0 W071 25 01.2  19  15  1
RAFAEL_HERNANDEZ/AGUADILLA_PR  TJBQ    N18 29 37.7     W067 07 58.6    237.000000    10.000000  1
RALEIGH_CO_MEMORIAL/BECKLEY_WV KBKW    N37 47 14.4     W081 07 27.0    2504.000000    6.000000  1
RALEIGH-DURHAM_INTL/NC KRDU    N35 52 39.5     W078 47 14.9    435.000000    7.000000  1
RANDOLPH_AFB/UNIVERSAL_CITY_TX KRND N29 31 58.8 W098 16 58.8  762  -7  1
READING_REGL-CARL_A._SPAATZ_FLD/PA KRDG  N40 22 42.6   W075 57 54.9    344.000000    12.000000  1
REDSTONE_AAF/HUNTSVILLE_AL KHUA N34 40 58.8 W086 40 58.8  685  0
REINA_SOFIA/TENERIFE_SUR_SPAIN   GCTS    N28 02 34.0     W016 34 14.0   210.000000    10.000000  1
REPUBLIC/FARMINGDALE_NY KFRG    N40 43 43.6     W073 24 48.3    82.000000    14.000000  1
RICHARD_B_RUSSELL/ROME_GA KRMG    N34 21 2.2      W085 09 28.9    644.000000    2.000000  1
RICHMOND_INTL/VA      KRIC    N37 30 18.6     W077 19 10.8    167.000000    9.000000  1
RICKENBACKER_INTL/COLUMBUS_OH KLCK N39 49 01.2 W082 55 01.2  744  5  1
ROANOKE_REGL-WOODRUM_FIELD/VA KROA    N37 19 31.7     W079 58 31.5    1176.000000    6.000000  1
ROCK_HILL-YORK_CO-BRYANT_FIELD/SC K29J    N34 59 16.2     W081 03 25.8   667.000000    5.000000  1
ROCKINGHAM-HAMLET/NC K45J    N34 53 27.9     W079 45 32.6    358.000000    7.000000  1
ROCKVILLE/RICHMOND_VA K0VA5   N37 41 39.5     W077 39 42.0    280.000000    8.000000  0
ROCKY_MOUNT-WILSON_REGL/NC KRWI    N35 51 18.0     W077 53 34.6    159.000000    8.000000  0
ROGERS_MUNI-CARTER_FIELD/AR KROG    N36 22 20.3     W094 06 24.7    1353.000000    -4.000000  1
ROMEO_STATE/MI        KD98    N42 47 49.2     W082 58 31.0    745.000000    6.000000  1
RONALD_REAGAN_WASHINGTON_NATIONAL/DC KDCA    N38 51 7.5   W077 02 15.8   16.000000    9.000000  1
ROSARIO_SEAPLANE_BASE/WA KW49    N48 38 44.4     W122 52 4.7     0.000000    -21.000000  0
ROWAN_CO/SALISBURY_NC KRUQ    N35 38 45.2     W080 31 13.1    773.000000    6.000000  1
SABRE AHP/FT_CAMPBELL-CLARKSVILLE_TN   KEOD  N36 34 1    W087 28 50.0  588.000000    7.000000   1
SALINA_MUNI/KS        KSLN    N38 47 29.3     W097 39 2.2     1273.000000    -7.000000  0
SALISBURY-OCEAN_CITY_WICOMICO_REGL/MD KSBY    N38 20 25.9   W075 30 37.0  52.000000  12.000000  1
SALT_LAKE_CITY_INTL/UT KSLC    N40 47 18.2     W111 58 40.0    4227.000000    -14.000000  1
SAMPSON_CO/CLINTON_NC KCTZ N34 58 32.2 W078 21 52.6  148  8  1
SAMUELS_FIELD/BARDSTOWN_KY KBRY    N37 48 51.6     W085 29 58.7    669.000000    3.000000  1
SAN_ANGELO_REGL-MATHIS_FIELD/TX KSJT    N31 21 27.9     W100 29 46.7    1919.000000  -8.000000  1
SAN_ANTONIO_INTL/TX   KSAT    N29 32 1.3      W098 28 11.2    809.000000    -8.000000  1
SAN_DIEGO_INTL-LINDBERGH_FIELD/CA KSAN    N32 44 0.8      W117 11 22.8    14.000000 -13.000000  1
SANFORD_REGL/MAINE KSFM N43 23 59.9 W070 43 01.2  244  17  1
SAN_FRANCISCO_INTL/CA KSFO    N37 37 8.4      W122 22 29.4    11.000000    -17.000000  1
SAN_JOSE_INTL/CA      KSJC    N37 21 42.7     W121 55 44.4    58.000000    -16.000000  1
SANGSTER_INTL/MONTEGO_BAY_JAMAICA   MKJS    N18 30 1.0      W077 54 57.0  4.000000    3.000000  1
SANTA_MONICA_MUNI/CA  KSMO    N34 00 57.0     W118 27 4.7     175.000000    -14.000000  1
SAO_PAULO_INTL/BRAZIL SBGR S23 26 06.0 W046 28 22.0  2459  19  1
SARASOTA/BRANDENTON_INTL/FL KSRQ    N27 23 43.2     W082 33 14.8    27.000000    2.000000  1
SARATOGA_CO/SARATOGA_SPRINGS_NY K5B2    N43 03 4.5      W073 51 40.3  433.000000    14.000000  1
SAVANNAH_INTL/GA      KSAV    N32 07 39.3     W081 12 7.7     50.000000    4.000000  1
SCHENECTADY_CO/NY     KSCH    N42 51 8.8      W073 55 43.9    378.000000    14.000000  1
SCOTT_AFB-MIDAMERICA/BELLEVILLE_IL KBLV N38 32 59.9 W089 50 59.9  459  -2  1
SEATTLE-TACOMA_INTL/WA KSEA    N47 26 56.3     W122 18 33.5    429.000000    -20.000000  1
SENECA_CO/TIFFIN_OH   K16G    N41 05 38.6     W083 12 45.0    786.000000    5.000000  1
SEYMOUR_JOHNSON_AFB/GOLDSBORO_NC KGSB N35 19 58.8 W077 58 01.2  110  8  1
SHANGHAI-HONGQIAO/CHINA ZSSS N31 11 59.9 E121 20 01.2  9  5  1
SHANNON/FREDERICKSBURG_VA KEZF    N38 16 0.6      W077 26 57.1    85.000000    10.000000  1
SHAW_AFB/SUMTER_SC KSSC N33 58 01.2 W080 28 01.2  242  5  1
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SHELBY_CO/ALABASTER_AL_(EET) K21A    N33 10 40.1     W086 46 59.7    584.000000    0.000000  1
SHENANDOAH_VALLEY_REGL/STAUNTON_VA KSHD    N38 15 49.8  W078 53 47.2  1201.000000    7.000000  1
SHERMAN_AAF/FT_LEAVENWORTH_KS KFLV    N39 22 6.0      W094 54 52.9    772.000000    -5.000000  1
SILER_CITY_MUNICIPAL/NC K5W8    N35 42 10.5     W079 30 19.1    614.000000    7.000000  1
SIMMONS_AAF-FT_BRAGG/NC KFBG    N35 07 54.6     W078 56 12.1    242.000000    7.000000  1
SIMON_BOLIVAR_INTL/EQUADOR SEGU S02 09 12.0 W079 53 01.2  17  -1  1
SKY_HAVEN/ENDERLIN_ND K5N4    N46 37 37.9     W097 37 13.4    1147.000000    -7.000000  0
SMITH_FIELD/FORT_WAYNE_IN KSMD    N41 08 36.1     W085 09 10.0    834.000000    3.000000  1
SMITH_REYNOLDS/WINSTON_SALEM_NC KINT    N36 08 1.4      W080 13 19.2    969.000000    7.000000  1
SMYRNA_ARPT/TN         KMQY    N36 00 32.3     W086 31 12.3    543.000000    1.000000  1
SOUTH_BEND_REGL/IN    KSBN    N41 42 32.2     W086 19 6.5     799.000000    2.000000  1
SOUTH_CAPITAL_STREET_HELIPORT/DC K09W    N38 52 7.4      W077 00 26.9    10.000000    9.000000  0
SOUTH_JERSEY_REGL/MT_HOLLY_NJ_(VAY) K7MY  N39 56 34.4   W074 50 44.6    53.000000    12.000000  1
SOUTHERN_ILLINOIS-CARBONDALE/IL KMDH    N37 46 41.1     W089 15 7.3   411.000000    -1.000000  1
SOUTHWEST_FLORIDA_INTL/FT_MYERS_FL KRSW    N26 32 10.2     W081 45 18.6  30.000000    2.000000  1
SPARTANBURG_DOWNTOWN_MEMORIAL/SC KSPA    N34 54 56.6     W081 57 23.4   801.000000    5.000000  1
SPIRIT_OF_ST_LOUIS/MO KSUS    N38 39 42.7     W090 39 4.4     463.000000    -2.000000  1
SPRINGDALE_MUNI/AR    KASG    N36 10 35.1     W094 07 9.3     1353.000000    -4.000000  1
SPRINGFIELD-BECKLEY_MUNI/OH KSGH    N39 50 25.0     W083 50 24.5    1052.000000    4.000000  1
SPRINGFIELD-BRANSON_REGL/MO KSGF    N37 14 39.6     W093 23 12.7    1267.000000    -3.000000  1
SPRINGFIELD-ROBERTSON_CO/TN KM91    N36 32 14.1     W086 55 14.5    706.000000    1.000000  1
SPRUCE_CREEK/DAYTONA_BEACH_FL_(7FL6) K44J N29 04 58.8 W081 02 59.9  24  3  0
ST_AUGUSTINE/FL        KSGJ    N29 57 33.3     W081 20 23.1    10.000000    4.000000  1
ST_CLAIR_CO_INTL/PORT_HURON_MI KPHN    N42 54 39.4     W082 31 43.9    650.000000    7.000000  1
ST_GEORGE_MUNI/UT      KSGU    N37 05 26.1     W113 35 35.0    2941.000000    -14.000000  0
ST_LOUIS_DOWNTOWN-PARKS/CAHOKIA_IL KCPS  N38 34 14.6   W090 09 22.4    413.000000    -1.000000  1
ST_LOUIS_INTL-LAMBERT_FIELD/MO KSTL    N38 44 51.7     W090 21 36.0    604.000000    0.000000  1
ST_LOUIS_REGL/ALTON_IL KALN    N38 53 25.0     W090 02 45.8    544.000000    -2.000000  1
ST_LUCIE_CO_INTL/FT_PIERCE_FL KFPR    N27 29 42.2     W080 22 5.8     23.000000    4.000000  0
ST_PETERSBURG-CLEARWATER_INTL/FL KPIE    N27 54 38.7     W082 41 14.8    11.000000    2.000000  1
STATESVILLE_MUNI/NC    KSVH    N35 45 55.0     W080 57 24.2    965.000000    5.000000  1
STEWART_INTL/NEWBURGH_NY KSWF    N41 30 14.7     W074 06 17.4    491.000000    14.000000  1
STUART_POWELL_FLD/DANVILLE_KY KDVK N37 34 58.8 W084 46 01.2  1022  3  1
SUFFOLK_MUNI/VA        KSFQ    N36 40 56.5     W076 36 6.7     72.000000    10.000000  1
SUGAR_LAND_MUNI-HULL_FLD/HOUSTON_TX KSGR    N29 37 20.1   W095 39 23.5  82.000000    -5.000000  1
SULLIVAN_CO_INTL/MONTICELLO_NY KMSV N41 42 00.0 W074 47 59.9  1403  12  1
SUMMERSVILLE_ARPT/WV_(SXL) KI07    N38 13 53.9     W080 52 14.9    1820.000000    5.000000  1
SUMTER_MUNI/SC         KSMS    N33 59 44.5     W080 21 41.4    182.000000    5.000000  1
SUSSEX_CO/GEORGETOWN_DE KGED    N38 41 21.1     W075 21 32.0    50.000000    11.000000  1
SW_GEORGIA_REGL/ALBANY_GA KABY    N36 00 32.3     W086 31 12.3    197.000000    2.000000  1
SYRACUSE-HANCOCK_INTL/NY KSYR    N43 06 40.3     W076 06 22.7    421.000000    13.000000  1
TALLAHASSEE_REGL/FL   KTLH    N30 23 47.5     W084 21 1.2     81.000000    1.000000  1
TAMPA_INTL/FL          KTPA    N27 58 31.7     W082 31 59.7    26.000000    2.000000  1
TAPACHULA_INTL/CHIAPAS_MEXICO MMTP N14 48 00.0 W092 22 01.2  96  -5  1
TAZEWELL_CO/RICHLANDS_VA K6V3    N37 03 49.5     W081 47 53.8    2652.000000    6.000000  1
TERRE_HAUTE_INTL-HULMAN_FLD/IN KHUF    N39 27 5.3      W087 18 27.2    589.000000    2.000000  1
TETERBORO/NJ                KTEB    N40 51 0.4      W074 03 39.0    9.000000    12.000000  1
THE_EASTERN_IOWA_ARPT/CEDAR_RAPIDS_IA KCID    N41 53 4.5   W091 42 39.1 864.000000   -2.000000  1
THE_FLORIDA_KEYS_MARATHON_ARPT/FL KMTH    N24 43 34.1     W081 03 5.0    7.000000    2.000000  0
THEODORE_F_GREEN_STATE/PROVIDENCE_RI KPVD    N41 43 26.4  W071 25 41.6  55.000000    15.000000  1
THOMASVILLE_MUNI/GA   KTVI    N30 54 5.6      W083 52 52.8    264.000000    2.000000  1
TIMEHRI_INTL/GUYANA SYTM N06 29 18.0 W058 15 57.0  95  13  1
TINKER_AFB/OKLAHOMA_CITY_OK KTIK N35 25 01.2 W097 22 58.8  1291  -7  1
TOCCOA-LETOURNEAU_FLD/GA KTOC    N34 35 37.6     W083 17 44.9    994.000000    5.000000  1
TOKEEN_SEAPLANE_BASE/AK K57A    N55 56 13.7     W133 19 36.2    0.000000    -26.000000  0
TOKYO-NARITA/JAPAN RJAA N35 46 01.2 E140 23 18.0  135  7  1
TOLEDO_EXPRESS/OH      KTOL    N41 35 12.5     W083 48 28.2    684.000000    5.000000  1
TORONTO-BUTTONVILLE/ON CYKZ    N43 51 44.0     W079 22 12.0    650.000000    10.000000  1
TORONTO-LESTER_B_PEARSON_INTL/ON CYYZ    N43 40 38.0     W079 37 50.0    569.000000  10.000000  1
TRAVIS_AFB/FAIRFIELD_CA KSUU N38 16 01.2 W121 55 58.8  62  -16  1
TRENTON_MERCER/NJ      KTTN    N40 16 36.1     W074 48 48.5    213.000000    12.000000  1
TRI_CITY_INTL/SAGINAW_MI KMBS    N43 31 58.5     W084 04 46.7    668.000000    5.000000  1
TRI-CITIES_REGL/BRISTOL_TN KTRI    N36 28 30.8     W082 24 26.7    1519.000000    5.000000  1
TRI-COUNTY/AHOSKIE_NC KASJ    N36 17 51.1     W077 10 15.1    68.000000    10.000000  1
TRIPLE_W/RALEIGH_NC K5W5 N35 37 01.2 W078 42 00.0  244  7  0
TRI-STATE-M_J_FERGUSON_FLD/HUNTINGTON_WV KHTS    N38 22 0.0  W082 33 28.9 828.000000  6.000000  1
TUCSON_INTL/AZ         KTUS    N32 06 57.9     W110 56 27.7    2643.000000    -12.000000  1
TULSA_INTL/OK          KTUL    N36 11 54.1     W095 53 17.7    677.000000    -6.000000  1
TUPELO_REGL/MS         KTUP    N34 16 5.2      W088 46 11.6    346.000000    -1.000000  1
TWEED-NEW_HAVEN/CT    KHVN    N41 15 50.0     W072 53 13.6    14.000000    14.000000  1
TWIN_COUNTY/GALAX-HILLSVILLE_VA KHLX N36 46 01.2 W080 49 01.2  2693  6  1
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TWIN_LAKES/MOCKSVILLE_NC K8A7    N35 54 53.7     W080 27 24.5    818.000000    6.000000  1
UNION_CO/MARYSVILLE_OH KI78 N40 13 58.8 W083 20 59.9  1021  5  1
UNIVERSITY_PARK/STATE_COLLEGE_PA KUNV    N40 50 57.4     W077 50 55.3   1239.000000  10.000000  0
UNIVERSITY-OXFORD_ARPT/MS  KUOX    N34 23 3.5      W089 32 7.1     452.000000    -1.000000  0
VAN_NUYS/CA            KVNY    N34 12 35.3     W118 29 23.9    799.000000    -14.000000  1
VENICE_MUNI/FL         KVNC    N27 04 17.8     W082 26 25.2    18.000000    2.000000  1
VERO_BEACH_MUNI/FL     KVRB    N27 39 20.0     W080 25 4.6     24.000000    4.000000  0
VICKSBURG_MUNI/MS      KVKS    N32 14 21.5     W090 55 42.4    106.000000    -3.000000  0
VINTON_CO/MCARTHUR_OH K22I N39 19 58.8 W082 27 00.0  958  5  0
VIRGINIA_HIGHLANDS/ABINGDON_VA KVJI    N36 41 13.6     W082 02 0.0     2088.000000    5.000000  1
VIRGINIA_TECH/BLACKSBURG_VA KBCB    N37 12 28.2     W080 24 30.0    2132.000000    6.000000  1
W_K_KELLOGG/BATTLE_CREEK_MI KBTL    N42 18 26.2     W085 15 5.3     952.000000    4.000000  1
WADE_PLANTATION/SYLVANIA_GA KA00    N32 58 37.6     W081 32 10.4    146.000000    4.000000  0
WADSWORTH_MUNI/OH      K3G3    N41 00 5.7      W081 45 18.5    987.000000    7.000000  1
WALLOPS_FLIGHT_FACILITY/VA KWAL    N37 56 24.7     W075 27 59.0    40.000000    10.000000  1
WARNER_ROBINS_AFB/GA KWRB N32 37 58.8 W083 35 59.9  295  2  1
WARREN_FIELD/WASHINGTON_NC KOCW    N35 34 13.7     W077 02 59.3    38.000000    8.000000  1
WARRENTON-FAUQUIER/VA KW66 N38 34 58.8 W077 43 01.2  329  9  1
WASHINGTON_CO/PA       KAFJ    N40 08 11.4     W080 17 24.7    1184.000000    8.000000  1
WASHINGTON_DULLES_INTL/DC KIAD    N38 56 40.3     W077 27 20.9    313.000000    9.000000  1
WASHINGTON_EXEC-HYDE_FLD/DC KW32    N38 44 53.7     W076 55 58.1    249.000000    9.000000  0
WATERBURY-OXFORD/CT    KOXC    N41 28 42.8     W073 08 6.9     726.000000    14.000000  1
WATERLOO_MUNI/IOWA    KALO N42 34 01.2 W092 24 00.0  873  -3  1
WATERLOO-GUELPH_REGL/ON_CANADA CYKF N43 28 01.2 W080 22 58.8  1040  9  1
WATERTOWN_INTL/NY      KART    N43 59 30.9     W076 01 18.3    325.000000    13.000000  1
WAUKEGAN_REGL/CHICAGO_IL KUGN    N42 25 19.8     W087 52 4.5     727.000000    1.000000  1
WAYNE_CO/WOOSTER_OH KBJJ N40 52 01.2 W081 52 58.8  1135  7  1
WEIDE_AHP/EDGEWOOD_ARSENAL_MD KEDG    N39 23 31.4     W076 17 27.8    30.000000    10.000000  1
WELLSVILLE_MUNI-TARANTINE_FLD/NY KELZ    N42 06 34.2     W077 59 31.0   2123.000000  10.000000  0
WENDELL_H_FORD/HAZARD_KY KK20 N37 22 58.8 W083 16 01.2  1253  4  1
WEST_MEMPHIS_MUNI/AR  KAWM    N35 08 6.2      W090 14 4.0     212.000000    -1.000000  1
WESTCHESTER_CO/WHITE_PLAINS_NY KHPN    N41 04 1.0      W073 42 27.3    439.000000    13.000000  1
WESTERLO/NY            K4B5    N42 31 20.3     W074 01 43.5    1400.000000    14.000000  0
WESTERLY_STATE/RI      KWST    N41 20 58.6     W071 48 12.2    81.000000    15.000000  1
WESTOVER_ARB-METRO/SPRINGFLD_MA KCEF    N42 11 52.3     W072 31 48.3    245.000000    15.000000  1
WHEELER-SACK_AAF/FT_DRUM_NY KGTB N44 02 59.9 W075 43 58.8  691 13  1
WICHITA/MID-CONTINENT/KS KICT    N37 38 59.9     W097 25 59.0    1332.000000    -7.000000  1
WILEY_POST/OKLAHOMA_CITY_OK KPWA    N35 32 4.4      W097 38 50.0    1299.000000    -7.000000  1
WILKES_CO/N_WILKESBORO_NC KUKF    N36 13 22.2     W081 05 54.0    1300.000000    5.000000  0
WILKES-BARRE/SCRANTON_INTL/PA KAVP    N41 20 17.3     W075 43 27.4    962.000000    12.000000  1
WILL_ROGERS_WORLD/OKLAHOMA_CITY_OK KOKC  N35 23 35.1  W097 36 2.6    1295.000000    -7.000000  1
WILLIAM_M_TUCK/SOUTH_BOSTON_VA KW78    N36 42 36.2     W078 50 52.9    420.000000    8.000000  1
WILLIAM_P_GWINN/JUPITER_FL KUTX    N26 54 30.2     W080 19 44.2    28.000000    3.000000  0
WILLIAM_P_HOBBY/HOUSTON_TX KHOU    N29 38 43.5     W095 16 44.0    46.000000    -5.000000  1
WILLIAMS_CO/BRYAN_OH  K0G6    N41 28 2.5      W084 30 23.6    730.000000    5.000000  1
WILLIAMSBURG-JAMESTOWN/VA KJGG    N37 14 21.0     W076 42 57.9    49.000000    10.000000  1
WILLIAMSON_CO_REGL/MARION_IL KMWA N37 45 00.0 W089 01 01.2  472  -1  1
WILLIAMSPORT_REGL/PA  KIPT    N41 14 30.6     W076 55 15.9    529.000000    11.000000  1
WILLOUGHBY_LOST_NATION_MUNI/OH KLNN    N41 41 2.1      W081 23 25.1    626.000000    8.000000  1
WILLOW_GROVE_NAS-JRB/PA KNXX    N40 12 1.4      W075 08 52.6    362.000000    12.000000  1
WILLOW_RUN/DETROIT_MI KYIP    N42 14 16.5     W083 31 49.5    716.000000    6.000000  1
WILMINGTON_INTL/NC     KILM    N34 16 14.2     W077 54 9.2     32.000000    7.000000  1
WINCHESTER_REGL/VA     KOKV    N39 08 36.7     W078 08 40.0    727.000000    10.000000  1
WINDER-BARROW_ARPT/GA KWDR N33 58 58.8 W083 40 01.2  943  3  1
WINDSOR/ON_CANADA      CYQG    N42 16 29.0     W082 57 30.0    622.000000    6.000000  1
WINGS_FIELD/PHILADELPHIA_PA KN67    N40 08 11.3     W075 16 1.3     302.000000    11.000000  1
WINTER_HAVEN'S_GILBERT_ARPT/FL KGIF    N28 03 46.5     W081 45 11.9    145.000000    2.000000  1
WITHAM_FIELD/STUART_FL KSUA    N27 10 54.1     W080 13 15.9    18.000000    5.000000  1
WITTMAN_REGL/OSHKOSH_WI KOSH N43 58 58.8 W088 32 59.9  808  1  1
WOOD_CO-G_R_WILSON_FLD/PARKERSBURG_WV KPKB    N39 20 42.4   W081 26 21.1  858.000000  7.000000  0
WOODWARD_FLD/CAMDEN_SC KCDN    N34 17 0.9      W080 33 53.5    302.000000    5.000000  0
WORCESTER_REGL/MA      KORH    N42 16 2.4      W071 52 32.6    1009.000000    15.000000  1
WRIGHT_PATTERSON_AFB/DAYTON_OH KFFO    N39 49 34.2     W084 02 53.8    823.000000    4.000000  1
WYNNE_MUNI/AR          KM65    N35 13 53.8     W090 45 41.6    370.000000    -3.000000  0
YAMPA_VALLEY/STEAMBOAT_SPGS_CO KHDN    N40 28 52.2     W107 13 3.6     6602.000000  -13.000000  0
YEAGER/CHARLESTON_WV  KCRW    N38 22 23.3     W081 35 35.5    982.000000    6.000000  1
YOKOTA_AIRBASE/TOKYO_JAPAN RJTY N35 44 54.6 E139 20 54.5  461  7  1
YORK_ARPT/PA           KTHV    N39 55 1.2      W076 52 22.9    480.000000    10.000000  1
YOUNGSTOWN_ELSER_METRO/OH K4G4 N40 58 01.2 W080 40 58.8  1070  8  1
YOUNGSTOWN-WARREN_REGL/OH KYNG    N41 15 38.6     W080 40 44.7    1196.000000    8.000000  1
ZURICH/SWITZERLAND     LSZH    N47 27 34.0     E008 32 57.0    1416.000000    0.600000  1
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Appendix D

Flight Data for SATS Airports

Flight Operations in the Virginia SATS AOI (CY 2000)						
	Terminal Area Forecast (TAF) Data					
SATS Cluster	ICAO Identifier	Air Carrier	Air Taxi/ Commuter	General Aviation	Military	Airport Total
1	***DCA**	175138	76500	58279	20821	330738
	GAI	0	10700	38200	5	48905
	W32	0	300	600	200	1100
	***IAD**	116933	256128	65225	7664	445950
	JYO	0	800	5635	0	6435
	HEF	1	3161	94154	573	97889
2	***BWI**	186038	77224	30919	3366	297547
	FDK	0	2908	37379	1238	41525
	MTN	0	210	71191	6166	77567
	W54	0	175	25000	140	25315
3	HGR	1	4118	32873	882	37874
	***MRB**	0	250	15000	20000	35250
	OKV	0	1000	25746	0	26746
4	FCI	0	500	10000	100	10600
	OFP	0	0	14000	0	14000
	PTB	0	1200	7500	5500	14200
	***RIC**	40871	33756	38662	8267	121556
5	BCB	0	600	8502	570	9672
	PSK	0	1400	3600	1500	6500
	***ROA**	6710	30465	28211	935	66321
6	FVX	0	125	2500	125	2750
	***LYH**	10	12708	23476	706	36900
7	CPK	0	1400	19900	1000	22300
	***ORF**	34983	22863	75743	0	133589
	***PHF**	2439	14804	65226	20434	102903
	PVG	0	2005	65000	300	67305
8	0A9	0	312	1845	0	2157
	***TRI**	6239	15046	36240	494	58019
	VJI	0	900	7000	100	8000

Flight Operations in the Virginia SATS AOI (CY 2000)						
	Terminal Area Forecast (TAF) Data					
SATS Cluster	ICAO Identifier	Air Carrier	Air Taxi/ Commuter	General Aviation	Military	Airport Total
9	BUY	0	890	15000	450	16340
	DAN	0	200	12000	225	12425
	***GSO**	46513	25239	51391	726	123869
	INT	107	2912	40510	67	43596
	MTV	0	600	7155	150	7905
10	***CHO**	27	25342	32709	1232	59310
	SHD	0	2653	7665	93	10411
11	BKW	8850	3400	4000	900	17150
	BLF	1800	35	9100	100	11035
	HSP	0	0	4000	300	4300
	***LWB**	261	2851	15396	630	19138
12	2N9	0	800	16000	2000	18800
	AVC	0	0	560	0	560
	HNZ	0	100	9000	1000	10100
	***RDU**	108174	61372	74451	5072	249069
	TDF	0	550	18000	1200	19750
Grand Total:		**165732**	**126944**	**316937**	**14145**	**623758**

Flight Operations in the Virginia SATS AOI on 11/12/2000 (TAF)

SATS Cluster	ICAO Identifier	AC Dep	AC Arr	AT/Comm Departures	AT/Comm Arrivals	GA Dep	GA Arr	Mil Dep	Mil Arr
1	***DCA**	297	304	54	54	88	92	14	15
	GAI	0	0	8	8	58	60	1	1
	W32	0	0	1	1	1	1	1	1
	***IAD**	246	247	321	317	54	63	4	4
	JYO	0	0	2	1	5	6	0	0
	HEF	1	1	4	4	78	91	1	1
2	***BWI**	295	296	61	65	48	43	4	4
	FDK	0	0	3	3	58	51	2	2
	MTN	0	0	1	1	111	97	6	7
	W54	0	0	1	1	39	35	1	1
3	HGR	1	1	4	4	34	33	27	24
	***MRB**	0	0	1	1	16	15	612	540
	OKV	0	0	1	1	27	26	0	0
4	FCI	0	0	1	1	12	11	1	1
	OFP	0	0	0	0	17	15	0	0
	PTB	0	0	1	1	9	8	6	6
	***RIC**	63	59	26	28	47	41	9	9
5	BCB	0	0	1	1	9	9	18	16
	PSK	0	0	2	2	4	4	46	41
	***ROA**	12	12	26	26	29	29	29	26
6	FVX	0	0	1	1	3	3	4	4
	***LYH**	1	1	11	11	24	24	22	20
7	CPK	0	0	2	2	8	7	206	180
	***ORF**	70	73	23	24	28	27	0	0
	***PHF**	5	6	15	16	24	23	4192	3668
	PVG	0	0	2	3	24	23	62	54
8	0A9	0	0	1	1	2	2	0	0
	***TRI**	12	12	13	13	37	37	16	14
	VJI	0	0	1	1	8	7	4	3

			Flight Operations in the Virginia SATS AOI on 11/12/2000 (TAF)						
SATS Cluster	ICAO Identifier	AC Dep	AC Arr	AT/Comm Departures	AT/Comm Arrivals	GA Dep	GA Arr	Mil Dep	Mil Arr
9	BUY	0	0	1	1	14	14	2	2
	DAN	0	0	1	1	11	11	1	1
	***GSO**	66	67	19	19	47	47	3	3
	INT	1	1	3	3	37	37	1	1
	MTV	0	0	1	1	7	7	1	1
10	***CHO**	1	1	22	22	34	33	38	34
	SHD	0	0	3	3	8	8	3	3
11	BKW	16	16	3	3	5	4	28	25
	BLF	4	4	1	1	10	10	4	3
	HSP	0	0	0	0	5	4	10	9
	***LWB**	1	1	3	3	16	16	20	18
12	2N9	0	0	1	1	13	13	5	5
	AVC	0	0	0	0	1	1	0	0
	HNZ	0	0	1	1	8	8	3	3
	***RDU**	224	220	40	39	58	59	13	13
	TDF	0	0	1	1	15	15	3	3
Grand Total:		**1316**	**1322**	**688**	**691**	**1191**	**1170**	**5423**	**4766**

Flight Operations in the Virginia SATS AOI (CY 2010)						
	Terminal Area Forecast (TAF) Data					
SATS Cluster	ICAO Identifier	Air Carrier	Air Taxi/ Commuter	General Aviation	Military	Airport Total
1	***DCA**	189473	79378	58279	20821	347951
	GAI	0	10700	38200	5	48905
	W32	0	300	600	200	1100
	***IAD**	165584	291407	68408	7664	533063
	JYO	0	800	7124	0	7924
	HEF	1	3161	108281	573	112016
2	***BWI**	243487	81940	36973	3366	365766
	FDK	0	2908	37379	1238	41525
	MTN	0	210	71191	6166	77567
	W54	0	175	25000	140	25315
3	HGR	1	4118	32873	882	37874
	***MRB**	0	250	15000	20000	35250
	OKV	0	1000	29481	0	30481
4	FCI	0	500	10000	100	10600
	OFP	0	0	14000	0	14000
	PTB	0	1200	7500	5500	14200
	***RIC**	43865	47036	36790	8267	135958
5	BCB	0	600	10512	570	11682
	PSK	0	1400	3600	1500	6500
	***ROA**	6710	37185	28211	935	73041
6	FVX	0	125	2500	125	2750
	***LYH**	10	13270	25927	706	39913
7	CPK	0	1400	19900	1000	22300
	***ORF**	34983	28875	86562	0	150420
	***PHF**	2743	14804	74452	20434	112433
	PVG	0	2005	65000	300	67305
8	0A9	0	312	1845	0	2157
	***TRI**	6239	18472	41366	494	66571
	VJI	0	900	7000	100	8000

Flight Operations in the Virginia SATS AOI (CY 2010)						
	Terminal Area Forecast (TAF) Data					
SATS Cluster	ICAO Identifier	Air Carrier	Air Taxi/ Commuter	General Aviation	Military	Airport Total
9	BUY	0	890	15000	450	16340
	DAN	0	200	12000	225	12425
	***GSO**	86929	35800	55421	726	178876
	INT	107	2912	40510	67	43596
	MTV	0	600	7933	150	8683
10	***CHO**	27	31693	36623	1232	69575
	SHD	0	2988	7665	93	10746
11	BKW	8850	3400	4000	900	17150
	BLF	1800	35	9100	100	11035
	HSP	0	0	4000	300	4300
	***LWB**	261	3155	17595	630	21641
12	2N9	0	800	16000	2000	18800
	AVC	0	0	560	0	560
	HNZ	0	100	9000	1000	10100
	***RDU**	132496	65851	80697	5072	284116
	TDF	0	550	18000	1200	19750
Grand Total:		**923566**	**793405**	**1298058**	**115231**	**3130260**

Flight Operations in the Virginia SATS AOI on 11/12/2010 (TAF)

SATS Cluster	ICAO Identifier	AC Dep	AC Arr	AT/Comm Departures	AT/Comm Arrivals	GA Dep	GA Arr	Mil Dep	Mil Arr
1	***DCA**	321	329	56	56	88	92	14	15
	GAI	0	0	8	8	58	60	1	1
	W32	0	0	1	1	1	1	1	1
	***IAD**	348	349	366	361	57	66	4	4
	JYO	0	0	2	1	6	7	0	0
	HEF	1	1	4	4	90	105	1	1
2	***BWI**	386	388	65	69	58	51	4	4
	FDK	0	0	3	3	58	51	2	2
	MTN	0	0	1	1	111	97	6	7
	W54	0	0	1	1	39	35	1	1
3	HGR	1	1	4	4	34	33	27	24
	***MRB**	0	0	1	1	16	15	612	540
	OKV	0	0	1	1	30	30	0	0
4	FCI	0	0	1	1	12	11	1	1
	OFP	0	0	0	0	17	15	0	0
	PTB	0	0	1	1	9	8	6	6
	***RIC**	68	64	37	39	44	39	9	9
5	BCB	0	0	1	1	11	11	18	16
	PSK	0	0	2	2	4	4	46	41
	***ROA**	12	12	32	32	29	29	29	26
6	FVX	0	0	1	1	3	3	4	4
	***LYH**	1	1	12	12	27	26	22	20
7	CPK	0	0	2	2	8	7	206	180
	***ORF**	70	73	29	31	32	31	0	0
	***PHF**	6	6	15	16	27	27	4192	3668
	PVG	0	0	2	3	24	23	62	54
8	0A9	0	0	1	1	2	2	0	0
	***TRI**	12	12	16	16	42	42	16	14
	VJI	0	0	1	1	8	7	4	3

Flight Operations in the Virginia SATS AOI on 11/12/2010 (TAF)

SATS Cluster	ICAO Identifier	AC Dep	AC Arr	AT/Comm Departures	AT/Comm Arrivals	GA Dep	GA Arr	Mil Dep	Mil Arr
9	BUY	0	0	1	1	14	14	2	2
	DAN	0	0	1	1	11	11	1	1
	***GSO**	123	125	26	26	50	51	3	3
	INT	1	1	3	3	37	37	1	1
	MTV	0	0	1	1	8	8	1	1
10	***CHO**	1	1	27	27	38	37	38	34
	SHD	0	0	3	3	8	8	3	3
11	BKW	16	16	3	3	5	4	28	25
	BLF	4	4	1	1	10	10	4	3
	HSP	0	0	0	0	5	4	10	9
	***LWB**	1	1	3	3	18	18	20	18
12	2N9	0	0	1	1	13	13	5	5
	AVC	0	0	0	0	1	1	0	0
	HNZ	0	0	1	1	8	8	3	3
	***RDU**	274	269	43	42	63	64	13	13
	TDF	0	0	1	1	15	15	3	3
Grand Total:		**1646**	**1653**	**781**	**784**	**1249**	**1231**	**5423**	**4766**

Flight Operations in the Virginia SATS AOI (CY 2015)						
	Terminal Area Forecast (TAF) Data					
SATS Cluster	ICAO Identifier	Air Carrier	Air Taxi/ Commuter	General Aviation	Military	Airport Total
1	***DCA**	191375	80979	58279	20821	351454
	GAI	0	10700	38200	5	48905
	W32	0	300	600	200	1100
	***IAD**	190101	309047	70000	7664	576812
	JYO	0	800	7869	0	8669
	HEF	1	3161	115032	573	118767
2	***BWI**	273130	84474	40000	3366	400970
	FDK	0	2908	37379	1238	41525
	MTN	0	210	71191	6166	77567
	W54	0	175	25000	140	25315
3	HGR	1	4118	32873	882	37874
	***MRB**	0	250	15000	20000	35250
	OKV	0	1000	31349	0	32349
4	FCI	0	500	10000	100	10600
	OFP	0	0	14000	0	14000
	PTB	0	1200	7500	5500	14200
	***RIC**	45362	53677	35855	8267	143161
5	BCB	0	600	11518	570	12688
	PSK	0	1400	3600	1500	6500
	***ROA**	6710	40904	28211	935	76760
6	FVX	0	125	2500	125	2750
	***LYH**	10	13551	27153	706	41420
7	CPK	0	1400	19900	1000	22300
	***ORF**	34983	30557	92538	0	158078
	***PHF**	2909	14804	79065	20434	117212
	PVG	0	2005	65000	300	67305
8	0A9	0	312	1845	0	2157
	***TRI**	6239	20185	43929	494	70847
	VJI	0	900	7000	100	8000

Flight Operations in the Virginia SATS AOI (CY 2015)						
	Terminal Area Forecast (TAF) Data					
SATS Cluster	ICAO Identifier	Air Carrier	Air Taxi/ Commuter	General Aviation	Military	Airport Total
9	BUY	0	890	15000	450	16340
	DAN	0	200	12000	225	12425
	***GSO**	91000	39000	57436	726	188162
	INT	107	2912	40510	67	43596
	MTV	0	600	8323	150	9073
10	***CHO**	27	35112	38580	1232	74951
	SHD	0	3205	7665	93	10963
11	BKW	8850	3400	4000	900	17150
	BLF	1800	35	9100	100	11035
	HSP	0	0	4000	300	4300
	***LWB**	261	3307	18810	630	23008
12	2N9	0	800	16000	2000	18800
	AVC	0	0	560	0	560
	HNZ	0	100	9000	1000	10100
	***RDU**	144658	68091	83820	5072	301641
	TDF	0	550	18000	1200	19750
Grand Total:		**997524**	**838444**	**1335190**	**115231**	**3286389**

			Flight Operations in the Virginia SATS AOI on 11/12/2015 (TAF)						
SATS Cluster	ICAO Identifier	AC Dep	AC Arr	AT/Comm Departures	AT/Comm Arrivals	GA Dep	GA Arr	Mil Dep	Mil Arr
1	***DCA**	324	332	57	57	88	92	14	15
	GAI	0	0	8	8	58	60	1	1
	W32	0	0	1	1	1	1	1	1
	***IAD**	399	401	388	383	58	68	4	4
	JYO	0	0	2	1	7	8	0	0
	HEF	1	1	4	4	95	111	1	1
2	***BWI**	433	435	67	71	62	55	4	4
	FDK	0	0	3	3	58	51	2	2
	MTN	0	0	1	1	111	97	6	7
	W54	0	0	1	1	39	35	1	1
3	HGR	1	1	4	4	34	33	27	24
	***MRB**	0	0	1	1	16	15	612	540
	OKV	0	0	1	1	32	32	0	0
4	FCI	0	0	1	1	12	11	1	1
	OFP	0	0	0	0	17	15	0	0
	PTB	0	0	1	1	9	8	6	6
	***RIC**	70	66	42	44	43	38	9	9
5	BCB	0	0	1	1	12	12	18	16
	PSK	0	0	2	2	4	4	46	41
	***ROA**	12	12	35	35	29	29	29	26
6	FVX	0	0	1	1	3	3	4	4
	***LYH**	1	1	12	12	28	28	22	20
7	CPK	0	0	2	2	8	7	206	180
	***ORF**	70	73	31	32	34	33	0	0
	***PHF**	6	7	15	16	29	28	4192	3668
	PVG	0	0	2	3	24	23	62	54
8	0A9	0	0	1	1	2	2	0	0
	***TRI**	12	12	17	18	45	44	16	14
	VJI	0	0	1	1	8	7	4	3

Flight Operations in the Virginia SATS AOI on 11/12/2015 (TAF)

SATS Cluster	ICAO Identifier	AC Dep	AC Arr	AT/Comm Departures	AT/Comm Arrivals	GA Dep	GA Arr	Mil Dep	Mil Arr
9	BUY	0	0	1	1	14	14	2	2
	DAN	0	0	1	1	11	11	1	1
	***GSO**	128	131	28	28	52	53	3	3
	INT	1	1	3	3	37	37	1	1
	MTV	0	0	1	1	8	8	1	1
10	***CHO**	1	1	30	30	40	39	38	34
	SHD	0	0	3	3	8	8	3	3
11	BKW	16	16	3	3	5	4	28	25
	BLF	4	4	1	1	10	10	4	3
	HSP	0	0	0	0	5	4	10	9
	***LWB**	1	1	3	3	20	19	20	18
12	2N9	0	0	1	1	13	13	5	5
	AVC	0	0	0	0	1	1	0	0
	HNZ	0	0	1	1	8	8	3	3
	***RDU**	299	294	44	44	66	67	13	13
	TDF	0	0	1	1	15	15	3	3
Grand Total:		**1779**	**1789**	**823**	**827**	**1279**	**1261**	**5423**	**4766**

Terminal Area Forecast Data
Annual Operations

BWI

Year	Air Carrier	AT/Comm	GA	Military	Total
1997	153263	82923	21780	1635	259601
1998	160932	78385	24246	2598	266161
1999	182033	77070	30314	3366	292783
Totals:	496228	238378	76340	7599	818545

DCA

Year	Air Carrier	AT/Comm	GA	Military	Total
1997	179055	81260	49513	5100	314928
1998	172383	80390	50170	5368	308311
1999	174614	76424	58279	20821	330138
Totals:	526052	238074	157962	31289	953377

GSO

Year	Air Carrier	AT/Comm	GA	Military	Total
1997	40153	24349	51469	578	116549
1998	44026	22848	50585	726	118185
1999	45269	24043	50988	726	121026
Totals:	129448	71240	153042	2030	355760

IAD

Year	Air Carrier	AT/Comm	GA	Military	Total
1997	88566	188104	60514	6984	344168
1998	91908	216939	65953	7428	382228
1999	113088	252601	64907	7664	438260
Totals:	293562	657644	191374	22076	1164656

ORF

Year	Air Carrier	AT/Comm	GA	Military	Total
1997	36884	21820	75616	13	134333
1998	34983	20632	75585	13	131213
1999	34983	21808	74738	13	131542
Totals:	106850	64260	225939	39	397088

RDU

Year	Air Carrier	AT/Comm	GA	Military	Total
1997	91157	64636	74059	6297	236149
1998	103310	60477	73202	5072	242061
1999	105742	60924	73826	5072	245564
Totals:	300209	186037	221087	16441	723774

CODAS Data
Annual Operations

BWI			AT/Comm	AT/Comm				
Year	AC Dep	AC Arr	Departures	Arrivals	GA Dep	GA Arr	Mil Dep	Mil Arr
1997	222	218	66	72	31	40	5	6
1998	268	273	61	64	43	35	2	1
1999	296	298	60	62	44	29	0	1
Total:	786	789	187	198	118	104	7	8
% of Total Operations:	0.001584	0.001590	0.000784	0.000831	0.001546	0.001362	0.000921	0.001053

DCA			AT/Comm	AT/Comm				
Year	AC Dep	AC Arr	Departures	Arrivals	GA Dep	GA Arr	Mil Dep	Mil Arr
1997	278	287	52	56	89	88	18	19
1998	300	312	55	55	79	87	1	1
1999	312	312	60	54	69	73	2	2
Total:	890	911	167	165	237	248	21	22
% of Total Operations:	0.001692	0.001732	0.000701	0.000693	0.001500	0.001570	0.000671	0.000703

GSO			AT/Comm	AT/Comm				
Year	AC Dep	AC Arr	Departures	Arrivals	GA Dep	GA Arr	Mil Dep	Mil Arr
1997	57	59	14	14	50	52	6	7
1998	59	60	14	14	41	40	0	0
1999	66	66	23	23	46	47	1	1
Total:	182	185	51	51	137	139	7	8
% of Total Operations:	0.001406	0.001429	0.000716	0.000716	0.000895	0.000908	0.003448	0.003941

IAD			AT/Comm	AT/Comm				
Year	AC Dep	AC Arr	Departures	Arrivals	GA Dep	GA Arr	Mil Dep	Mil Arr
1997	153	151	222	213	55	70	2	6
1998	188	191	269	265	53	62	5	2
1999	275	276	333	335	50	52	2	1
Total:	616	618	824	813	158	184	9	9
% of Total Operations:	0.002098	0.002105	0.001253	0.001236	0.000826	0.000961	0.000408	0.000408

CODAS Data
Annual Operations

ORF			AT/Comm	AT/Comm				
Year	AC Dep	AC Arr	Departures	Arrivals	GA Dep	GA Arr	Mil Dep	Mil Arr
1997	64	66	19	19	29	27	6	5
1998	76	78	18	20	24	23	2	2
1999	72	78	27	28	28	29	0	0
Total:	212	222	64	67	81	79	8	7
% of Total Operations:	0.001984	0.002078	0.000996	0.001043	0.000359	0.000350	0.205128	0.179487

RDU			AT/Comm	AT/Comm				
Year	AC Dep	AC Arr	Departures	Arrivals	GA Dep	GA Arr	Mil Dep	Mil Arr
1997	150	147	34	32	51	57	38	35
1998	202	196	43	44	62	55	2	2
1999	268	266	43	42	59	63	0	2
Total:	620	609	120	118	172	175	40	39
% of Total Operations:	0.002065	0.002029	0.000645	0.000634	0.000778	0.000792	0.002433	0.002372

RIC			AT/Comm	AT/Comm				
Year	AC Dep	AC Arr	Departures	Arrivals	GA Dep	GA Arr	Mil Dep	Mil Arr
1997	53	50	20	22	57	57	12	12
1998	65	60	24	25	56	39	13	13
1999	66	63	29	30	52	48	1	1
Total:	184	173	73	77	165	144	26	26
% of Total Operations:	0.001535	0.001443	0.000767	0.000809	0.001195	0.001043	0.000969	0.000969

Composite Airport			AT/Comm	AT/Comm				
	AC Dep	AC Arr	Departures	Arrivals	GA Dep	GA Arr	Mil Dep	Mil Arr
% of Total Operations:	0.001766	0.001772	0.0008376	0.000852	0.001014	0.000998	0.030568	0.02699

Appendix E

Simulation Output:

Sample Conflict/Aircraft Data

TAAM Report Acft Conflict Count, Sector WASH
All flights, (closest approach - absolute count)

Fri Feb 16 10:18:51 2001

Time	Collision	< 20%	20%-50%	50%-100%	100%-120%	120%-150%	150%-200%	Total
2:00- 2:30	0	0	0	0	0	0	0	0
2:30- 3:00	0	0	0	0	0	0	0	0
3:00- 3:30	0	0	0	0	0	0	0	0
3:30- 4:00	0	0	0	0	0	0	0	0
4:00- 4:30	0	0	0	0	0	0	0	0
4:30- 5:00	0	0	0	0	0	0	0	0
5:00- 5:30	0	0	0	0	0	0	0	0
5:30- 6:00	0	0	0	0	0	0	0	0
6:00- 6:30	0	0	0	0	0	0	0	0
6:30- 7:00	0	0	0	0	0	0	0	0
7:00- 7:30	0	0	0	0	0	0	0	0
7:30- 8:00	0	0	0	0	0	0	0	0
8:00- 8:30	0	0	0	0	0	0	0	0
8:30- 9:00	0	0	0	0	0	0	0	0
9:00- 9:30	0	0	0	1	1	0	0	2
9:30-10:00	0	0	0	0	0	0	0	0
10:00-10:30	0	0	0	1	0	0	1	2
10:30-11:00	0	0	1	6	2	1	0	10
11:00-11:30	0	0	1	2	1	2	0	6
11:30-12:00	0	0	1	4	7	7	6	25
12:00-12:30	0	2	6	18	20	28	32	106
12:30-13:00	0	1	11	47	22	32	36	149
13:00-13:30	0	3	12	52	36	52	53	208
13:30-14:00	0	3	4	29	20	35	43	134
14:00-14:30	0	5	11	46	24	43	57	186
14:30-15:00	0	0	7	21	11	10	21	70
15:00-15:30	0	2	11	20	9	24	18	84
15:30-16:00	0	0	12	21	18	26	26	103
16:00-16:30	0	2	14	39	27	47	39	168
16:30-17:00	0	1	3	14	10	13	20	61
17:00-17:30	0	0	15	44	30	50	37	176
17:30-18:00	0	2	8	30	22	49	37	148
18:00-18:30	0	0	8	45	14	43	37	147
18:30-19:00	0	0	9	18	18	15	17	77
19:00-19:30	0	3	8	20	16	32	17	96
19:30-20:00	0	3	7	29	14	18	27	98
20:00-20:30	0	0	0	0	0	0	0	0
20:30-21:00	0	0	0	0	0	0	0	0
Total	0	27	149	507	322	527	524	2056

Scenario:
Nov 12, 2000
0% SATS
Run #2

TAAM Report   Acft Conflict Count, Sector COMMONWEALTH_OF_VIRGINIA
All flights, (closest approach - absolute count)

Fri Feb 16 10:18:26 2001

Time	Collision	< 20%	20%-50%	50%-100%	100%-120%	120%-150%	150%-200%	Total
2:00- 2:30	0	0	0	0	0	0	0	0
2:30- 3:00	0	0	0	0	0	0	0	0
3:00- 3:30	0	0	0	0	0	0	0	0
3:30- 4:00	0	0	0	0	0	0	0	0
4:00- 4:30	0	0	0	0	0	0	0	0
4:30- 5:00	0	0	0	0	0	0	0	0
5:00- 5:30	0	0	0	0	0	0	0	0
5:30- 6:00	0	0	0	0	0	0	0	0
6:00- 6:30	0	0	0	0	0	0	0	0
6:30- 7:00	0	0	0	0	0	0	0	0
7:00- 7:30	0	0	0	0	0	0	0	0
7:30- 8:00	0	0	0	0	0	0	0	0
8:00- 8:30	0	0	0	0	0	0	0	0
8:30- 9:00	0	0	0	0	1	0	0	1
9:00- 9:30	0	0	0	1	0	0	0	1
9:30-10:00	0	0	0	0	0	1	1	2
10:00-10:30	0	0	2	1	0	0	1	4
10:30-11:00	0	0	1	2	0	0	3	6
11:00-11:30	0	0	2	3	0	4	2	11
11:30-12:00	0	0	1	6	2	8	4	21
12:00-12:30	0	2	8	19	4	15	23	71
12:30-13:00	0	2	5	35	24	27	33	126
13:00-13:30	0	6	25	73	34	71	70	279
13:30-14:00	0	6	12	40	25	40	44	167
14:00-14:30	0	10	12	72	34	68	67	263
14:30-15:00	0	5	9	43	19	34	44	154
15:00-15:30	0	13	8	55	39	46	47	208
15:30-16:00	0	3	8	31	19	30	20	111
16:00-16:30	0	6	15	45	21	43	40	170
16:30-17:00	0	2	11	42	20	32	36	143
17:00-17:30	0	7	11	56	30	51	64	219
17:30-18:00	0	3	9	39	16	35	21	123
18:00-18:30	0	9	18	46	25	39	50	187
18:30-19:00	0	6	7	33	18	22	44	130
19:00-19:30	0	7	19	63	36	53	52	230
19:30-20:00	0	3	11	60	34	46	49	203
20:00-20:30	0	0	0	0	0	0	0	0
20:30-21:00	0	0	0	0	0	0	0	0
Total	0	90	194	765	401	665	715	2830

Scenario:
Nov 12, 2000
0% SATS
Run #2

```
TAAM Report          Acft Conflict Count, Sector SATS_AOI-SECONDARY
                  All flights, (closest approach - absolute count)

Fri Feb 16 10:18:39 2001


Time,Collision,< 20%,20%-50%,50%-100%,100%-120%,120%-150%,150%-200%,Total

 2:00- 2:30,0,0,0,0,0,0,0,0
 2:30- 3:00,0,0,0,0,0,0,0,0
 3:00- 3:30,0,0,0,0,0,0,0,0
 3:30- 4:00,0,0,0,0,0,0,0,0
 4:00- 4:30,0,0,0,0,0,0,0,0
 4:30- 5:00,0,0,0,0,0,0,0,0
 5:00- 5:30,0,0,0,0,0,0,0,0
 5:30- 6:00,0,0,0,0,0,0,0,0
 6:00- 6:30,0,0,0,0,0,0,0,0
 6:30- 7:00,0,0,0,0,0,0,0,0
 7:00- 7:30,0,0,0,0,0,0,0,0
 7:30- 8:00,0,0,0,0,0,0,0,0
 8:00- 8:30,0,0,0,0,0,0,0,0
 8:30- 9:00,0,0,0,0,0,0,0,0
 9:00- 9:30,0,0,0,0,0,0,0,0
 9:30-10:00,0,0,0,0,0,0,0,0
10:00-10:30,0,0,0,0,0,0,1,1
10:30-11:00,0,0,0,0,0,1,1,2
11:00-11:30,0,0,0,0,2,1,1,4
11:30-12:00,0,0,0,3,2,4,0,9
12:00-12:30,0,0,8,12,7,14,27,68
12:30-13:00,0,1,4,13,6,12,14,50
13:00-13:30,0,3,7,18,15,26,29,98
13:30-14:00,0,1,6,16,14,16,24,77
14:00-14:30,0,4,6,28,21,30,21,110
14:30-15:00,0,4,6,50,19,24,45,148
15:00-15:30,0,2,10,45,26,36,40,159
15:30-16:00,0,2,11,18,12,13,20,76
16:00-16:30,0,2,12,21,8,19,15,77
16:30-17:00,1,3,3,11,6,9,10,43
17:00-17:30,0,3,6,37,9,16,27,98
17:30-18:00,0,5,8,38,19,19,21,110
18:00-18:30,0,4,7,29,13,23,21,97
18:30-19:00,0,1,1,19,14,10,20,65
19:00-19:30,0,0,1,20,16,21,16,74
19:30-20:00,0,2,3,32,15,10,26,88
20:00-20:30,0,0,0,0,0,0,0,0
20:30-21:00,0,0,0,0,0,0,0,0
Total,1,37,99,410,224,304,379,1454
```

Scenario:
Nov 12, 2000
0% SATS
Run #2

TAAM Report Acft Conflict Count, Sector WASH
All flights, (closest approach - absolute count)

Fri Feb 23 16:03:32 2001

Time	Collision	< 20%	20%-50%	50%-100%	100%-120%	120%-150%	150%-200%	Total
2:00- 2:30	0	0	0	0	0	0	0	0
2:30- 3:00	0	0	0	0	0	0	0	0
3:00- 3:30	0	0	0	0	0	0	0	0
3:30- 4:00	0	0	0	0	0	0	0	0
4:00- 4:30	0	0	0	0	0	0	0	0
4:30- 5:00	0	0	0	0	0	0	0	0
5:00- 5:30	0	0	0	0	0	0	0	0
5:30- 6:00	0	0	0	0	0	0	0	0
6:00- 6:30	0	0	0	0	0	0	0	0
6:30- 7:00	0	0	0	0	0	0	0	0
7:00- 7:30	0	0	0	0	0	0	0	0
7:30- 8:00	0	0	0	0	0	0	0	0
8:00- 8:30	0	0	0	0	0	0	0	0
8:30- 9:00	0	0	0	0	0	0	0	0
9:00- 9:30	0	0	0	0	0	1	0	1
9:30-10:00	0	0	0	1	0	1	1	3
10:00-10:30	0	0	1	2	0	3	1	7
10:30-11:00	0	0	0	4	0	5	4	13
11:00-11:30	0	1	0	7	5	13	17	43
11:30-12:00	0	1	9	28	17	34	30	119
12:00-12:30	0	6	24	63	48	74	63	278
12:30-13:00	0	2	24	69	40	71	62	268
13:00-13:30	0	7	84	274	135	251	242	993
13:30-14:00	0	11	45	190	100	185	175	706
14:00-14:30	0	14	36	188	98	199	176	711
14:30-15:00	0	10	52	152	110	139	162	625
15:00-15:30	0	6	34	141	82	122	146	531
15:30-16:00	0	3	21	112	62	90	100	388
16:00-16:30	0	6	37	115	80	117	132	487
16:30-17:00	0	2	32	112	60	97	86	389
17:00-17:30	0	12	33	158	78	124	125	530
17:30-18:00	0	15	70	218	111	193	190	797
18:00-18:30	0	7	61	220	118	196	196	798
18:30-19:00	0	8	32	133	68	117	102	460
19:00-19:30	0	10	52	130	76	135	106	509
19:30-20:00	0	12	41	124	81	129	129	516
20:00-20:30	0	0	0	3	1	1	6	11
20:30-21:00	0	0	0	0	0	0	0	0
Total	0	133	688	2444	1370	2297	2251	9183

Scenario:
Nov 12, 2000
5% SATS
Run #4

```
TAAM Report         Acft Conflict Count, Sector COMMONWEALTH_OF_VIRGINIA
                 All flights, (closest approach - absolute count)

Fri Feb 23 16:01:55 2001


Time,Collision,< 20%,20%-50%,50%-100%,100%-120%,120%-150%,150%-200%,Total

 2:00- 2:30,0,0,0,0,0,0,0,0
 2:30- 3:00,0,0,0,0,0,0,0,0
 3:00- 3:30,0,0,0,0,0,0,0,0
 3:30- 4:00,0,0,0,0,0,0,0,0
 4:00- 4:30,0,0,0,0,0,0,0,0
 4:30- 5:00,0,0,0,0,0,0,0,0
 5:00- 5:30,0,0,0,0,0,0,0,0
 5:30- 6:00,0,0,0,0,0,0,0,0
 6:00- 6:30,0,0,0,0,0,0,0,0
 6:30- 7:00,0,0,0,0,0,0,0,0
 7:00- 7:30,0,0,0,0,0,0,0,0
 7:30- 8:00,0,0,0,0,0,0,0,0
 8:00- 8:30,0,0,0,0,1,1,0,2
 8:30- 9:00,0,0,0,0,0,0,2,2
 9:00- 9:30,0,0,0,0,1,1,1,3
 9:30-10:00,0,0,0,1,0,1,0,2
10:00-10:30,0,0,0,2,2,2,1,7
10:30-11:00,0,1,2,3,6,4,4,20
11:00-11:30,0,0,6,19,14,23,22,84
11:30-12:00,0,3,14,45,29,42,54,187
12:00-12:30,0,7,18,67,45,62,68,267
12:30-13:00,0,4,24,95,53,54,66,296
13:00-13:30,0,7,55,205,108,183,185,743
13:30-14:00,0,15,43,156,72,143,157,586
14:00-14:30,1,18,61,208,113,176,206,783
14:30-15:00,0,15,60,187,91,151,186,690
15:00-15:30,0,17,65,201,104,190,200,777
15:30-16:00,0,5,42,113,65,92,126,443
16:00-16:30,0,11,37,134,75,124,132,513
16:30-17:00,0,6,32,107,59,103,96,403
17:00-17:30,0,14,48,163,77,145,177,624
17:30-18:00,0,14,43,148,57,97,105,464
18:00-18:30,0,17,46,208,94,151,164,680
18:30-19:00,1,10,35,107,73,108,110,444
19:00-19:30,2,18,71,245,111,202,209,858
19:30-20:00,0,15,52,174,87,137,137,602
20:00-20:30,0,0,0,0,0,0,0,0
20:30-21:00,0,0,0,0,0,0,0,0
Total,4,197,754,2588,1337,2192,2408,9480




Scenario:
Nov 12, 2000
5% SATS
Run #4
```

TAAM Report   Acft Conflict Count, Sector SATS_AOI-SECONDARY
All flights, (closest approach - absolute count)

Fri Feb 23 16:02:08 2001

Time	Collision	< 20%	20%-50%	50%-100%	100%-120%	120%-150%	150%-200%	Total
2:00- 2:30	0	0	0	0	0	0	0	0
2:30- 3:00	0	0	0	0	0	0	0	0
3:00- 3:30	0	0	0	0	0	0	0	0
3:30- 4:00	0	0	0	0	0	0	0	0
4:00- 4:30	0	0	0	0	0	0	0	0
4:30- 5:00	0	0	0	0	0	0	0	0
5:00- 5:30	0	0	0	0	0	0	0	0
5:30- 6:00	0	0	0	0	0	0	0	0
6:00- 6:30	0	0	0	0	0	0	0	0
6:30- 7:00	0	0	0	0	0	0	0	0
7:00- 7:30	0	0	0	0	0	0	0	0
7:30- 8:00	0	0	0	0	0	0	0	0
8:00- 8:30	0	0	0	0	0	0	0	0
8:30- 9:00	0	0	0	0	0	0	1	1
9:00- 9:30	0	0	0	1	1	1	1	4
9:30-10:00	0	0	0	2	0	2	1	5
10:00-10:30	0	0	0	1	0	0	1	2
10:30-11:00	0	1	1	2	1	1	1	7
11:00-11:30	0	0	0	4	3	2	1	10
11:30-12:00	0	1	3	20	5	4	19	52
12:00-12:30	0	6	19	45	21	35	59	185
12:30-13:00	0	1	8	38	12	30	38	127
13:00-13:30	0	6	18	72	45	62	62	265
13:30-14:00	0	4	12	41	30	38	52	177
14:00-14:30	0	5	16	75	36	60	69	261
14:30-15:00	0	12	26	95	53	78	92	356
15:00-15:30	0	14	17	92	60	71	102	356
15:30-16:00	0	9	19	53	34	55	65	235
16:00-16:30	1	5	18	67	31	42	47	211
16:30-17:00	0	4	8	29	25	27	40	133
17:00-17:30	0	7	8	64	24	43	53	199
17:30-18:00	0	10	15	65	25	45	52	212
18:00-18:30	0	9	19	68	23	46	60	225
18:30-19:00	0	6	15	39	22	33	26	141
19:00-19:30	0	5	8	58	25	36	45	177
19:30-20:00	1	6	14	67	32	46	64	230
20:00-20:30	0	0	0	0	0	0	0	0
20:30-21:00	0	0	0	0	0	0	0	0
Total	2	111	244	998	508	757	951	3571

Scenario:
Nov 12, 2000
5% SATS
Run #4

```
TAAM Report          Acft Conflict Count, Sector WASH
                 All flights, (closest approach - absolute count)

Mon Mar  5 13:55:41 2001


Time,Collision,< 20%,20%-50%,50%-100%,100%-120%,120%-150%,150%-200%,Total

 2:00- 2:30,0,0,0,0,0,0,0,0
 2:30- 3:00,0,0,0,0,0,0,0,0
 3:00- 3:30,0,0,0,0,0,0,0,0
 3:30- 4:00,0,0,0,0,0,0,0,0
 4:00- 4:30,0,0,0,0,0,0,0,0
 4:30- 5:00,0,0,0,0,0,0,0,0
 5:00- 5:30,0,0,0,0,0,0,0,0
 5:30- 6:00,0,0,0,0,0,0,0,0
 6:00- 6:30,0,0,0,0,0,0,0,0
 6:30- 7:00,0,0,0,0,0,0,0,0
 7:00- 7:30,0,0,0,0,0,0,0,0
 7:30- 8:00,0,0,0,2,0,0,0,2
 8:00- 8:30,0,0,0,1,0,0,2,3
 8:30- 9:00,0,0,0,0,0,0,0,0
 9:00- 9:30,0,0,0,0,0,1,2,3
 9:30-10:00,0,0,1,1,0,2,0,4
10:00-10:30,0,0,0,2,1,1,1,5
10:30-11:00,0,0,0,9,7,4,8,28
11:00-11:30,0,3,10,22,13,33,24,105
11:30-12:00,0,3,15,48,31,41,55,193
12:00-12:30,0,9,54,174,78,153,173,641
12:30-13:00,0,14,56,158,91,187,216,722
13:00-13:30,0,25,109,474,225,389,474,1696
13:30-14:00,0,41,128,410,212,389,461,1641
14:00-14:30,0,29,121,375,227,370,416,1538
14:30-15:00,0,12,78,242,112,207,251,902
15:00-15:30,0,14,74,256,134,213,248,939
15:30-16:00,0,19,51,179,98,172,189,708
16:00-16:30,1,23,59,196,118,183,205,785
16:30-17:00,0,14,64,261,119,174,199,831
17:00-17:30,1,19,106,327,181,287,310,1231
17:30-18:00,0,14,56,257,123,203,252,905
18:00-18:30,0,49,116,428,232,341,403,1569
18:30-19:00,0,17,65,206,89,158,182,717
19:00-19:30,0,23,82,276,167,233,293,1074
19:30-20:00,0,38,95,223,117,202,201,876
20:00-20:30,0,0,0,5,2,1,2,10
20:30-21:00,0,0,0,0,0,0,0,0
Total,2,366,1340,4532,2377,3944,4567,17128




Scenario:
Nov 12, 2000
10% SATS
Run #5
```

TAAM Report Acft Conflict Count, Sector COMMONWEALTH_OF_VIRGINIA
All flights, (closest approach - absolute count)

Mon Mar 5 13:55:22 2001

Time	Collision	< 20%	20%-50%	50%-100%	100%-120%	120%-150%	150%-200%	Total
2:00- 2:30	0	0	0	0	0	0	0	0
2:30- 3:00	0	0	0	0	0	0	0	0
3:00- 3:30	0	0	0	0	0	0	0	0
3:30- 4:00	0	0	0	0	0	0	0	0
4:00- 4:30	0	0	0	0	0	0	0	0
4:30- 5:00	0	0	0	0	0	0	0	0
5:00- 5:30	0	0	0	0	0	0	0	0
5:30- 6:00	0	0	0	0	0	0	0	0
6:00- 6:30	0	0	0	0	0	0	0	0
6:30- 7:00	0	0	0	0	0	0	0	0
7:00- 7:30	0	0	0	0	0	0	0	0
7:30- 8:00	0	0	0	0	0	0	0	0
8:00- 8:30	0	0	0	0	0	1	0	1
8:30- 9:00	0	0	1	0	0	1	1	3
9:00- 9:30	0	0	0	1	0	1	1	3
9:30-10:00	0	0	1	1	0	1	3	6
10:00-10:30	0	0	1	6	1	5	2	15
10:30-11:00	0	0	0	8	5	14	9	36
11:00-11:30	0	4	8	64	28	47	55	206
11:30-12:00	0	2	17	92	55	77	115	358
12:00-12:30	0	5	36	166	92	157	171	627
12:30-13:00	0	15	67	254	128	210	242	916
13:00-13:30	0	31	109	389	218	331	371	1449
13:30-14:00	0	17	74	258	130	192	234	905
14:00-14:30	0	26	92	380	206	293	319	1316
14:30-15:00	0	25	65	274	159	262	268	1053
15:00-15:30	0	36	91	311	182	242	300	1162
15:30-16:00	1	26	93	278	130	173	243	944
16:00-16:30	0	37	73	277	150	206	261	1004
16:30-17:00	0	16	38	163	97	145	199	658
17:00-17:30	0	36	94	355	206	306	339	1336
17:30-18:00	1	31	77	204	100	174	208	795
18:00-18:30	0	45	109	396	212	292	341	1395
18:30-19:00	0	30	94	256	141	220	258	999
19:00-19:30	0	45	105	461	204	344	329	1488
19:30-20:00	0	41	102	332	186	318	312	1291
20:00-20:30	0	0	0	3	5	0	3	11
20:30-21:00	0	0	0	0	0	0	0	0
Total	2	468	1347	4929	2635	4012	4584	17977

Scenario:
Nov 12, 2000
10% SATS
Run #5

TAAM Report Acft Conflict Count, Sector SATS_AOI-SECONDARY
All flights, (closest approach - absolute count)

Mon Mar 5 13:55:32 2001

Time	Collision	< 20%	20%-50%	50%-100%	100%-120%	120%-150%	150%-200%	Total
2:00- 2:30	0	0	0	0	0	0	0	0
2:30- 3:00	0	0	0	0	0	0	0	0
3:00- 3:30	0	0	0	0	0	0	0	0
3:30- 4:00	0	0	0	0	0	0	0	0
4:00- 4:30	0	0	0	0	0	0	0	0
4:30- 5:00	0	0	0	0	0	0	0	0
5:00- 5:30	0	0	0	0	0	0	0	0
5:30- 6:00	0	0	0	0	0	0	0	0
6:00- 6:30	0	0	0	0	0	0	0	0
6:30- 7:00	0	0	0	0	0	0	0	0
7:00- 7:30	0	0	0	0	0	0	0	0
7:30- 8:00	0	0	0	0	0	0	0	0
8:00- 8:30	0	0	0	0	0	0	3	3
8:30- 9:00	0	0	0	0	0	0	0	0
9:00- 9:30	0	0	0	0	0	0	0	0
9:30-10:00	0	0	1	1	1	0	2	5
10:00-10:30	0	0	0	1	3	1	3	8
10:30-11:00	0	0	0	3	7	5	5	20
11:00-11:30	0	1	3	18	11	11	14	58
11:30-12:00	0	3	4	20	12	20	24	83
12:00-12:30	0	2	18	74	39	73	67	273
12:30-13:00	1	10	13	73	30	40	61	228
13:00-13:30	0	8	27	87	53	89	119	383
13:30-14:00	0	7	28	95	57	61	118	366
14:00-14:30	1	11	28	116	57	101	131	445
14:30-15:00	0	18	42	141	73	107	84	465
15:00-15:30	0	29	46	170	92	160	148	645
15:30-16:00	0	15	45	106	74	63	100	403
16:00-16:30	0	11	37	111	47	90	100	396
16:30-17:00	0	10	19	71	31	55	58	244
17:00-17:30	0	10	28	108	55	83	80	364
17:30-18:00	0	6	22	75	35	56	74	268
18:00-18:30	0	13	34	101	57	69	89	363
18:30-19:00	0	7	26	89	27	56	51	256
19:00-19:30	1	13	31	97	54	71	84	351
19:30-20:00	0	13	22	86	59	75	70	325
20:00-20:30	0	0	0	0	0	0	0	0
20:30-21:00	0	0	0	0	0	0	0	0
Total	3	187	474	1643	874	1286	1485	5952

Scenario:
Nov 12, 2000
10% SATS
Run #5

TAAM Report Acft Conflict Count, Sector WASH

All flights, (closest approach - absolute count)

Mon Mar 19 13:45:31 2001

Time	Collision	< 20%	20%-50%	50%-100%	100%-120%	120%-150%	150%-200%	Total
0:00- 0:30	0	0	0	0	0	0	0	0
0:30- 1:00	0	0	0	0	0	0	0	0
1:00- 1:30	0	0	0	0	0	0	0	0
1:30- 2:00	0	0	0	0	0	0	0	0
2:00- 2:30	0	0	0	0	0	1	0	1
2:30- 3:00	0	0	0	1	1	0	0	2
3:00- 3:30	0	0	0	0	1	0	0	1
3:30- 4:00	0	0	0	1	1	1	0	3
4:00- 4:30	0	0	0	2	1	1	0	4
4:30- 5:00	0	0	0	0	0	1	1	2
5:00- 5:30	0	1	0	0	0	2	3	6
5:30- 6:00	0	0	0	0	0	0	0	0
6:00- 6:30	0	0	0	0	0	0	0	0
6:30- 7:00	0	0	1	0	0	1	0	2
7:00- 7:30	0	0	0	1	0	0	2	3
7:30- 8:00	0	0	0	0	0	0	1	1
8:00- 8:30	0	0	0	3	1	1	0	5
8:30- 9:00	0	0	0	0	1	0	0	1
9:00- 9:30	0	0	0	0	0	0	1	1
9:30-10:00	0	0	0	0	1	1	0	2
10:00-10:30	0	0	0	0	0	0	0	0
10:30-11:00	0	0	1	0	1	2	4	8
11:00-11:30	0	0	3	8	3	9	7	30
11:30-12:00	0	1	8	25	19	14	27	94
12:00-12:30	0	2	20	65	34	68	80	269
12:30-13:00	0	9	24	155	75	122	165	550
13:00-13:30	0	8	65	218	109	218	207	825
13:30-14:00	0	12	65	224	122	187	226	836
14:00-14:30	0	19	98	316	203	313	307	1256
14:30-15:00	0	20	48	138	84	143	164	597
15:00-15:30	0	8	41	160	100	156	204	669
15:30-16:00	0	10	43	161	87	132	161	594
16:00-16:30	0	15	46	159	112	155	164	651
16:30-17:00	1	11	40	136	86	137	150	561
17:00-17:30	0	5	56	226	116	207	226	836
17:30-18:00	0	10	67	194	105	176	219	771
18:00-18:30	0	9	59	203	92	199	238	800
18:30-19:00	0	13	42	102	53	134	115	459
19:00-19:30	0	11	50	190	104	179	202	736
19:30-20:00	0	20	58	198	121	170	221	788
20:00-20:30	0	0	0	0	0	2	2	4
20:30-21:00	0	0	0	0	0	0	0	0
Total	1	184	835	2886	1633	2732	3097	11368

Scenario:
Nov 12, 2010
5% SATS
Run #4

TAAM Report   Acft Conflict Count, Sector COMMONWEALTH_OF_VIRGINIA
All flights, (closest approach - absolute count)

Mon Mar 19 13:44:56 2001

Time,Collision,< 20%,20%-50%,50%-100%,100%-120%,120%-150%,150%-200%,Total

0:00- 0:30,0,0,0,0,0,0,0,0
0:30- 1:00,0,0,0,0,0,0,0,0
1:00- 1:30,0,0,0,0,0,0,0,0
1:30- 2:00,0,0,0,0,0,0,0,0
2:00- 2:30,0,0,0,0,0,0,0,0
2:30- 3:00,0,0,0,0,0,1,2,3
3:00- 3:30,0,0,0,1,0,1,3,5
3:30- 4:00,0,0,1,2,1,0,1,5
4:00- 4:30,0,0,0,4,1,3,6,14
4:30- 5:00,0,0,0,1,2,2,4,9
5:00- 5:30,0,0,0,3,0,1,1,5
5:30- 6:00,0,0,1,0,0,3,1,5
6:00- 6:30,0,0,0,0,0,1,0,1
6:30- 7:00,0,0,0,1,0,0,1,2
7:00- 7:30,0,0,0,0,0,0,0,0
7:30- 8:00,0,0,0,0,0,0,0,0
8:00- 8:30,0,0,0,0,0,0,0,0
8:30- 9:00,0,0,0,1,0,0,1,2
9:00- 9:30,0,0,0,1,0,0,0,1
9:30-10:00,0,0,0,1,0,1,0,2
10:00-10:30,0,0,0,5,1,1,6,13
10:30-11:00,0,0,1,2,0,3,1,7
11:00-11:30,0,1,6,23,8,27,11,76
11:30-12:00,0,3,18,59,23,47,54,204
12:00-12:30,0,5,36,141,74,97,116,469
12:30-13:00,0,9,32,143,83,96,114,477
13:00-13:30,0,18,68,246,115,176,216,839
13:30-14:00,0,11,50,200,84,159,190,694
14:00-14:30,0,27,76,261,137,237,307,1045
14:30-15:00,0,22,67,251,142,215,224,921
15:00-15:30,0,27,69,260,156,237,295,1044
15:30-16:00,0,15,68,185,82,154,159,663
16:00-16:30,0,11,56,225,118,167,207,784
16:30-17:00,0,12,33,135,71,135,166,552
17:00-17:30,0,18,82,230,124,225,248,927
17:30-18:00,1,21,66,221,113,189,208,819
18:00-18:30,0,25,92,275,141,231,267,1031
18:30-19:00,0,13,53,178,99,122,165,630
19:00-19:30,0,22,83,329,192,261,307,1194
19:30-20:00,0,14,76,303,139,196,241,969
20:00-20:30,0,0,0,0,0,0,0,0
20:30-21:00,0,0,0,0,0,0,0,0
Total,1,274,1034,3687,1906,2988,3522,13412

Scenario:
Nov 12, 2010
5% SATS
Run #4

TAAM Report Acft Conflict Count, Sector SATS_AOI-SECONDARY
All flights, (closest approach - absolute count)

Mon Mar 19 13:45:16 2001

Time	Collision	< 20%	20%-50%	50%-100%	100%-120%	120%-150%	150%-200%	Total
0:00- 0:30	0	0	0	0	0	0	0	0
0:30- 1:00	0	0	0	0	0	0	0	0
1:00- 1:30	0	0	0	0	0	0	0	0
1:30- 2:00	0	0	0	0	0	0	0	0
2:00- 2:30	0	0	0	0	0	0	0	0
2:30- 3:00	0	0	0	0	0	0	0	0
3:00- 3:30	0	0	0	1	1	1	0	3
3:30- 4:00	0	0	0	3	0	1	4	8
4:00- 4:30	0	0	2	2	0	3	2	9
4:30- 5:00	0	0	0	2	0	0	2	4
5:00- 5:30	0	0	0	1	0	1	0	2
5:30- 6:00	0	0	0	1	0	1	0	2
6:00- 6:30	0	0	0	2	0	0	0	2
6:30- 7:00	0	0	0	1	0	0	1	2
7:00- 7:30	0	0	0	0	0	0	0	0
7:30- 8:00	0	0	0	0	0	0	1	1
8:00- 8:30	0	0	0	0	0	0	0	0
8:30- 9:00	0	0	0	0	0	0	0	0
9:00- 9:30	0	0	0	0	0	1	0	1
9:30-10:00	0	0	0	1	0	0	2	3
10:00-10:30	0	0	0	2	0	3	1	6
10:30-11:00	0	0	0	5	0	2	5	12
11:00-11:30	0	2	1	6	2	7	10	28
11:30-12:00	0	1	1	16	13	10	16	57
12:00-12:30	0	3	17	67	40	39	52	218
12:30-13:00	0	2	13	50	28	38	42	173
13:00-13:30	0	5	17	74	35	60	78	269
13:30-14:00	0	2	23	70	47	65	79	286
14:00-14:30	0	10	20	99	50	79	109	367
14:30-15:00	0	14	57	174	101	149	152	647
15:00-15:30	0	11	52	172	91	148	154	628
15:30-16:00	0	9	38	147	64	97	139	494
16:00-16:30	0	10	24	107	54	81	80	356
16:30-17:00	0	2	18	82	41	61	77	281
17:00-17:30	0	7	32	115	49	68	101	372
17:30-18:00	0	9	28	115	42	71	73	338
18:00-18:30	0	9	29	106	48	86	105	383
18:30-19:00	0	7	29	76	47	87	86	332
19:00-19:30	0	6	24	113	63	81	85	372
19:30-20:00	0	8	22	132	64	78	103	407
20:00-20:30	0	0	0	0	0	0	0	0
20:30-21:00	0	0	0	0	0	0	0	0
Total	0	117	447	1742	880	1318	1559	6063

Scenario:
Nov 12, 2010
5% SATS
Run #4

TAAM Report Acft Conflict Count, Sector WASH
All flights, (closest approach - absolute count)

Thu Feb 15 10:40:24 2001

Time	Collision	< 20%	20%-50%	50%-100%	100%-120%	120%-150%	150%-200%	Total
0:00- 0:30	0	0	0	0	0	0	0	0
0:30- 1:00	0	0	0	0	0	0	0	0
1:00- 1:30	0	0	0	0	0	0	0	0
1:30- 2:00	0	0	0	0	1	1	0	2
2:00- 2:30	0	0	1	3	1	2	2	9
2:30- 3:00	0	0	2	5	2	5	7	21
3:00- 3:30	0	0	5	20	10	9	11	55
3:30- 4:00	0	1	4	13	9	7	10	44
4:00- 4:30	0	0	2	14	2	11	8	37
4:30- 5:00	0	0	0	3	0	1	4	8
5:00- 5:30	0	0	3	2	2	4	8	19
5:30- 6:00	0	1	0	1	4	0	1	7
6:00- 6:30	0	0	1	2	0	0	0	3
6:30- 7:00	0	0	0	0	1	1	1	3
7:00- 7:30	0	0	0	0	0	0	0	0
7:30- 8:00	0	0	0	0	0	0	1	1
8:00- 8:30	0	0	0	0	0	0	0	0
8:30- 9:00	0	0	0	0	0	0	0	0
9:00- 9:30	0	0	0	0	0	1	2	3
9:30-10:00	0	0	0	0	0	1	0	1
10:00-10:30	0	0	1	5	1	3	0	10
10:30-11:00	0	0	0	5	3	6	6	20
11:00-11:30	0	1	2	15	7	14	18	57
11:30-12:00	0	2	24	80	54	60	81	301
12:00-12:30	0	6	61	177	94	128	171	637
12:30-13:00	0	11	86	273	167	247	332	1116
13:00-13:30	0	27	107	396	241	382	439	1592
13:30-14:00	0	33	156	549	287	427	597	2049
14:00-14:30	0	33	141	498	269	403	526	1870
14:30-15:00	0	17	99	374	229	362	384	1465
15:00-15:30	0	22	76	276	175	254	297	1100
15:30-16:00	0	25	91	332	187	281	313	1229
16:00-16:30	0	30	111	367	186	279	308	1281
16:30-17:00	0	16	89	323	184	310	312	1234
17:00-17:30	0	36	139	491	303	449	492	1910
17:30-18:00	1	49	190	597	360	498	663	2358
18:00-18:30	2	55	208	658	353	548	631	2455
18:30-19:00	0	45	146	490	250	390	414	1735
19:00-19:30	0	67	216	593	311	507	568	2262
19:30-20:00	0	41	145	481	251	457	489	1864
20:00-20:30	0	0	0	0	0	0	0	0
20:30-21:00	0	0	0	0	0	0	0	0
Total	3	518	2106	7043	3944	6048	7096	26758

Scenario:
Nov 12, 2015
10% SATS
Run #1

```
TAAM Report      Acft Conflict Count, Sector COMMONWEALTH_OF_VIRGINIA
                   All flights, (closest approach - absolute count)

Thu Feb 15 10:45:46 2001


Time,Collision,< 20%,20%-50%,50%-100%,100%-120%,120%-150%,150%-200%,Total

 0:00- 0:30,0,0,0,0,0,0,0,0
 0:30- 1:00,0,0,0,0,0,0,0,0
 1:00- 1:30,0,0,0,0,0,0,0,0
 1:30- 2:00,0,0,0,0,0,0,0,0
 2:00- 2:30,0,0,0,0,1,0,1,2
 2:30- 3:00,0,0,0,3,2,1,1,7
 3:00- 3:30,0,0,0,4,1,2,0,7
 3:30- 4:00,0,1,2,9,2,13,4,31
 4:00- 4:30,0,0,1,1,2,7,2,13
 4:30- 5:00,0,2,1,2,2,4,2,13
 5:00- 5:30,0,0,0,6,1,3,1,11
 5:30- 6:00,0,0,1,1,2,2,3,9
 6:00- 6:30,0,0,0,1,3,2,1,7
 6:30- 7:00,0,0,0,1,0,2,0,3
 7:00- 7:30,0,1,1,3,1,1,2,9
 7:30- 8:00,0,0,0,0,1,0,0,1
 8:00- 8:30,0,0,0,1,1,0,1,3
 8:30- 9:00,0,0,0,2,1,3,1,7
 9:00- 9:30,0,0,0,1,1,3,1,6
 9:30-10:00,0,0,0,1,0,2,0,3
10:00-10:30,0,0,0,1,0,3,4,8
10:30-11:00,0,1,0,8,2,7,12,30
11:00-11:30,0,1,5,43,19,22,37,127
11:30-12:00,0,5,29,78,48,94,101,355
12:00-12:30,0,12,58,222,118,190,246,846
12:30-13:00,0,30,81,298,187,292,313,1201
13:00-13:30,0,26,86,346,218,326,322,1324
13:30-14:00,0,22,89,391,243,355,418,1518
14:00-14:30,0,40,134,544,268,513,591,2090
14:30-15:00,0,44,148,534,286,435,530,1977
15:00-15:30,0,39,115,495,238,376,465,1728
15:30-16:00,0,36,140,420,192,353,437,1578
16:00-16:30,0,40,121,371,204,279,350,1365
16:30-17:00,0,42,119,365,194,291,393,1404
17:00-17:30,0,54,156,521,264,440,559,1994
17:30-18:00,0,59,152,607,295,479,591,2183
18:00-18:30,0,66,210,662,333,504,561,2336
18:30-19:00,0,58,195,578,285,448,487,2051
19:00-19:30,0,82,256,727,387,632,655,2739
19:30-20:00,0,63,205,663,361,518,574,2384
20:00-20:30,0,0,0,0,0,0,0,0
20:30-21:00,0,0,0,0,0,0,0,0
Total,0,724,2305,7910,4163,6602,7666,29370


Scenario:
Nov 12, 2015
10% SATS
Run #1
```

TAAM Report Acft Conflict Count, Sector SATS_AOI-SECONDARY

All flights, (closest approach - absolute count)

Thu Feb 15 10:40:06 2001

Time	Collision	< 20%	20%-50%	50%-100%	100%-120%	120%-150%	150%-200%	Total
0:00- 0:30	0	0	0	0	0	0	0	0
0:30- 1:00	0	0	0	1	0	0	0	1
1:00- 1:30	0	0	0	0	0	0	0	0
1:30- 2:00	0	0	0	1	1	0	0	2
2:00- 2:30	0	0	0	0	0	0	0	0
2:30- 3:00	0	0	0	1	0	1	2	4
3:00- 3:30	0	0	0	0	0	0	1	1
3:30- 4:00	0	0	0	0	1	2	2	5
4:00- 4:30	0	0	1	2	1	3	4	11
4:30- 5:00	0	0	0	2	1	1	3	7
5:00- 5:30	0	0	0	4	1	0	6	11
5:30- 6:00	0	0	0	0	2	2	2	6
6:00- 6:30	0	0	1	1	2	1	4	9
6:30- 7:00	0	0	0	1	2	2	1	6
7:00- 7:30	0	0	0	1	1	3	1	6
7:30- 8:00	0	0	0	0	1	0	0	1
8:00- 8:30	0	0	0	0	2	0	0	2
8:30- 9:00	0	0	0	0	0	0	1	1
9:00- 9:30	0	0	1	2	0	2	3	8
9:30-10:00	0	0	0	2	1	2	0	5
10:00-10:30	0	0	0	0	2	3	1	6
10:30-11:00	0	0	0	3	2	3	2	10
11:00-11:30	0	0	2	13	6	12	13	46
11:30-12:00	0	2	7	20	26	17	35	107
12:00-12:30	0	5	26	79	56	92	107	365
12:30-13:00	0	5	24	69	36	82	111	327
13:00-13:30	0	13	43	131	82	107	161	537
13:30-14:00	0	13	34	134	80	100	153	514
14:00-14:30	0	23	59	217	114	156	212	781
14:30-15:00	0	30	81	301	140	225	259	1036
15:00-15:30	0	35	73	306	186	279	311	1190
15:30-16:00	0	48	101	245	140	190	219	943
16:00-16:30	0	59	111	280	137	197	247	1031
16:30-17:00	1	43	90	219	95	165	167	780
17:00-17:30	0	60	117	291	143	207	240	1058
17:30-18:00	0	44	90	259	162	240	278	1073
18:00-18:30	0	64	128	348	159	242	282	1223
18:30-19:00	0	34	92	209	112	144	145	736
19:00-19:30	0	49	109	275	149	220	217	1019
19:30-20:00	0	54	126	338	155	272	315	1260
20:00-20:30	0	0	0	2	1	0	0	3
20:30-21:00	0	0	0	0	0	0	0	0
Total	1	581	1316	3757	1999	2972	3505	14131

Scenario:
Nov 12, 2015
10% SATS
Run #1

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Appendix F

TAAM Plus Static Data Files

```
# The data in this file are aircraft types used in the simulation
# Aircraft types are coupled to performance data


B7372 7372 B732 732
B7374 B737 737 B73F B73S B73L B737S 733 734 73A 735 B7375 B7373 7373 7374 7375
B73V 73B 73L 73P 73W 73S DA01
B7378 7378 738 B738
B727 AN72 B72S 72S YK42 Y42 YAK42 727 722 72L 72S 72X
B757 IL76 TU54 TU15 T154 TU154 TU5 AN22 757 752 TU204
7474 B744 B747 747 7471 7472 7473 C5 B74S C5A C51 74M B74F 747F B747F
B767 IL62 767 763 762 7672 7673 B67 B762 B763 767F B767F B76F
B777 777
B707 707 707F B707F C135 KC35 C137 C141 E3A

DC9 MD90 C9 DC95 DC93 DC91 D9 D9S D9A D9F D93 TU134 T134 TU34S TU34 TU13 TU3
DC10 KC10 DC10F D10F D1C D14 D10 L101 L10 L11 L1011
MD83 MD80 MD81 MD82 MD87 MD88 MD90 MD8 M80 M88 M81 M83 M8L M8T LOH
MD11 M11 M11F MD11F MD11ER
DC87 DC86 DC8 DC8F DC8S VC10 E3A NIM

A300 EA30 AB60 EA3 IL86 IL96 AB3 ABW
A310 EA31 ME A31 310 C17 C17A
A320 EA32 320 A319 EA319 319
A321 EA321 321
A330 EA33 330
A340 EA34 340

FK27 F27 BE02 U21 U21A YS11
FK50 F50 BATP HP7 BATB CN35 OV1 OV10 E110 E111 IL114 BA41
FK28 F28 F280
FK100 FK10 FK70 F100 S600 S601 MU3 S210 BA11 B11 VF614 VF14 MU30 S212 AN4R
AJ25 100

C150 C152
C172 BE33 B33
C182 PA22 C177 PE66 SF28 VA17 PARO C180 PA20 ST10 PC9 PC12
C310 C320 C303 C340 C411 C402 C414 C421
C500 C501 C525 HF20 HF320 BE40 N265
C560 C551 C550 C650

PA24 AN2
PA28 PA32 BN2 BN2A AC12 O200 TB10 BE23 PA3 PA38 PA39 PA25 C305
PA31 PA30 PA34 PA41 PAYE PAE P180 PA42
PA42
PARO
PASE BE24 FH20 PA44 PAZT DH6 DHC6 C337 PE55 AA5 AA5B AA7 PA23

LR31 LR35 LR36 LR25 LR24 C20A C20F C21A LR60 LR55 G2 G2B G3 G4 LR23
BA146 RJ70 RJ85 RJ100 146 BA46 BA14 B146 BAE146
HS25 BA25 BA125 BA10
CL60 DA50 DA90 CL65 C601 C604 SJ30
DA20 DA10 DA21 C140 L329 Y40 YK40 YAK40 P808 BJ40
CRJ CJ EMB145 E145 EM145

J31 JSTRM BA31 BAE31 BE02 BE9F BE90 BE99 BE92 BEST BE03 J41
BE20 C12 BE30 BA20 BF30 BE3B BE3L Y12 YUN12 B200
```

SW4 SW03 SW3 C425 FA3 SW2 FA4 AC6T C441 MU24 FA22 C404 C402 C406
DHC8 DH8 E9 CL44 VC8 DH7 DHC7 VC9 DASH8 DHC-8
HS74 HS748 HS7 AP2S AP25 AN24 AN26 AN30 DO228 D228 ND26 C2 AP4S PL07 HS14
ND16 C160 AY22 G222 MD16
ATR42 AT4 AT42 AT52 ATR52 AT82 ATR
ATR72 AT72 AT82 ATR82 AT7
E120 E121 EMB RA06 120 BE19 BE1900 S360 M23 C26
SF340 SF34 TB70 L410 L610 SF3 SAAB
S2000 SB200 SB20
EM2
BE1 BE10
DO328 DO328 D328 DO32 328
MU2 MU2B MU

DO28 228 D228 DO228 DO82 DO8D D08D PN68 D8D YUN7
BE36 BE35 C206 C207 C210 TB20 C208 BE95 TB21 MO20 MO25 MO2J M20 M20K B35 MO2K
MO21 SC01 DR40 R100 T180 M20J MO23 AC20 LA25 C21
BE58 DC6 PA46 AC50 AC60 AC52 AC56 BE60 BE55 BE5B O410 SH33 SH36 BE50 BE65 BE76
DC3 C47 SH7 SC7 BE56

C130 IL18 EC24 L188 ATLA P3 P3A CV58 L100 AN12 P140 P3C P200 P201 P210 L382
AC68 PA60
AC90 A69 AC69 DHC5 G159 C23 AC9 CA25 C20 CD24 CD22

F18 CF18 F5 NF5A FA18 JAG WW02 WW24
F4 SB35 F16 F16F F104 MIR3 MIR MIR2 AMX F1 2F4 3F4 4F4 2F16 3F16 4F16
SR71
MRCA MRC TORN F15 F15C F14 JAGR F111 SU24 SU27 SU30 MIG29 MIG31
AJET HAR HARR 2HAR 3HAR 4HAR HARR 2HARR 3HARR 4HARR A6 A10 2A10 FT91 PROV A4
T38 T45 MB339 MB326 SU25

CH53 H53 S60 S70 CH47 H47 MI85 UH58 OH58 CH35 S61
B412 BH41 UH1 UH21 UH12 BH04 UH1D SK76 A109 S341 S342 HEL BH22 CCB4 CCB6 S365
WLSK WLLX WLL2 CK76
BO105 H3 BH05 A102 A1OU S316 MDH5 MBH5 MBK7 BK117 B105 UH60 H60 S341 MBX5 EH60
BH12 BH12S S330 S332 BO05 H1 H3 V17E SF25

B74SC 747SP 742
CONC
HOTOL
CTROT V22

```
# This is master project file <SATS_Farrell_1.prj> used in simulation runs
# Contains supporting data files, system settings, and parameters


# single_terminal
# data/map/gtool
Virginia_new.pol
DC_TERM_AREA.pol
SATS_Secondary.pol
# data/map/3d
# data/wpt
2015_CC_10_2.WPT
# data/apt
SATS_Virginia_BU_3.APT
# data/rts
2015_CC_10_2.RTS
# data/acf
2015_CC_10_2.ACF


$SATS/Blind Conflict Analysis-Revised System Parameters

Acft_label: 2 1 0 0 2 1 1

Period! 01,00:00 19,03:14

30.000000 20.000000 26.000000 10.000000 30.000002 70.000000 1.000000 6.000000
360.000000 180.000000 10.000000 0.000000 0.000000 2 1 0 3600
0 0 1 0 1 0 0 1 0 0 0 0 0 0 0 1
0 1 1 0 1 1 1 1 1 2 1 0 0
0 1 1 1 0 1 2 1 1
0 0 0 0 0 0 0 0 0 0
0 ? -1 -1 ? ? 0 1000 -1


Fl_Tab: flight_levels
Intrail_start_hold: 1
Intrail_merge_violation: 0
Intrail_automatic_hold_time: 120
Global_Confl_Res_Strat: default
Global_Pass_Tolerance: 0 0 0 0
Min_Desc_Rate: 100
Rad_Sep_Minmax: 0
Confl_Sev_Rep: 0
Confl_Sect_Determ: 0
Same_Track_Angle: 45
Global_Flt_Data_Rec: 0
Unique_Flight_Numbers_Data: 0
Binary_Flt_Data_Rec: 0
Global_Flt_Hist: 0
Global_Flt_Hist_Record_Which:
Global_Flt_Data_Freq: 300
Global_Flt_Data_Options: 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 1
VFR_Conflict_Options: 0
FlyFaster: 0
ZeroDelay: 0
Show_Waypoints:
```

```
Show_Airports:
EnforceClimbRest: 0
Confl_In_Uncontr_Airsp: 1


$$Selective Reports
waypoints{
*
}
airports{
*
}
sectors{
*
}
```

```
# This is gtool file <Virginia_new.pol> accessed by <SATS_Farrell_1.prj>
# Contains boundary points for <Commonwealth of Virginia>
# n-sided 3-D region, SFC - FL650
# Utilized by simulation to group blind conflicts within the defined zone


%Gtool
% $Id: $    %W% %G%
1
-84.0560179 34.6244887 -75.4920225 41.3731193
-84.0560179 34.6244887 -75.4920225 41.3731193
% no. polys
% minx, miny, maxx, maxy
% startx, starty, endx, endy
%> UNITS: DEGREES DEGREES DMS
1 5 "ATC Sector Boundary" <Commonwealth_of_Virginia>[0.0,65000.0]xyzf(set
color)
-83.6667454 36.5287328
-75.881295 36.5472728
-75.9837231 36.9455107
-76.2681732 37.0957109
-76.2539507 37.8917724
-76.6237358 38.1621328
-76.9224083 38.2071929
-77.0646334 38.4174733
-77.2779709 38.3423732
-77.0219659 38.8981142
-77.477086 39.2435748
-77.704646 39.3336949
-77.846871 39.1384346
-78.3588812 39.4688752
-79.3260114 38.4324933
-79.653129 38.5977136
-80.4922566 37.4411716
-81.6727244 37.2308912
-81.971397 37.5463117
```

```
# This is gtool file <DC_TERM_AREA.pol> accessed by <SATS_Farrell_1.prj>
# Contains boundary points for <Washington, D.C. Terminal Area and associated
# Class B airspace around Baltimore-Washington Intl Airprt (BWI), Dulles Intl
# Airprt (IAD) and Reagan National Airport (DCA)
# 6-sided 3-D region, SFC - FL650
# Utilized by simulation to group blind conflicts within the defined zone


%Gtool
% $Id: $    %W% %G%
2
-78.3624104 37.9308004 -75.8563957 39.8809282
-78.3624104 37.9308004 -75.8563957 39.8809282
% no. polys
% minx, miny, maxx, maxy
% startx, starty, endx, endy
%> UNITS: DEGREES DEGREES DMS
1 15 "ATC Sector Boundary" <WASH D.C. TERMINAL AREA>[0.0,65000.0]xyzf(set
color)
-78.1739886 38.0194426
-75.9862902 38.0219279
-75.9862902 39.7898007
-78.1739886 39.790867
0 6 "none" <NoName>
-76.9484294 38.6515029
```

```
# This is gtool file <SATS_Secondary.pol> accessed by <SATS_Farrell_1.prj>
# Contains boundary points for <SATS AOI> which includes <D.C. Terminal
# Area> and <Commonwealth of Virginia> regions plus portions of surrounding
# boundary states
# 7-sided 3-D region, SFC - FL650
# Utilized by simulation to group blind conflicts within the defined zone


%Gtool
% $Id: $    %W% %G%
1
-84.4156117 34.1662162 -75.341442 41.3407307
-84.4156117 34.1662162 -75.341442 41.3407307
% no. polys
% minx, miny, maxx, maxy
% startx, starty, endx, endy
%> UNITS: DEGREES DEGREES DMS
1 15 "ATC Sector Boundary" <SATS_AOI-Secondary>[0.0,65000.0]xyzf(set color)
-76.0008877 39.8430583
-75.7539043 35.4989214
-82.5047835 35.4989214
-84.0031494 36.5849556
-78.5036527 40.0080255
```

```
# This is gtool file <IAD-CL_B.pol> accessed by <SATS_Farrell_1.prj>
# Contains boundary points for Washington Dulles Class B airspace
# Includes 5NM ring (SFC - FL100), 12NM ring (1,500 ft - FL100),
# 15NM ring (2,500 ft – FL100), and 20NM ring (4,500 ft – FL100)
# Utilized by simulation to group blind conflicts within the defined zone


%Gtool
% $Id: $    %W% %G%
4
-78.4001263 38.2088415 -76.5118225 39.677507
-78.4001263 38.2088415 -76.5118225 39.677507
% no. polys
% minx, miny, maxx, maxy
% startx, starty, endx, endy
%> UNITS: DEGREES DEGREES DMS
1 3 "ATC Sector Boundary" <IAD_5NM>[0.0,10000.0]xyzf(set color)
-77.2921692 38.9431742
-77.2934591 38.9636766
-77.2973084 38.9838557
-77.3036566 39.0033932
-77.3124033 39.021981
-77.3234108 39.0393259
-77.3365053 39.0551545
-77.3514805 39.0692171
-77.3681 39.081292
-77.3861019 39.0911886
-77.4052023 39.0987509
-77.4250998 39.1038598
-77.4454807 39.1064345
-77.4660237 39.1064345
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1 3 "ATC Sector Boundary" <IAD_12NM>[1500.0,10000.0]xyzf(set color)
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Curriculum Vitae

Christopher M. Farrell

Christopher Michael Farrell
November 22, 2005

A. Personal History

Home Address:
63 Fenwick Road
Fort Monroe, Virginia 23651

Phone: 757.722.5538

Birth date: January 9, 1969

Citizenship: USA

B. Educational History

1. United States Military Academy, West Point, New York

Major: Systems Engineering
Degree: Bachelor of Science, 1991

C. Professional Positions

1. Major, U.S. Army.

   Aviation Officer

   101st Airborne Division (Air Assault), Fort Campbell, Kentucky (1992-95),
   U.S. Army Aviation Warfighting Center, Fort Rucker, Alabama (1991-92, 1996),
   Camp Eagle, Wonju, Republic of Korea (1996-98)

   Instructor, Department of Mathematical Sciences and Operations Research Analyst
   U.S. Military Academy, West Point, New York (2000-03)

   Chief Readiness Analyst, Headquarters, U.S. Army Training and Doctrine Command,
   Fort Monroe, Virginia (2003-06)

   Strategic Operations Research Analyst, Commanding General's Initiatives Group,
   Headquarters, Multi-National Force – Iraq, Camp Victory, Baghdad (2006-present)

D. Membership in Professional Associations

Aircraft Owners and Pilots Association

Army Aviation Association of America

American Mathematical Society

Institute for Operations Research and the Management Sciences

Society for Industrial and Applied Mathematics

E. Professional Activities

1. Member, Land Warrior Training Functional Working Group,
Lead: Omega Training Group, Inc., Columbus, Georgia 2001-02.

2. Member, Land Warrior Integrated Product Team,
Lead: Program Executive Office Soldier, Fort Belvoir, Virginia 2002.

F. Editorial Activities

1. Ad Hoc Editorial Consultant,
Land Warrior System Training Plan, 2000-01.

G. Grants

1. Project Manager Soldier Systems,
Program Executive Office Soldier, #DSE-R-0215,
Computer Based Training Methodology for Land
Warrior, $40,000, 2001-02. C.M. Farrell, Principal
Investigator

2. Academic Research Division, Dean of the Academic Board,
U.S. Military Academy, #DSE-R-0323,
Small Aircraft Transportation (SATS): Airspace Infrastructure
Modeling and Simulation, $1,300, 2002. C.M. Farrell,
Principal Investigator

3. Project Manager – Soldier Systems,

Program Executive Office Soldier, #DSE-R-0320,
Evaluating the Effectiveness of Interactive Multimedia Instruction for Soldier Tactical Mission Systems, $80,000, 2002-03. C.M. Farrell, Principal Investigator

H. Papers Presented

Farrell, C.M. (October 2003). Experimenting with Interactive Multimedia Instruction for Military Science Education. Paper presented at the annual meeting of the Institute for Operations Research and the Management Sciences (INFORMS), Atlanta, Georgia.

Farrell, C.M. (December 2003). Employing Interactive Multimedia Instruction in Military Science Education at the U.S. Military Academy. Paper presented at the Interservice/Industry Training, Simulation and Education Conference (I/ITSEC), Orlando, Florida.

Farrell, C.M. (June 2004). Effectiveness of Interactive Multimedia Instruction and Intermediate Desktop Simulation in an *e*-Learning Framework. Paper presented at the European Simulation Interoperability Workshop, University of Edinburgh, Scotland.

I. Publications

Farrell, C.M., C. Jacquet and W. Klimack (2003). Employing Interactive Multimedia Instruction in Military Science Education at the U.S. Military Academy. Published in the proceedings of the 25th I/ITSEC, Orlando, Florida. [Best conference paper finalist].

Farrell, C.M., B. Williams and E. Mosely (2004). Effectiveness of Interactive Multimedia

Instruction and Intermediate Desktop Simulation in an *e*-Learning Framework. Published in the proceedings of the European Simulation Interoperability Workshop (Euro SIW), University of Edinburgh, Scotland.

Major Farrell's research interests include graph theory, mixed integer linear programming, and numerical analysis. His applied interests are in the development of airspace models with network capacities for the purpose of risk assessment enabling mitigation strategies. He is also interested in the application of emerging technologies to further transform training and education. Major Farrell has taught Discrete Dynamical Systems, Calculus, Differential Equations, as well as senior level capstone courses in operations research and applied mathematics.