Summer 2014

# Time-Based Collision Risk Modeling for Air Traffic Management

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## Recommended Citation

Bell, Alan E.. "Time-Based Collision Risk Modeling for Air Traffic Management" (2014). Doctor of Philosophy (PhD), dissertation, Engineering Management, Old Dominion University, DOI: 10.25777/bkc8-tz77
https://digitalcommons.odu.edu/emse_etds/50

# TIME-BASED COLLISION RISK MODELING FOR AIR TRAFFIC MANAGEMENT

by

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A Dissertation Submitted to the Faculty of
Old Dominion University in Partial Fulfillment of the
Requirements for the Degree of

DOCTOR OF PHILOSOPHY

ENGINEERING MANAGEMENT

OLD DOMINION UNIVERSITY
August 2014

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# ABSTRACT

## TIME-BASED COLLISION RISK MODELING FOR AIR TRAFFIC MANAGEMENT

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Since the emergence of commercial aviation in the early part of last century, economic forces have driven a steadily increasing demand for air transportation. Increasing density of aircraft operating in a finite volume of airspace is accompanied by a corresponding increase in the risk of collision, and in response to a growing number of incidents and accidents involving collisions between aircraft, governments worldwide have developed air traffic control systems and procedures to mitigate this risk. The objective of any collision risk management system is to project conflicts and provide operators with sufficient opportunity to recognize potential collisions and take necessary actions to avoid them. It is therefore the assertion of this research that the currency of collision risk management is time.

Future Air Traffic Management Systems are being designed around the foundational principle of four dimensional trajectory based operations, a method that replaces legacy first-come, first-served sequencing priorities with time-based reservations throughout the airspace system. This research will demonstrate that if aircraft are to be sequenced in four dimensions, they must also be separated in four dimensions.

In order to separate aircraft in four dimensions, time must emerge as the primary tool by which air traffic is managed. A functional relationship exists between the time-based performance of aircraft, the interval between aircraft scheduled to cross some three dimensional point in space, and the risk of collision. This research models that relationship and presents two key findings. First, a method is developed by which the ability of an aircraft to meet a required time of arrival may be expressed as a robust standard for both industry and operations. Second, a method by which airspace system capacity may be increased while maintaining an acceptable level of collision risk is presented and demonstrated for the purpose of formulating recommendations for procedures regulating air traffic management methods and industry standards governing performance requirements for avionics designed to support trajectory based operations.

# ACKNOWLEDGMENTS

While I have taken credit as the author of this dissertation, a substantial portion of that credit is deserved by numerous people who have made this research possible.

Dr. Adrian Gheorghe has served as my advisor since I walked through the doors of Kaufman Hall, and nobody could ask for a more dedicated mentor. His encouragement led me at times to pursue goals I didn't think achievable, while at other times his caution reeled me in and prevented me from overwhelming myself.

The other members of my committee have each contributed substantially to the development of my research. Even before I applied to the program, Dr. Barry Ezell was instrumental in matching my research goals with the Engineering Management department, and he maintained interest in this work throughout my student tenure. Dr. Ariel Pinto was the Graduate Program Director when I arrived, and the time he invested on my behalf early in my program also helped to set me on the right course. Subsequently, his expertise in risk analysis has been of great value both to my current research and to developing industry tools I hope to contribute to in the future. Dr. Resit Unal's support as the department chair provided opportunities for me to succeed, and his teaching allowed me to develop insights into the nature of interaction effects that led me to additional research supporting the FAA's initiative to manage integrated risks. Dr. Patrick Hester's expertise in decision analysis and systemic thinking have greatly influenced my own thinking, and if I ever wind up in a position to teach, I hope I can replicate the learning environment he creates in his classes.

Beyond my committee, Dr. Andres Sousa-Poza provided valuable guidance and enrichment to my experience at ODU. His class opened my eyes to the vast world of research methods, and at a time when the scope of my research was beginning to spiral out

of control, his guidance allowed me to focus on achievable results. His leadership as graduate program director is enhancing student experiences every day and promises to create benefits for faculty as well. I'm also grateful to Dr. Holly Handley for allowing me to participate in her initial Enterprise Architecture class and look forward to further investigating research opportunities in that arena.

Beyond ODU, Dr. Michael Smith, Beth Harrison, Dr. Bill Scherer, Tom Brett, and Peter Whitehead at the University of Virginia all played important roles in shaping my academic goals while I was studying there, and I hope our paths cross again in the future.

Two people beyond academia have provided insight, criticism, and data to support and shape my research. Tom Teller, another former Navy S-3 pilot, is in my opinion one of the world's foremost experts on required time of arrival concepts. He led many of the simulation activities referenced in this document and provided a large portion of the data used in this effort. He also provided thorough reviews and thoughtful comments, often correcting my misinterpretations and helping to reshape theories for several papers I developed en route to this dissertation. Similarly, Jarrett Larrow of the FAA has invested substantial effort in support of my research, and I'm grateful that through his influence, RTCA Special Committee 227 has considered my research as they develop international time of arrival control standards.

Jennifer Lamont, President and CEO of Systems Enginuity, has provided numerous opportunities for me, funded a large portion of my research, and in doing so, allowed matching grants from NASA through the Virginia Space Grant Consortium. I hope I am able to find a way to repay her for her support and generosity in the years to come.

Finally, after making so many sacrifices during my years on active duty, I'm grateful to my wife and two daughters for enduring long hours of inattention necessitated by seemingly endless nights and weekends of study. I'm hopeful these efforts serve to provide a good role model for both kids, and I'm looking forward to freeing up time for all three of them once this degree is completed.

# NOMENCLATURE

| | |
|---|---|
| ADS-B | Automatic Dependent Surveillance - Broadcast. System that uses GPS-based transponders to report position and receive position of other proximate aircraft. |
| ATC | Air Traffic Control. |
| CASSIS | CTA/ATC System Integration Studies. A series of flight tests conducted in Europe to evaluate time of arrival control concepts. |
| CFR | Code of Federal Regulations. |
| Clearance | An instruction offered by an air traffic controller to a pilot to perform a specific maneuver or function. Once accepted, compliance with the instruction becomes compulsary. |
| Cost Index | A metric used by commercial air carriers to quantify total operating cost. It is the ratio of cost linked to flight time versus fuel cost. Flight time costs include costs incurred per flight hour, such as periodic maintenance inspections and flight crew expenses. |
| CTA | Controlled Time of Arrival, acronymn commonly used in Europe. |
| CTOA | Controlled Time of Arrival, acronymn commonly used in US. |
| EASA | European Aviation Safety Agency. |
| ETA | Estimated Time of Arrival. |
| EUROCAE | European Organization for Civil Aviation Equipment. Develops standards for avionics, European counterpart of RTCA. |
| FAA | Federal Aviation Administration. |

| | |
|---|---|
| FMS | Flight Management System. Avionics used to calculate aircraft trajectories, optimize performance, and cross three dimensional points at required times. |
| GPS | Global Positioning System. |
| HITL | Human-in-the-Loop simulation. |
| IFR | Instrument Flight Rules. |
| KIAS | Knots indicated airspeed. Speed historically displayed in aircraft cockpit based on measurements of static and dynamic pressure. |
| KCAS | Knots calibrated airspeed. KIAS adjusted for gauge errors. |
| KEAS | Knots equivelant airspeed. KCAS adjusted for compressibility of air. |
| KTAS | Knots true airspeed. KEAS adjusted for density of air. Also reflects the true speed of the aircraft through the air mass. |
| KGS | Knots ground speed. KTAS corrected for the effect of wind. Reflects the speed of the aircraft over the ground. |
| Mach | An aircraft speed relative to the local speed of sound. |
| Meter fix | A three dimensional point in space used as a flow control point for arrival traffic to assist in formation of a uniformly spaced sequence of traffic. |
| NATCA | National Air Traffic Controllers Association. |
| *NextGen* | Title of FAA's vision for the next generation air traffic management system. |
| NM | Nautical Mile. |
| RADAR | Radio Detection and Ranging. |
| RNP | Required Navigation Performance. |
| RPM | Revenue Passenger Miles. |

| | |
|---|---|
| RTCA | Radio Technical Commission for Aeronautics. Develops standards for avionics in US, counterpart of EUROCAE. |
| RTA | Required Time of Arrival. |
| RTP | Required Time Performance. A term proposed in FAA strategic planning documents referring to a time-based performance metric and developed through this research. |
| SMS | Safety Management System. |
| TET | Time Error Tolerance. A user-configurable setting specific to General Electric Flight Management Systems, with values ranging from 6 to 30 seconds. The exact influence on the system is proprietary information, but in general, lower settings reduce the threshold at which the system will correct for expected crossing time errors. |
| TMA | Traffic Management Advisor. This system creates a time-based schedule of runway threshold crossings at major US airports and calculates an associated time-based schedule for meter fix crossings that serve as flow control points around the airport for arrival traffic. |
| TBO | Trajectory Based Operations. |
| TOAC | Time of Arrival Control. |
| 3DPAM | Three Dimensional Path Arrival Management, a system used to provide offset waypoint assignments as a means of increasing distance flown by an aircraft to delay arrival at an airport. |

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# 1. Introduction

## 1.1. Air Traffic Demand and Capacity

For decades, demand for air travel in the United States has been closely tied to economic factors, and a strong correlation exists between economic metrics such as gross domestic product and demand for air travel. The relationship between real gross domestic product in billions of dollars and demand for air travel in terms of billions of revenue passenger miles is shown in Figure 1 from 1978 to 2012 (FAA, 2013b, p. 5, reprinted by permission).

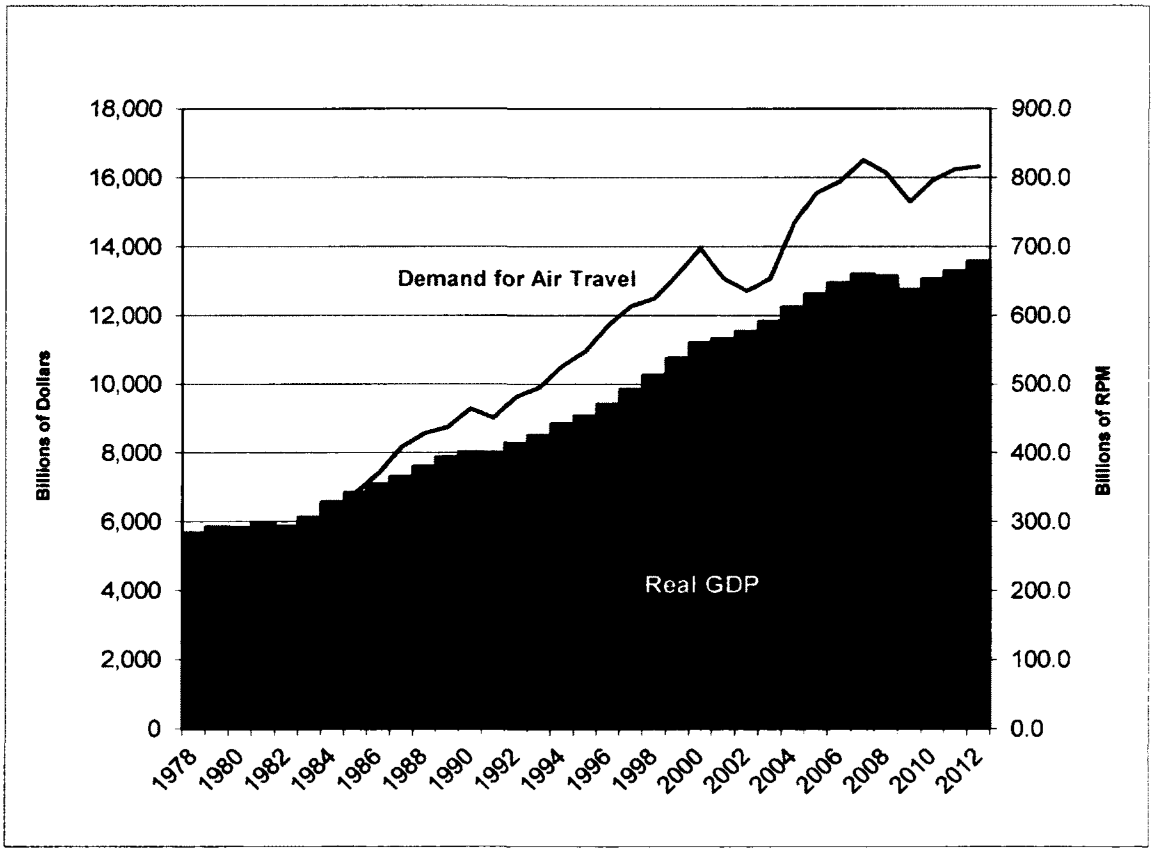

Figure 1: Demand for Air Travel and the Economy

While Figure 1 illustrates the historical demand for air travel, future demand is of greater interest to air system planners. The Federal Aviation Administration publishes an annual forecast of expected demand for air travel, and a recent projection for the coming two decades is illustrated by the bar chart shown in Figure 2 (Adapted from FAA, 2014, p. 43).

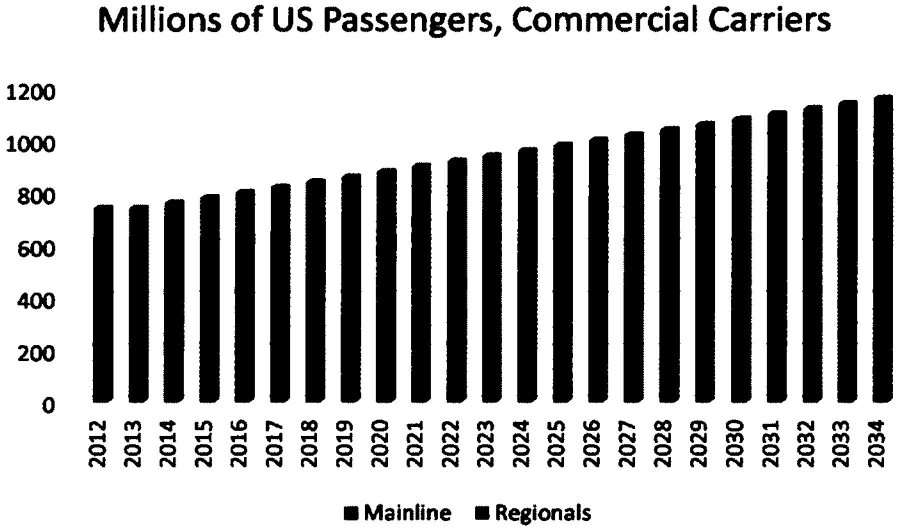

Figure 2: Projected Demand for Air Transportation

The demand for air transportation has more than doubled since the late seventies, and it is clear that substantial increases in demand are still expected in the coming decades. This is cause for concern as opportunities for investment in infrastructure to support growing demand have been nearly exhausted, resulting in frequent delays as demand routinely exceeds capacity during peak periods of operation. These delays ultimately result in substantial cost to numerous stakeholders. Airlines suffer increased expenses in terms of fuel and maintenance related costs, and frequently incur additional flight crew expenses as well. The flying public also incurs cost resulting from the increased time required for travel as flights are cancelled, connections are missed, and to some additional degree as air travel is avoided due to passenger expectation of such delays. According to a recent study estimating the cost of delays in financial terms, the total cost of US air transportation delays in 2007 was $32.1 billion (Ball, Barnhart, Dresner, Hansen, Neels, Odoni, Petereson, Sherry, Trani, & Zou, 2010). These fiscal costs do not include environmental impacts that result from untold amounts of additional carbon-based emissions associated with increased combustion of jet fuel during these delays.

A number of initiatives have been implemented in recent years or are being implemented to increase system capacity in each of the aviation domains. These domains are generally accepted to be en route airspace, terminal airspace, oceanic airspace, and airports. In the early part of this century, capacity of the most congested portions of en route airspace was effectively doubled by cutting in half the required vertical separation between aircraft from 2,000 feet to 1,000 feet between flight level 290 and flight level 410, airspace that serves as optimum cruise altitude for most jet aircraft (FAA, 2005). In the runway environment, a number of initiatives have been explored to increase the number of aircraft that can land on a runway in a given period of time by finding ways in which the effects of wake turbulence can be avoided (Bell, 2009). Additionally, new runways have been constructed at airports where geographic constraints allow physical expansion, resulting in increased system capacity at 16 airports in the US (FAA, 2011, p. 1). However, most of the feasible options for increasing capacity through infrastructure expansion and airspace restructuring are either in progress today or have already been completed, necessitating the introduction of new systems and procedures that allow the density of air traffic to be increased within limited volumes of airspace.

As air carriers increase the number of flights scheduled each year to accommodate increasing demand, the number and magnitude of expected delays associated with future air traffic operations is also expected to increase. In response, the US has proposed its Next Generation Air Traffic Management System, referred to as *NextGen*, as a new system for managing air traffic based on emerging technology and procedural changes. Similar efforts are underway in Europe under a parallel program entitled *Single European Sky*. Both of these programs are justified by claims that capacity can be increased to accommodate demand by improving efficiency while simultaneously improving safety and delivering environmental sustainability. One of the most promising concepts enabling development of both systems is the replacement of current "first come, first served" methodologies with time-based management of air traffic. An intuitive analogy can be drawn between this concept of air traffic management and other time-based scheduling problems such as those associated with restaurant management. A restaurant may accommodate customers as they arrive, and when demand exceeds capacity, queues develop and delays are incurred. In contrast, a restaurant that accepts reservations allows customers arriving at a negotiated time to be seated with little or no delay, and it is this notion that aviation leaders hope to capitalize on by offering time-based reservations to air traffic customers. However, while a time-based reservation system allows delays to be reduced for individual patrons, it does nothing to increase the total capacity of the system. Thus, at peak periods of operation, some customers will be denied service or offered service at other times until the system is saturated, a point at which no further demand will be accommodated.

Over the past several years, numerous studies have been commissioned by the FAA to explore the benefits of using time to sequence aircraft. Support systems have been developed to assist controllers with scheduling the arrival of aircraft at busy airports, and have shown some benefit in reducing the cost of delays by issuing clearances to aircraft that allow them to absorb necessary delays during en route portions of their flights. Prior to these efforts, delays were routinely incurred at low altitude and in close proximity to terminal areas where operating costs, particularly for jet aircraft, are highest. By assigning delays further from the arrival airport, the delays can be absorbed at higher altitudes where fuel burn rates are lowest, and cost is reduced.

However, changing the location at which delays are incurred does nothing to reduce the magnitude of the delays, and only marginal gains have been achieved as a result of employing time-based scheduling systems. Instead, they have only served to provide a measure of mitigation to the cost of the delays. In order to make significant advancements toward achieving the goals of *NextGen* and *Single European Sky*, capacity itself must be increased. Numerous constraints exist with regard to adding additional capacity to the existing airspace system, especially in the vicinity of the world's most frequent destinations, and few alternatives remain for the addition of new airports, additional runways at existing airports, or other similar measures that would increase the capacity through capital investment. Similarly, airspace in both terminal areas and en route sections of the system have been or are in the process of being optimized, leaving little room for additional capacity through design efforts. Thus, other methods by which capacity can be increased must be considered.

To achieve an increase in system capacity, the rate of arrivals and departures at saturated airports during peak periods of time must be increased. To accomplish this objective, the density of the air traffic must be increased such that a greater number of aircraft can operate in the same airspace simultaneously. However, arbitrarily reducing the distance between aircraft comes at the expense of safety. There are at least two concerns that arise with regard to determining safe operating separation between aircraft. The first involves encountering wake turbulence effects from preceding aircraft while the second involves the potential for collisions.

The specific effect of wake turbulence is beyond the scope of this project, but the methods develops herein can easily be adapted to compensate for wake turbulence risk mitigation. The focus of this document is to identify a method by which aircraft may be separated to achieve desired increases in capacity by increasing traffic density without exceeding an acceptable level of collision risk. In short, this paper offers a quantitative method for achieving important objectives of *NextGen* and the *Single European Sky.*

## 1.2. Problem Statement

Since the advent of modern air traffic control shortly after World War II, collision avoidance has been accomplished by maintaining an adequate *distance* between aircraft to ensure enough *time* is available to allow for both controller and pilot recognition of conflicts and subsequent corrective action to avoid potential collisions. However, today's technology allows development of systems and procedures whereby the underlying objective of providing adequate time for collision avoidance can be provided directly instead of using a distance-based standard as an approximation for the amount of time that is required. The challenge faced by aviation regulatory authorities is that if aircraft are sequenced by time, they cannot be separated by distance due to inescapable properties of aerospace physics. This study identifies the effect of those properties and proposes new methods and metrics by which aircraft sequenced in four dimensions may also be separated in four dimensions.

In order to arrive at a time-based separation standard, there are several sub problems that must be solved. First, an understanding of the capability with which modern aircraft can achieve an assigned crossing time at a specified location must be developed. Any aircraft that is assigned a required time of arrival at a point in space will arrive with some measurable error that can be expressed in units of time. The magnitude of that potential time error will be one of the independent variables in this study. A second independent variable is the time interval between aircraft scheduled to cross a three-dimensional point in space. As the interval between aircraft is increased, the magnitude of the deviations that would be necessary by each aircraft in order to arrive at the same point at the same time must necessarily be larger, and the corresponding probability of the aircraft arriving with enough error to collide decreases.

The dependent variable will be the probability of collision between aircraft. For any point in space, the total probability of collision is equal to the probability of the first aircraft being at that point at some time *and* the probability of the second aircraft being at that same point at the same time for every possible arrival time. If the probability of each aircraft arriving at the specified place and time is known, it is then possible to calculate the probability of collision. The relationship between the independent variables and the dependent variable will be expressed via mathematical functions that serve as the heart of the collision risk models developed through this research, and are referred to as a separation functions throughout this document.

Once a separation function is developed to express the relationship between arrival time error, interval, and collision risk, it can then be used as the basis for development of recommendations for new standards and flight procedures. At least two objectives will be pursued in this regard. First, distributions developed from flight and simulation test results will be used as evidence of the capability of aircraft equipped with modern flight management systems to achieve scheduled arrival times. From these observations, a number of alternatives will be considered with regard to developing a metric by which to express the performance of any aircraft as a probabilistic distribution. Subsequently, the separation functions developed herein will be used to demonstrate how a minimum interval between aircraft can be determined while being constrained to an acceptable probability of collision.

## 1.3. Research Questions

The preceding problem statement is reformulated in this section as three questions this research effort attempts to answer. These questions are presented to assist with delineating the scope of this research.

- How can the time-based performance of an aircraft be quantified as a metric that provides adequate design flexibility while maintaining sufficient control of underlying parameters of the error distribution?
- How can the probability of collision be determined for aircraft operating in a time-based operational environment?

- How can the density of air traffic be increased to meet expected demand while maintaining an acceptable level of collision risk?

# 2. Background

## 2.1. Evolution of Separation Standards

In order to fully understand the concepts developed in this study, it is beneficial to first understand how air traffic management systems and procedures evolved over the past century, beginning with the earliest days of commercial aviation, and continuing through present day operations to a reasonably forecastable point in the future. It is especially important to understand the origins of distance-based separation standards in order to conceptualize the inherent advantages, perhaps even necessity, of returning to the roots of air traffic control, and reverting to a time-based standard.

In the earliest days of aviation, fledgling pilots took to the sky only when visual conditions allowed ground reference to be maintained. Due to characteristics of aviation physiology that cause human sensory systems to be misled while flying, pilots are not able to rely on "seat of the pants" feel to maintain aircraft attitude. As a result, early pilots were required to maintain continuous reference to the horizon and terrestrial landmarks both for control of the aircraft as well as navigation. As commercial opportunities for aviation emerged, demand for technology allowing aircraft to be flown without ground reference grew. To satisfy this demand, two of the most influential technological breakthroughs in aviation history occurred in the years following World War I.

One of the first revolutionary innovations in aviation was introduced by the Sperry Gyroscope Company in England. Based on stabilized three-axis platforms being developed for maritime navigation applications, Sperry introduced the first artificial horizon known as the "Blind Flying Panel," providing sufficient attitude information to allow pilots to safely fly through clouds, at night, or during periods of low visibility (Sullivan, 1963). Once pilots could maintain control of their aircraft without ground reference, the ability to navigate came next. Frank Adcock, a British engineer, developed a radio direction finding antenna that provided pilots with a method by which to measure relative bearing from ground stations (Adcock, 1919). The US Army and Post Office built upon this technology and developed ground stations for aerial navigation in 1926, and by the 1930's, pilots were able to navigate by a growing number of radio beacons (Johnson, 2003).

An unexpected side effect of these technological improvements was a substantial shift in the density of air traffic. Prior to the development of ground antennae, pilots flew directly from one airport to another, and only during conditions that allowed for other aircraft to be seen and avoided. Once instrument navigation became feasible, flight operations could be conducted in any visibility conditions, and the number of aircraft flying between the limited numbers of radio beacons available for navigation increased local air traffic density, leading to a dramatic increase in collision risk. The effect of implementing these beacons is illustrated in Figure 3.

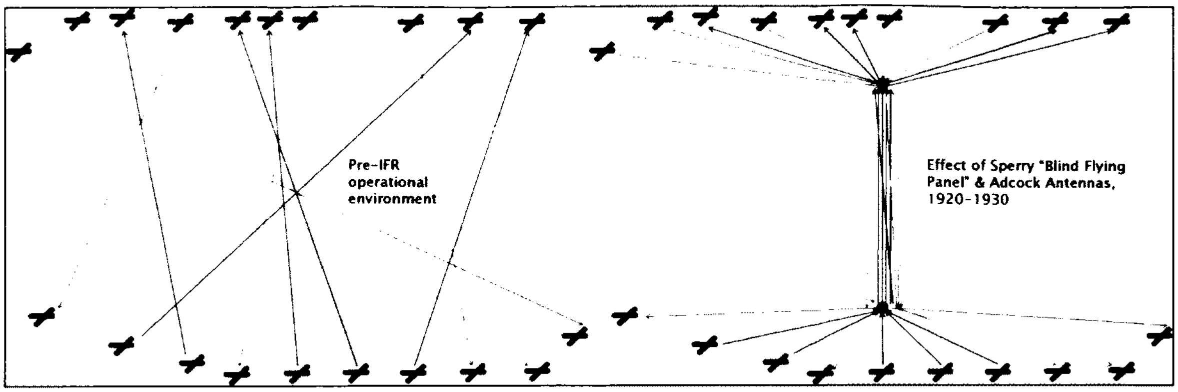

Figure 3: Effect of Adcock Antennas on Traffic Density

With concern for air traffic safety growing in the mid 1930's, the US Commerce Department created the first air route traffic control centers in Newark, Cleveland, and Chicago. Controllers in these centers used maps and blackboards to create models of air traffic based on perceptions of aircraft speed, direction of flight, and elapsed time. These perceptions were derived from flight plans and the reception of periodic communications from aircraft, relayed by various ground stations. The controllers then modeled their perceptions by moving miniature airplanes referred to as "shrimp boats" across maps to reflect their understanding of position information and to track aircraft progress as that information was updated. The Federal Radio Commission appointed ARINC to provide essential communications between air carriers and air traffic control, introducing capabilities that included phones, radios, and teletypes to receive rapid updates of aircraft positions at corresponding times and to relay deconfliction instructions back to pilots (ARINC, 2013). Due to the round trip communication time and the positional uncertainty associated with navigation accuracy in that era, time-based separation standards were introduced to ensure adequate collision avoidance time, and as refinements to communication and navigation technology emerged, the standards evolved to reflect the incremental changes in capability (NATCA, 2010).

Separation standards experienced a game-changing event during the Battle of Britain in 1940 when RADAR was introduced by the Royal Air Force. This new technology allowed air traffic controllers to see the relative position and distance between aircraft, but not time. As a result, distance-based standards were introduced to approximate existing time-based separation requirements. In the US, a high profile collision over the Grand Canyon in 1956 prompted the national government to invest heavily in RADAR technology, leading to widespread implementation as well as the development of complementary technologies such as the transponder (NATCA, 2010). At the same time, navigation precision advanced with developments of both ground based and airborne navigation improvements. Land based navigation aids such as early low frequency long range navigation systems (LORAN), VHF Omni Directional Radio Range (VOR) and the military Tactical Air Navigation System (TACAN) all served to steadily improve the accuracy of overland navigation (DOT, 2001). Simultaneously, airborne navigational capabilities such as inertial navigation systems allowed improved navigation in all phases of flight, including oceanic flight where reference to ground stations and RADAR surveillance were not possible. These technological improvements both in the air and on the ground allowed distance-based separation requirements to evolve until modern standards were reached, resulting in current requirements for five nautical miles of separation in the en route environment and three nautical miles in comparatively slower terminal environments (FAA, 2012).

## 2.2. Trajectory Based Operations

Trajectory Based Operations are a cornerstone of future air traffic management systems in both Europe and the United States. The concept retains existing requirements for precise navigation in three dimensions (latitude, longitude, and altitude), and adds a new dimension: time. As systems are developed to enable trajectory based operations, regulatory agencies like the Federal Aviation Administration (FAA) and the European Aviation Safety Agency (EASA) will be called upon to make decisions with regard to regulations governing performance standards for avionics on aircraft, ground based support systems, and air traffic management procedures that ensure acceptable levels of collision risk, environmental sustainability, and adequate system capacity. Expected increases in demand for air travel in the coming decades will require increasing the density of air traffic in the US National Airspace System (NAS) and in Europe's international airspace system as well as other airspace systems around the globe. As air traffic density is increased, an associated requirement emerges for unprecedented levels of navigation precision in all four dimensions if desired capacity increases are to be achieved in concert with desired levels of safety. To ensure today's systems are developed with the precision necessary to execute tomorrow's operations, it is essential that flight standards and regulations be equally precise in prescribing performance requirements.

In the United States, the FAA has embarked on a multi-decade capital investment program to develop *NextGen*, and this system is founded largely on trajectory based operational concepts. European Union aviation regulation is provided by a parallel organization called the European Aviation Safety Agency (EASA, 2012), and its partner organization, Eurocontrol, which is pursuing similar time-based initiatives under the *Single*

*European Sky* program (Eurocontrol, 2012). The seemingly revolutionary concept of trajectory based operations that both of these systems depend on effectively requires a reversion from two-dimensional surveillance and distance-based separation procedures back to the origins of air traffic management and a return to a methodology employing time-based sequencing and separation of aircraft.

Since the advent and refinement RADAR and radio communication technologies in the mid-twentieth century, air traffic control in both Europe and the US has evolved as a system to increase the efficiency and safety of air traffic operations. The systems are based primarily on an air traffic controller's ability to observe the position of aircraft either visually or electronically. The routing and separation of aircraft is accomplished by orchestrating aircraft movements through the issuance of instructions called *clearances* that are designed to maximize capacity while ensuring an adequate distance between aircraft is maintained in various operating environments. A potential change associated with future air traffic management is the transfer of a significant portion of the responsibility for sequencing and separation to pilots supported by avionics automation capabilities. This change requires aircraft to arrive at various points in space not only with currently required positional accuracy in three dimensions, but additionally at a specified time. This method of air traffic management is commonly referred to as Four Dimensional Trajectory Based Operations (4D TBO).

A number of support systems and procedures have been developed in an effort to sequence aircraft by time, and several tests of these new capabilities have been executed on both continents. In the cockpit, a number of leading avionics manufacturers, including Honeywell, General Electric, and Thales have added a required time of arrival capability to their flight management systems, allowing the aircraft auto-pilot system to be guided by commands that adjust speed such that the aircraft arrives at a three-dimensional fix at the time specified by the flight crew. In en route air traffic control centers, the *Traffic Management Advisor* (TMA) system automatically schedules runway threshold crossing times for arrivals as well as associated crossing times at flow control points referred to as meter fixes. However, most tests conducted to evaluate the potential of time-based systems have met with limited success or failure in terms of demonstrating an implementable solution to safety and capacity challenges expected in the coming decades. Existing literature describing the research to date indicates the limiting factors are most often attributed to an inability to maintain adequate separation distance between aircraft when sequencing them by time. The lack of progress has prompted the FAA to pursue alternative approaches that appear to be more achievable, and substantial investment is being made to determine the requirements and capability necessary for ground systems to issue speed commands in an attempt to deliver aircraft to various flow control points at desired times (Levitt & Weitz, 2011). This initiative, referred to as interval management, includes two subsets of operations. Flight Interval Management (FIM) is a cockpit technology that allows aircraft to modulate speed to maintain a constant interval between sequential aircraft, but virtually abandons the objectives of previous time-based sequencing concepts defined in strategic documents. Its counterpart, Ground Interval Management (GIM), is based on ground systems estimating aircraft performance and environmental conditions and then issuing speed commands to aircraft in order to deliver them to desired three dimensional points at scheduled times. However, substantial evidence has been collected through flight and simulation testing of such concepts, and the evidence indicates that due to unsolvable uncertainty associated with environmental parameters such as wind, temperature, pressure, and operator-dependent aircraft performance limitations, it is not feasible for ground stations to issue speed commands with the frequency and fidelity necessary to achieve desired objectives (Moertl, Arthur, Pollack, Stein, & Zheng, 2009).

The theory developed in this study is that the failures experienced in various trajectory based operations experiments have been, at least in part, the result of attempting to sequence aircraft using a new time-based methodology while attempting to manage collision risk using legacy distance-based separation criteria. Therefore, the position of this paper is to advocate a migration of air traffic management philosophy toward trajectory based operations that not only sequence aircraft by time, but separate them by time as well.

## 2.3. Airspeed Expressions

Terminology used to describe the speed of an aircraft is important when considering time versus distance-based criteria for separation. The speed of an aircraft in flight is expressed in nautical miles per hour, or knots, but important characteristics of aerospace physics requires airspeed to be described in several different ways. An understanding of the differences between various airspeed expressions as well as their application is important to the arguments that follow. One of the oldest and most commonly used airspeed measurement processes compares dynamic air pressure measured by pitot tubes and static ports on the exterior of the aircraft, and is referred to as *indicated airspeed,* or more formally, *knots indicated airspeed* (KIAS). This measurement has historically been the value displayed to the pilot in the cockpit. When this value is corrected for gauge errors, the result is referred to as *calibrated airspeed* (KCAS), and today is commonly displayed in modern aircraft equipped with air data computers that automatically account for these errors. When calibrated airspeed is corrected for the compressibility of air, the result is a value called *equivalent airspeed* (KEAS). At low airspeeds, the differences between KIAS, KCAS, and KEAS are typically negligible. As altitude increases and the density of air decreases, yet another airspeed value can be expressed to quantify the speed the aircraft travels through the air mass. This speed is referred to as *true airspeed* (KTAS). The air mass itself is constantly in motion, and adjusting true airspeed for the influence of wind results in a value that is of great importance to both navigation and air traffic control, that being *ground speed* (KGS), the speed at which the aircraft is traveling over the earth's surface. *Ground Speed* also provides an opportunity for common reference as it is the speed reported by the Global Positioning System, and can be approximated by air traffic control systems through measurement of the change in observed position over time. To complete a summary of air speed expressions, one final value should be mentioned. At very high speeds aircraft often express speed as a fraction of the local speed of sound. This value is referred to as *Mach number* (M) and has important aeronautical engineering properties with regard to the design and limitations of the airframe.

## 2.4. Literature Review

A review of the available literature in the area of time-based air traffic management (ATM) reveals several important insights. First, there is virtually no discussion or investigation of the influence of aerospace physics on the amount of separation that exists between aircraft that are sequenced via time-based schedules, leading to a conclusion that this topic has yet to be explored in depth. Further, while many documents assert that future air traffic control systems will need to ensure an acceptable level of safety, few researchers define what this would mean in quantitative terms or how the desired level of safety would be achieved. Surprisingly, while there has been little focus on safety metrics, suggestions have nonetheless been published with regard to performance specifications for systems that are necessary to enable the future vision of trajectory based operations, including its safety. However, these specifications have been stated as single parameter, or a "bookend" standard that is not robust enough to ensure the performance of the airspace system will meet the stated objectives. In fact, unexpected consequences of initially proposed standards are possible even if vendors meet design specifications and provide independent testing to validate compliance of their products with the currently envisioned standards. Finally, and perhaps most importantly in terms of the justification of the research proposed herein, while multiple studies have been conducted to assess the feasibility and value of sequencing aircraft by time, all of the research to date has been based on an assumption of retaining distance-based separation requirements similar to those that have been in place since the 1950's.

The literature cited in this review is derived from two primary sources:

(1) Documents published by various regulatory organizations, reviewed to establish existing or envisioned policy with regard to air traffic management. These include:

- US Federal Aviation Administration (FAA)
- European Aviation Safety Administration (EASA)
- Radio Technical Commission for Aeronautics (RTCA)
- European Organization for Civil Aviation Equipment (EUROCAE)
- Joint Planning and Development Office (JPDO)
- Eurocontrol.

(2) Journal articles, conference proceedings, and test reports that describe related research regarding the development of the *NextGen*, Trajectory Based Operations (TBO), Required Time of Arrival (RTA), merging (or sequencing) and spacing, and aircraft collision probability.

The literature is reviewed by topic under the following broad categories:

- Articles that describe the evolution of distance-based standards in parallel with the development of RADAR and radio technology
- Documents outlining the vision for a future air traffic management system
- Articles describing controlled time of arrival studies
- Articles describing interval management studies
- Articles discussing the results of controlled or required time of arrival flight tests
- Articles presenting methods of determining collision probability.

The vast majority of the experimentation conducted to date has focused on the en route phase of commercial aircraft flight, including transition to the terminal phase of flight, and therefore the majority of the documentation reviewed describes operations within these domains. However, the methods developed herein are equally applicable to all phases of flight. Additionally, General Aviation (GA) operations, typically consisting of light civilian aircraft being flown privately, have not yet been a focus of time-based air traffic management research, and thus no reference to this category of aircraft is cited in this study. However, the methods of time-based separation developed in this research are applicable to future general aviation operations conducted under applicable instrument flight rules.

### 2.4.1. Historical Perspective

In order to fully understand the concepts developed in this study, it is helpful to review literature describing the history of air traffic management systems and procedural evolution. It is especially important to understand the origins of distance-based separation standards in order to understand arguments supporting a reversion to a time-based standard. The National Air Traffic Controllers Association provides an excellent overview of the history of air traffic control in a presentation format on their website (NATCA, 2010). Another brief explanation of the development of air traffic control, focusing on objectives, is included in a NASA document proposing a new method of separation referred to as Autonomous Flight Rules (Wing & Cotton, 2011). A somewhat dated, but still relevant historical article describing development of gyroscopic technology by the Sperry Corporation in the early 1900's is also helpful in establishing a historical framework with regard to the evolution of flight instruments and the need for air traffic control as aircraft developed the ability to fly in low visibility conditions (Sullivan, 1963). Similarly, a series of three articles published in 2003 editions of the Journal of Air Transportation describe in detail the origins of aeronautical communication, navigation, and surveillance systems (Johnson, 2003). Finally, one of the most comprehensive documents available describing many of the historical developments of early 20th century air traffic control is authored by one of the founding fathers of air traffic management, Glen A. Gilbert. Published in the early 1970's, his description of the development of the Air Traffic Control System is an original account of the system's history as viewed by one of its earliest operators (Gilbert, 1973). Together, these documents help to illustrate how the amount of time required to recognize and avoid collisions has been provided by ensuring a measurable distance exists between aircraft under RADAR control.

Equally as important to understanding the past is to have a realistic expectation of the future. Two documents produced by the FAA attempt to project the demand for air travel in the coming decades as well as the anticipated level of investment the country is willing to make in order to meet that demand. In its annual Aerospace Forecast, the FAA projects a steady growth in the demand for air travel in the coming decades, with an increase from approximately 800 million passengers in 2012 to 1.2 billion passengers embarking by 2030 (FAA, 2013a). To support this increased demand, Congressional budget projections indicate a corresponding increase in financial investment. Over the next five years of that period, the *FAA Capital Investment Plan* calls for expenditures of $2.78 billion in 2014, gradually increasing to $3 billion by 2018 (FAA, 2013b).

### 2.4.2. *NEXTGEN* and Trajectory Based Operations

The vision for US air traffic management in the coming decades is described in several documents. The highest level document addressing *NextGen* is published by the Administrator of the Federal Aviation Administration, and is called "*Destination 2025*" to highlight the agency's goal of implementing a new system of air traffic management by that time (FAA, 2011). A more detailed description of specific elements of this plan can be found in the *NextGen Concept of Operations*, which presents eight key concepts associated with the implementation of this new system. Among these is Trajectory Based Operations, defined in the document as a method that "dynamically adjusts a flight path in space (longitude, latitude, altitude) and time using a known position and intent; more accurately allowing the decrease in separation and increase in National Airspace System capacity" (JPDO, 2010, p. 3).

A closely related document is a report published by the JPDO regarding Trajectory Based Operations. This document provides detailed analysis of existing capabilities and overviews of implementation challenges that are directly related to this study. The first involves flight performance of avionics systems, and recognizes that "today's avionics were not built for TBO" (JPDO, 2011, p. 92). It goes on to acknowledge that different algorithms produce different performance, and a need is envisioned for common avionics performance standards for manufacturers of both avionics and ground based air traffic management automation systems. Another portion of this document focuses on TBO safety, and the discussion provides an indication of the current mindset with regard to safety. The document states that "One objective of TBO is to increase safety to meet the increase in traffic, reduction in separation, and greater use of automation to manage traffic" (JPDO, 2011, p. 99). This statement provides insight into the common understanding among today's air traffic control community that distance-based standards will continue to be relied upon for future separation, and subtly acknowledging that with an increase in traffic, there will be a necessary reduction in the distance between aircraft in order to achieve capacity goals. Notably absent is discussion of a new method of separation, such as one in which a time-based standard is developed for the separation of aircraft. Finally, this document mentions a new concept, referred to as "Required Time Performance (RTP)," where "the objective is to meet the required time with a precision consistent with the density of traffic" (JPDO, 2011, p. 104). This statement once again provides insight into the nature of the current thinking regarding time-based operations, and reflects an arrival mentality whereby the system is considered from the perspective of an arrival facility. Specifically, the notion that accuracy requirements increase as aircraft get closer to their destination is expressed, potentially overlooking requirements for accuracy that may exist even in low density traffic environments, such as jet route crossing points in high altitude en route sectors or merge points between jet routes as traffic arriving from numerous origination points experience a funnel effect en route to meter fixes. Additionally, no consideration is given to aerospace physics and the influence of air density, temperature, and wind, all of which may exert significant influence on the system and result in requirement variations as crossing altitudes vary vertically.

The issue of safety is one that cannot be overlooked when proposing changes to the National Airspace System. The methods by which safety risk must be assessed whenever such changes are made to the US National Airspace System are outlined in the *FAA Air Traffic Organization Safety Management System Manual* (FAA, 2008a). This document provides detailed methodologies for identifying hazards that may be introduced when changes are made, determining the likelihood of hazards being realized, and the severity of the potential outcomes. A particularly relevant portion of the document provides guidance for determining the acceptable probability for any catastrophic event, such as a mid-air collision between two aircraft (FAA, 2008a, p. 42). A closely related document is the *Safety Risk Management Guidance for System Acquisitions*, which provides additional detail regarding the safety requirements for systems being developed for use in support of air traffic management operations (FAA, 2008b).

The numerous government-produced documents available clearly identify the objective of using trajectory based operations as a platform for the nation's next generation air traffic control system, but while time-based sequencing alternatives are discussed, there is no mention of using time for separation of aircraft. Instead, all references to flight safety and separation assume the use of existing or modified distance-based standards. The next section further investigates literature related to the use of time to sequence aircraft by assigning arrival times.

### 2.4.3. Controlled or Required Time of Arrival

Controlled Time of Arrival (CTOA) procedures are not included as standard operating procedure either in the United States or in Europe, and therefore, there are not yet flight standards in place to govern their operational use. However, both European and US aviation standards development organizations have suggested parameters that must be met regarding arrival control parameters. The European Organization for Civil Aviation Equipment (EUROCAE), and its US counterpart RTCA, have released documents that prescribe requirements for industry that currently serve as the basis for evaluation of current capability. For example, in a standards document published by RTCA, while a time of arrival control function is not mandated, it stipulates that if one does exist, it "shall control the time of arrival at a specified lateral fix in the flight plan with a 95% accuracy of 30 seconds" (RTCA, 2003, p. E53). This document has been updated since its original publication, and additional updates are anticipated to address time of arrival control standards in more detail.

Several studies have been conducted to investigate theories that suggest efficiency benefits can be achieved through a process of controlling aircraft arrival time. One of the first such studies was presented in Europe, and discussed the utility of sequencing aircraft by time in an attempt to reduce controllers' workload (Graham, Hoffmann, Pusch, &

Zeghal, 2003). The general recommendation of the study was to sequence aircraft in the en route phase by time to establish a more uniform flow of traffic for controllers in the terminal environment. This study was cited by a group of researchers at the NASA Ames Research Center, who conducted experiments to explore the possibility of implementing such a process. Notably, Prevot reported results with regards to the delivery accuracy of a modern flight management system (FMS), and this is the earliest available study to report usage of an experimental Required Time of Arrival (RTA) function on an FMS (Prevot, Lee, Callantine, Smith, & Palmer, 2003). An interesting feature of this study was the objective of the data collection which was to measure the time between aircraft crossing a meter fix. The group used a ground based system, the Traffic Management Advisor (TMA), to calculate the amount of time in seconds that should be assigned to aircraft in order to achieve a resulting distance between aircraft expressed in nautical miles, with 7 nautical miles being the desired separation for their test. This variable is selectable in TMA via an adjustable value referred to as a "Stream Class Setting," and a detailed explanation of the method by which a desired separation distance is achieved by converting the requirement to a time-based separation is provided in a NASA document describing functionality of the "Dynamic Planner" (Wong, 2000, p. 35). In hindsight, this is an interesting development as the team clearly demonstrated an awareness of a relationship between time and distance, but still chose to use distance as the metric by which separation was judged. A note in their results section foreshadows results obtained in future studies, including this dissertation. It states "Aircraft less than 58 seconds apart had less than five NM lateral separation and were therefore delivered at different altitudes to avoid the separation loss" (Prevot, et al., 2003, p. 4) With regard to delivery accuracy, the Prevot study reported a mean accuracy of 1.43 seconds more than their desired interval with a standard deviation of 18.75 seconds. One other note from the Prevot study is that aircraft were required to cross the arrival meter fix at 11,000 feet and 250 KIAS, a condition that is not specifically discussed in the study, but is noteworthy as different altitude and airspeed combinations at the meter fix influence the results of similar subsequent studies.

In 2007, David De Smedt and Gerhard Berz published results of FMS simulation testing, pointing out variances in system performance levels and providing summary data on overall accuracy of the systems in use at the time (De Smedt & Berz, 2007). This study included substantial investigation of the effect of wind on the achievability of an RTA clearance, and documented a conclusion that in order to achieve desired distance-based spacing requirements, "FMS algorithms would need to be robust enough to consistently achieve arrival times within a small fraction of a minute – possibly less than the current state of the art of +/- 6 seconds" (De Smedt & Berz, 2007, pp. 1.D.5-8). However, there is no further justification or defense of the suggestion that a 6 second accuracy level is achievable either currently or in the future. It appears that these researchers assume that the lowest time error tolerance setting on the General Electric FMS, 6 seconds, would result in a maximum crossing time error of six seconds. However, later testing has demonstrated that this is not the case.

Another analysis performed by De Smedt, working with Joel Klooster of General Electric (GE) Aviation Systems, a major manufacturer of Flight Management Systems, stated an objective of evaluating the distance between aircraft sequenced by time at a meter fix. The study, which included over 30,000 simulation events, asserted a primary benefit of using RTA is more efficient sequencing and spacing at a metering fix, reducing the variance of aircraft arrival times over that fix (Klooster & De Smedt, 2011). The experiment was designed to evaluate the frequency with which separation losses, defined as less than 5 NM separation and less than 1000 feet vertical separation, occur between pairs of aircraft assigned to cross the meter fix at 8,000 feet with a 90 second time interval scheduled between them. After observing initial disappointing results, the test was re-run with a 120 second interval. The results indicate that approximately five percent of the aircraft pairs suffered separation losses (Klooster & De Smedt, 2011) with a 90 second interval, and 2.5% when the interval was increased to 120 seconds. The study did not consider the influence of the comparatively low meter fix crossing altitude of 8,000 feet on the results, and all discussion of separation is based on current distance-based standards. The study goes on to recommend development of a complex support tool to alert controllers to situations that may result in less than 5 NM of separation, effectively conceding that controller intervention will be necessary to achieve acceptable collision risk levels if distance-based standards are maintained.

### 2.4.4. Interval Management

Another approach to sequencing aircraft using time has been proposed. In contrast to using time for sequencing and separation, interval management concepts focus on using a variety of systems to deliver speed guidance to aircraft in an effort to deliver them to meter fixes at scheduled times while maintaining a constant distance or time between aircraft through cockpit-based applications. This subject is briefly reviewed as efforts in this area may complement, or potentially replace, separation objectives currently associated with trajectory based operations.

The NASA Langley Research Center has tested a time-based airborne inter-arrival spacing tool that capitalizes on the emergence of Automatic Dependent Surveillance – Broadcast (ADS-B) to maintain a constant time between arrival aircraft. The tool, Advanced Terminal Area Approach Spacing (ATAAS), computes speed commands for the aircraft to maintain a desired time interval behind another aircraft. The stated objective of the tool is to allow aircraft to vary speeds to reduce excess spacing that occurs in traffic streams (Lohr, Oseguera-Lohr, Abbott, & Capron, 2003), and the tool shows promise, delivering a mean accuracy of less than 1 second more than the desired interval with an 8 second standard deviation. However, a number of challenges are noted in the document, including an accordion effect as aircraft speed oscillates in an effort to maintain spacing. While a number of benefits of using this tool are envisioned, no documentation exists to report demonstration of these benefits or to provide evidence that they are achievable. However, it may be a valuable tool to enhance the ability of aircraft to maintain a time-based interval in a TBO environment.

A similar study was conducted by the MITRE Corporation in cooperation with United Parcel Service at the Louisville, KY International Airport. The test evaluated an Airline Based En Route Sequencing and Spacing (ABESS) tool, designed to predict the time of arrival at a meter fix, and then issue speed commands to aircraft in an effort to achieve a uniform separation between arriving aircraft (Moertl, et al., 2009). The concept proved unsuccessful as errors exceeded an average of 1 minute on 50% of the test days, an unacceptable level of variability.

While new applications of time-based intervals such as the preceding two examples have recently been tested, the concept of using time to separate aircraft is not a new idea, nor is it only a relic of aviation's early history. In fact, the majority of the planet's skies currently employ this method of separation as it is the primary means of deconflicting trans-oceanic flights that operate in non-radar environments. Pilots make position reports to oceanic controllers via HF radio, or via digital data link systems, reporting the time they crossed a specific latitude and longitude as well as a projection of the time they will cross a future point on their flight plan. Beginning with the first trans-Atlantic flights in 1919, overwater navigation systems have included inherent inaccuracies as methods of determining position evolved from dead reckoning to celestial navigation, and eventually to the use of inertial navigation systems. However, even advanced inertial systems suffered from position errors significant enough to require excessive amounts of time between aircraft, making application of the concept in radar environments infeasible due to lack of efficiency. Of note, in a 2011 article, Ryoto Mori suggests methods by which collision risk may be calculated between aircraft separated by time on oceanic routes, and suggests the amount of time currently required between flights may be safely reduced. Additional collision risk modeling documents are described in a subsequent section. The objectives and underlying assumptions behind Mori's work are different from those of this study, but he clearly identifies a mathematical relationship between time interval and collision probability (Mori, 2011).

Another paper, presented at the Integrated Communications Navigation and Surveillance Conference in 2012, summarized data obtained through flight and simulation testing of the RTA function of GE Flight Management Systems used on board Alaska Airlines Boeing 737 aircraft. The paper discusses relevant aerospace physics concepts that influence the amount of distance that results when aircraft are separated by time at various altitudes. The paper goes on to develop a probability distribution from flight and simulation test samples, and suggests avenues by which standards for sequencing and separation might be developed to achieve acceptable risk levels (Bell, 2012). However, the method of determining collision probability presented in that paper is iterative in nature and limited to a determination of the point at which maximum collision probability is observed rather than total probability of collision.

Finally, the United States Navy uses time to separate aircraft in order to achieve precise intervals between fixed wing arrivals to aircraft carriers. A Cold War era operational requirement to recover aircraft at sea with no emissions from radar or radio forced development of a time-based system of sequencing and separating aircraft that optimized recovery efficiency in an effort to minimize the time the aircraft carrier was required to steam into the prevailing wind. The procedures for accomplishing this are delineated in the *Aircraft Carrier Naval Aviation Training and Operating Procedures Standardization* (CV NATOPS) document, portions of which are re-printed in individual aircraft flight manuals. However, these documents are not publicly available.

### 2.4.5. Flight Tests

In addition to documents developing the theory of time-based operations and simulations, several flight tests and simulations have been performed by the FAA and Eurocontrol to evaluate the performance of modern flight management systems as well as the ability of aircraft to cross a three dimensional fix at a specified time. The published reports of these tests will be briefly reviewed in this section, and a more thorough review of the data collected during these tests as well as its application to this research is presented in Chapter 4.

Two recent flight trials have been conducted in Europe and two additional flight demonstrations of a similar nature have been conducted in the US. In each of these tests, aircraft were assigned crossing times at various arrival fixes, and data was collected with regard to the actual crossing times achieved by the aircraft. In Europe, the tests were conducted by the CTA/ATC System Integration Studies (CASSIS) program, and featured a variety of aircraft and flight management systems. These aircraft included Boeing 737 variants with a modern GE FMS, Airbus A321 and A330 with a Honeywell Pegasus FMS, and McDonnell Douglas MD-80, which does not include an FMS with RTA functionality, but instead features only an estimated time of arrival (ETA) function, requiring pilots to manually adjust speed to meet timing requirements. The US flight trials consisted entirely of Boeing 737 aircraft equipped with a GE FMS.

The CASSIS program outlined results in two reports, one for each of the flight trials. In the first trial, data was captured on 308 arrivals to Stockholm Arlanda Airport, and results were summarized as follows:

> The results show that aircraft equipped with the most advanced Flight Management Systems were able to meet an assigned time with 30 second accuracy in 88% of the CASSIS trials. Even MD80 pilots who adjusted speed manually to meet a CTA could do so with 30 second accuracy in 73% of the case." (Swedavia, 2009, p. 6)

Another interesting and relevant result is captured in tabular format, expressing the numeric accuracy of the various aircraft involved in the testing. Airbus aircraft, using a Honeywell FMS, tended to be early with a mean crossing time of 8.33 seconds early. In contrast, the GE FMS on the 737 aircraft tended to arrive late, with a mean crossing time of 1.1 seconds late. It is also interesting to note that the manually piloted MD-80 aircraft also demonstrated a tendency to arrive early, but with much greater variance (Swedavia, 2009).

The second CASSIS trial results, once again evaluating the performance of Stockholm arrivals, were summarized by stating "90% met their assigned time with 30 second accuracy and 97% met their CTA with 60 second accuracy" (Eurocontrol, 2010, p. 5). Once again, differences with regard to the proprietary FMS systems existed, showing a tendency for the Airbus and manually flown MD-80 aircraft to arrive earlier than the 737, and substantially higher variance in manually flown arrivals than those controlled by an FMS (Eurocontrol, 2010).

Similarly, flight trials in the US were reported using a series of categorical outcomes based on a 20 second performance measure. There is no explanation provided for use of a this measure, but flights that crossed the assigned fix within 20 seconds were considered successful, while those that were outside of that tolerance were considered failures. In the comparatively limited 2010 flight trial, 92% of the 38 arrivals to Seattle, WA met the 20 second tolerance, and 94.7% arrived within 30 seconds (Smith, 2011). The second flight trial was considerably more robust, with 595 arrivals completing RTA crossings. Of that sample, 86.4% crossed within 20 seconds and 96.6% crossed within 30 seconds (Wynnyk & Gouldey, 2012).

The consistent theme of documented flight trials involving controlled time of arrival experiments is an identical method of evaluation that involves measuring aircraft performance against an arbitrary standard, foregoing the opportunity to fit the data to a continuous distribution in favor of treating each arrival as an independent Bernoulli trial.

If this method of testing and data reporting is used by manufacturers of flight management systems for the purpose of demonstrating compliance with standards, unexpected consequences may result as demonstrated in recent literature (Bell, Gheorghe, & Hester, 2013).

### 2.4.6. Collision Risk Modeling

Few researchers over the past half century have attempted to quantify airborne collision probability through analytic methods. Airborne collisions are rare events, and due to their infrequent nature, it is generally not feasible to assess collision probability through observation of the frequency of events, including those observed through simulation due to the dependency of simulation results on error distributions used in their formulation. Due to the complexity of formulating a three-dimensional stochastic collision model, most efforts to quantify collision probability have been attempted by mathematicians who are forced to make tradeoffs between the utility of the model as a tool that can be understood and employed by aviation regulatory authorities, and limitations that result from reliance on a variety of underlying assumptions that serve to simplify the problem.

One of the seminal works in aircraft collision probability determination was authored by British mathematician P. G. Reich. His article dealing with separation standards was a follow on to a series of papers he published in 1964 dealing with separation standards for the North Atlantic, and originally published in three parts by the Journal of Navigation in 1966. With virtually no other significant work published in this area during the three decades that followed, it was republished in its entirety in 1997 by the same Journal. Reich's influence on subsequent articles is clear, with even the most recent articles on collision risk citing Reich's original papers. Indeed, the objectives of this research parallel those of Reich's original work, which are in his words, "to set out the basic requirements for definitive estimates of collision risk; that is to say, estimates which are meant to influence choice of procedural separation standards or to specify the quality of navigation which is needed for given standards to be safe" (Reich, 1966, p. 437).

However, Reich's methods, and those who have followed his initial assumptions, are not as applicable to $21^{st}$ century trajectory based operations in which time rather than distance is used to manage air traffic. The premise of Reich's calculations is that collision risk arises from unintended deviations in aircraft position. He introduces a box of airspace surrounding an aircraft that he refers to as a proximity shell, and asserts that if one aircraft remains clear of another's proximity shell, neither aircraft will be exposed to a collision risk. His logical development of a model effectively asserts that collision risk is a function of the navigational position error expressed in units of distance from intended position, and calculations are based on limiting cases of error probability distributions. These distributions arise due to the inability of 1960's researchers to gather data regarding the true position of an aircraft versus the position estimated by navigators, a drawback that led Reich to view the development of accurate probability distributions as an intractable problem. Therefore, in the absence of data from which probability distributions could be formulated, he set an upper bound on position error probabilities to ensure a conservative estimate of collision risk.

Reich also presents seven rules for the development of separation standards that are as valid today as they were when first authored. Of particular interest is Reich's seventh rule, in which he states "a requirement which is almost self-evident, but seldom met: Estimates should be presented in a form suitable for executive use" (Reich, 1966, p. 446). It is the intent of this dissertation to hold true to that rule.

Reich's paper and model serve as the basis for collision risk determination in nearly all subsequent efforts. As an example, Qu Yuling and Han Songchen of Nanjing University in China published an article proposing a modification of Reich's model to account for variable distances between aircraft tracks (Yuling & Songchen, 2010). In 1979, D. A. Hsu attempted to explain navigation position variances and apply the resulting distribution to Reich's model (Hsu, 1979). He followed that article by proposing a method by which collision probability at intersections could be calculated, once again using a position error distribution (Hsu, 1981).

No authors have been as widely published on the subject of collision probability than mathematician L. M. B. C. Campos of the University of Lisbon's School of Engineering and his colleague, Professor JMG Marques of the Lusofona University, also in Lisbon. Campos and Marques have published numerous articles relating to the calculation of aircraft collision probabilities and frequently cite Reich in their work. Only a sampling of their publications is reviewed in this section.

A 2001 article by Campos on the probability of collision of aircraft drew upon Reich's intuition that collision risk is a function of navigational position error (Campos, 2001). The following year, Campos teamed with Marques to publish an article suggesting aircraft separation safety metrics in which they develop a root mean square error (rms) that serves as an important parameter in their calculations, both in this initial article and numerous subsequent articles (Campos & Marques, 2002a). That same year, a similar article focused on the use of collision probabilities as the basis for separation standards (Campos &

Marques, 2002b). Of note, in 2007, when separation standards in the oceanic region were being reviewed to allow aircraft to climb and descend with reduced separation standards, they published an article addressing collision risk associated with this operation (Campos & G. Marques, 2007). Among numerous other publications, one recent publication is of particular interest to this work. Their 2011 paper discussing the probability of collision for crossing aircraft addresses high aspect collision probabilities, demonstrating an enhancement to baseline collision risk models that assess the collision risk of aircraft operating along a common track (Campos & Marques, 2011). However, while Campos and Marques have emerged as the leading experts in the field of aviation collision risk, their work is still fundamentally based on Reich's 1966 paper, and depend entirely on distance-based metrics.

As future air traffic management concepts inevitably migrate toward time as the governing tool for sequencing and separating aircraft, distance-based methods that depend on quantification of position errors become less relevant. When Reich first developed his collision risk model, navigational position error was the dominant uncertainty in aircraft navigation, and Reich hypothesized that collision risk was primarily a result of this uncertainty. However, his model has never been validated, despite the numerous academic publications that have expanded on his initial theories and regulatory guidance that is based on his results and those of his successors. The advent of satellite navigation has revolutionized aircraft navigation and resulted in unprecedented accuracy levels in both vertical and horizontal azimuths. Aircraft position can now be determined with a degree of accuracy that makes position errors far less likely in virtually any collision risk calculation, and in subsequent sections, this research echoes assertions of international governance documents that the improvements in navigational accuracy actually create an inherent increase in collision risk rather than the expected decrease (ICAO, 1998). As a result, it is concluded that conversion to a time-based collision risk model for use as the basis for informing regulatory decisions regarding separation standards is warranted.

# 3. Research Methodology

## 3.1. Research Philosophy

Research methods supporting aviation safety studies are typically governed by research paradigms that fall into one of two categories, described as either quantitative or qualitative methods by authors of research design such as Creswell and Leedy. Alarmingly, evaluation of numerous safety assessments and research reports indicates that while research designed to develop air traffic control systems is primarily accomplished through quantitative methods, safety analyses performed by the FAA are largely qualitative in nature, and depend heavily on estimates of relevant values by subject matter experts who rely on intuition developed through experience applying legacy air traffic control paradigms.

In contrast to most of the existing literature, the approach to this study does not follow either of these traditional methods. According to Leedy, if the research does not fall into one of the two defined categories of research, it must be a mixed method approach that draws from each of the available methods such that "all aspects substantially contribute to a single, greater whole" (Leedy, 2013, p. 258). However, this research is not simply a combination of qualitative and quantitative methods, and a deeper understanding of the methods applied, the canons associated with those methods, and justification of their use is necessary to build a foundation from which the research can be discussed, critiqued, and defended. To that end, the research methods will be described by investigating three divisions of research: the mode of reasoning, the ontological philosophy, and the epistemological approach.

Each division of research includes a spectrum along which the research falls, with each end of the respective spectrum labeled to describe its nature. The modes of reasoning fall into either inductive or deductive categories, ontology is described as either positivist or constructivist, and the epistemological position is characterized as either empiricist or rationalist (Siangchokyoo & Sousa-Poza, 2012). These divisions of research may be illustrated in the form of a cube, an example of which is shown in Figure 4. Note that classic quantitative methods as defined by both Creswell and Leedy fall into the lower, left, front portion of the cube, depicted in red, while qualitative methods appear in the upper, right, front portion, depicted in green. In addition to providing an overview of these divisions as a framework for discussion and defense of the selected methods, it also allows deeper insight into the results of this research and perhaps more importantly, the limitations of its conclusions.

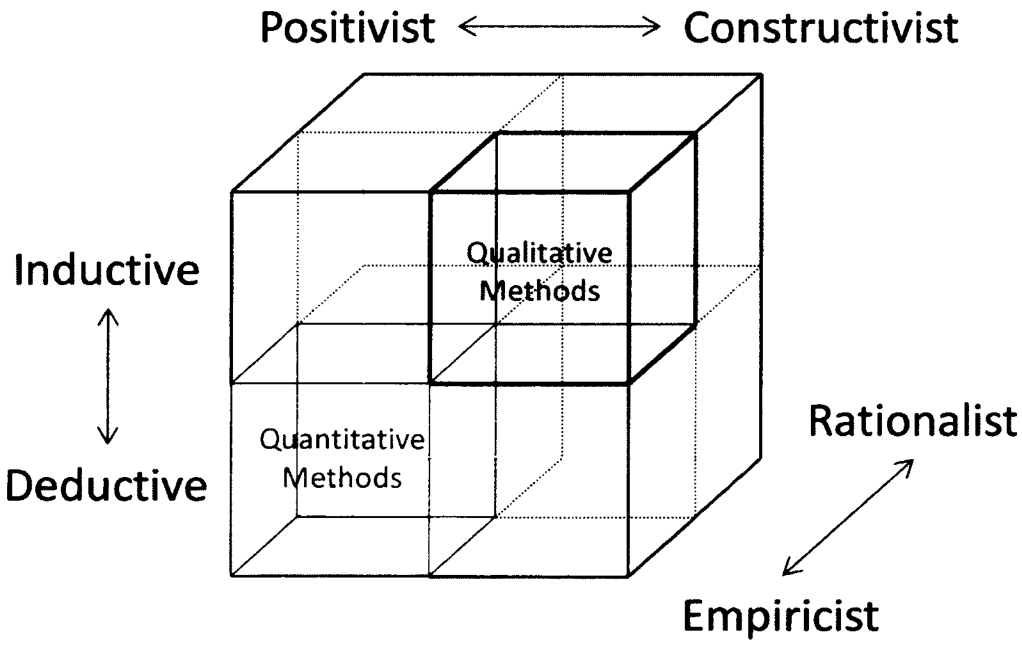

Figure 4: Research Methods Cube with Creswell's Traditional Methods

To begin with, this study employs an inductive mode of reasoning. The process of inductive research involves analysis of data, and subsequent abstraction of a theory through identification of patterns or other features that suggest explanations for its variance. This method is in stark contrast to deductive methods which begin with some form of hypothesis and use confirmatory methods to either accept or reject a hypothesis based on results of experimentation. In this study, the data analyzed involves thousands of flight and simulation events in which aircraft were assigned crossing times at three dimensional fixes in space, and their performance in achieving those times recorded in data sets. From this large combined data set, consisting of many different types of aircraft, environments, and operators, trends emerge with regard to performance, and these trends can be expressed quantitatively using statistical data analysis methods. More specifically, the data can be presented in the form of tables and histograms, and with sufficient sample sizes, the data can be reasonably fitted to known probability density functions. Through observation of these data, a generalized theory may be developed to predict the future performance of similar aircraft systems being flown under similar circumstances, and a model can be developed to express the theory as well as provide a platform from which to extract these predictions.

Another division of research methods is made with regard to its ontological position. Ontology refers to the nature of reality, and there are two possible positions. While Leedy confines the mind-dependent nature of the constructivists to qualitative methods, he eloquently describes the division in his introduction to qualitative research (Leedy, 2013, p. 139). He begins by describing the positivist position in which the researcher aims for objectivity, avoiding any influence of the researcher due to impressions or bias. Thus, the positivist in a general sense is represented by a philosophy in which research describes the elements of the real world without need of interpretation – it is mind independent. Results of a positivist approach would be expected to yield objective conclusions, and those should not be significantly different among different researchers who study the topic. The opposing view is a constructivist approach in which the research is formulated through mind-dependent processes, relying on subjective evaluation of reality by participants or the judgment of experts in the field. To quote Leedy, "the [constructivist] researcher is an instrument in much the same way an oscilloscope, sociogram, or rating scale is an instrument" (Leedy, 2013, p. 139). The research proposed for this dissertation is heavily weighted toward a positivist position in that the theory developed through this research is largely based on the data described above. Finally, since the concept of acceptable risk is inherently dependent upon human judgment, implying there must be some level of mind-dependent influence, this paper relies primarily on well-established quantitative expressions for acceptable collision risk, defined by both the FAA in the United States and by the International Civil Aviation Organization on behalf of the international aviation community. Once defined, the separation functions developed herein treat collision risk as a dependent variable without further interpretation. Indeed, the value of collision risk modeling lies largely within the expected standardization of the process and uniform application by clients, necessitating a positivist methodology that may be replicated not only by other researchers, but by practitioners in similar fields.

Finally, research is also influenced by its epistemological approach, a concept that refers to the method by which human beings develop understanding of reality. Once again, the possibilities are divided to describe two ends of a spectrum with one end being referred to as empiricist and the other rationalist in nature. Empiricism suggests that research is accomplished through observation, while rationalism seeks knowledge through reasoning. While a substantial data set has been accumulated and studied in preparation for this research, the approach to developing a working collision risk model is largely rationalist in its nature, and is not dependent on the data itself. The observation of modern, commercial aircraft, nearly all of which are equipped with state-of-the-art flight management systems, allows insight into the limits of their performance. By observing the performance of these aircraft from an external perspective, it is not necessary to understand the complex, and often proprietary, algorithms that govern aircraft performance. Instead, by quantifying the performance of a wide range of aircraft, and using this as one of the independent variables in the collision risk model, the requirement for improved performance beyond current capability can be inferred through a rationalist argument that ties expected future demand to required performance levels. Similarly, observation of degraded performance in malfunctioning or less capable systems allows insight into the magnitude of system capacity limitations when managing aircraft that cannot meet optimum performance levels. Ultimately, a metric capable of describing performance levels is envisioned for development through a subsequent rationalist argument. Further explanation for this expectation is provided in subsequent chapters.

In summary, the research process described in the next section will be accomplished through application of an approach that has been described as a synthetic method and is positioned in the research cube as illustrated in Figure 5 (Sousa-Poza, 2013).

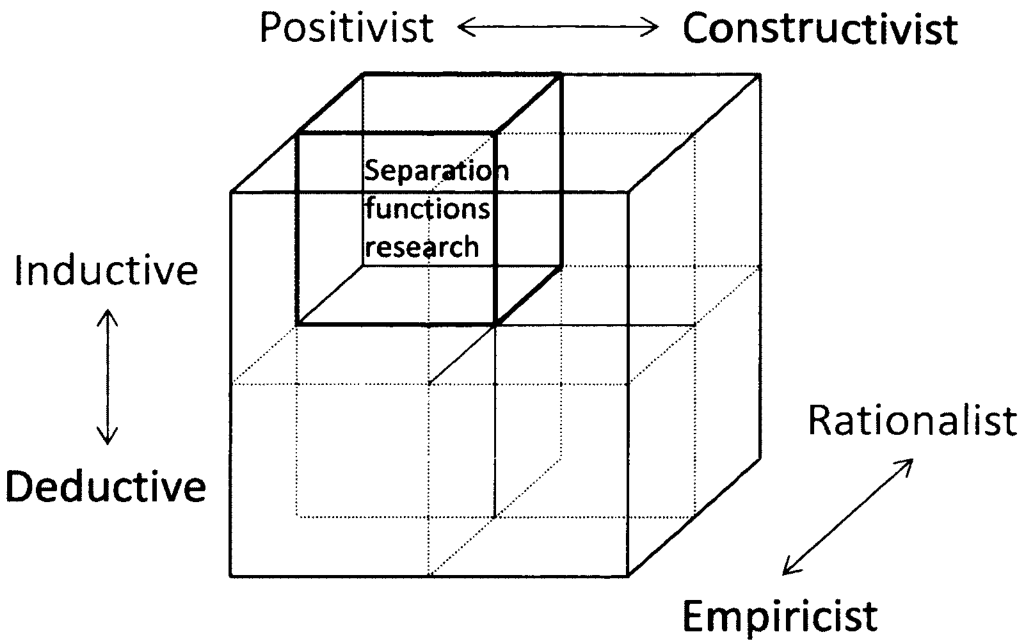

Figure 5: Research Method for Development of Separation Functions

This method is executed by applying an inductive mode of reasoning in combination with rationalist and positivist research philosophies. The result is the development of a mathematical theory, expressed as a stochastic model that allows management to prescribe standards for system performance and to make decisions with regard to system capacity necessary to meet demand while maintaining an acceptable level of risk.

## 3.2. Research Process

This section provides an overview of the process developed for answering the research questions presented in Section 1.3 and ultimately developing recommendations for aviation regulatory authorities. The first step in the research process is to present a method by which the performance of the aircraft may be quantified as a performance metric. Once that is accomplished, the performance metrics can be applied for use in determining the separation between aircraft that is necessary to both meet capacity goals as well as result in an acceptable level of collision risk. The objective of the final research question is to determine the level of performance future aircraft will need to achieve in order to sequence aircraft with an interval that safely accommodates expected demand.

The process begins with collection and analysis of data regarding the demonstrated performance of aircraft in capturing assigned crossing times as reported in flight and simulation reports. Using both graphical and numerical descriptive statistics, and by fitting the data to continuous probability distributions, insight can be achieved as to the magnitude of the error that has been demonstrated by a large sample of aircraft, and should be expected of the general population when modern aircraft operated with a variety of flight management systems are assigned discrete crossing times at various points in three dimensional space.

Once this data analysis is complete, a functional relationship may be developed between the variables of interest; namely the interval between aircraft expressed in terms of time, the risk of collision, and the performance metrics of the aircraft. This functional relationship allows for manipulation of the variables to achieve estimates of desired performance requirements that can then be used as the basis for the formulation of flight standards as well as performance standards for avionics designed to support four dimensional trajectory based operations.

For the purpose of developing the desired recommendations, the primary independent variable is the performance of aircraft in capturing assigned crossing times. Using the data set created from the flight and simulation test results, inductive principles are exercised to quantify time-based performance such that all aircraft can be certified for time-based air traffic management operations with a degree of accuracy corresponding to the certification level of their platform. It is an objective of this research to develop a performance metric that is consistent with existing flight standards, including navigation performance standards that are governed by the same guidance documents expected to govern time of arrival control standards.

Once the various levels of aircraft performance are expressed in quantitative terms, it is then necessary to estimate the level of risk that is considered acceptable by governmental regulatory authorities. Numerous publically available documents may be consulted to determine the level of risk with regard to mid-air collisions that is acceptable. Subsequently, this value may be considered a constraint for use in determining the minimum interval that may be assigned between aircraft of varying performance levels in order to achieve an acceptable level of collision risk. The ability to determine the necessary interval for aircraft of varying performance capability is essential to the development of flight standards governing future trajectory based operations. It should be noted however that collision risk is not the only variable that must be considered when establishing minimum interval requirement as other factors beyond the scope of this research, such as wake turbulence, may be limiting factors.

Another application of this research is to inform aviation regulators as to decisions that need to be made with regard to certification standards of avionics used in support of future trajectory based operations. This is done through a different manipulation of the relationship between the previously described variables. An identical constraint with regard to acceptable collision risk is developed in the same way as described above, and should be applied consistently between applications. However, in this application, the future demand for air transportation is used to estimate the interval between aircraft that will be necessary to accommodate that level of demand. By converting the interval variable to the independent variable, and the performance of the aircraft to a dependent variable, it is then possible to determine a level of performance that will be required to meet future system demands, allowing this level of performance to be prescribed as a new performance standard for future flight management systems.

The following model attempts to graphically depict the approach to the research with an objective of deriving a mathematical separation function driving stochastic models that can be used as the basis for submitting recommendations for the development of flight standards for both the manufacture of flight management systems and management of separation of aircraft by time.

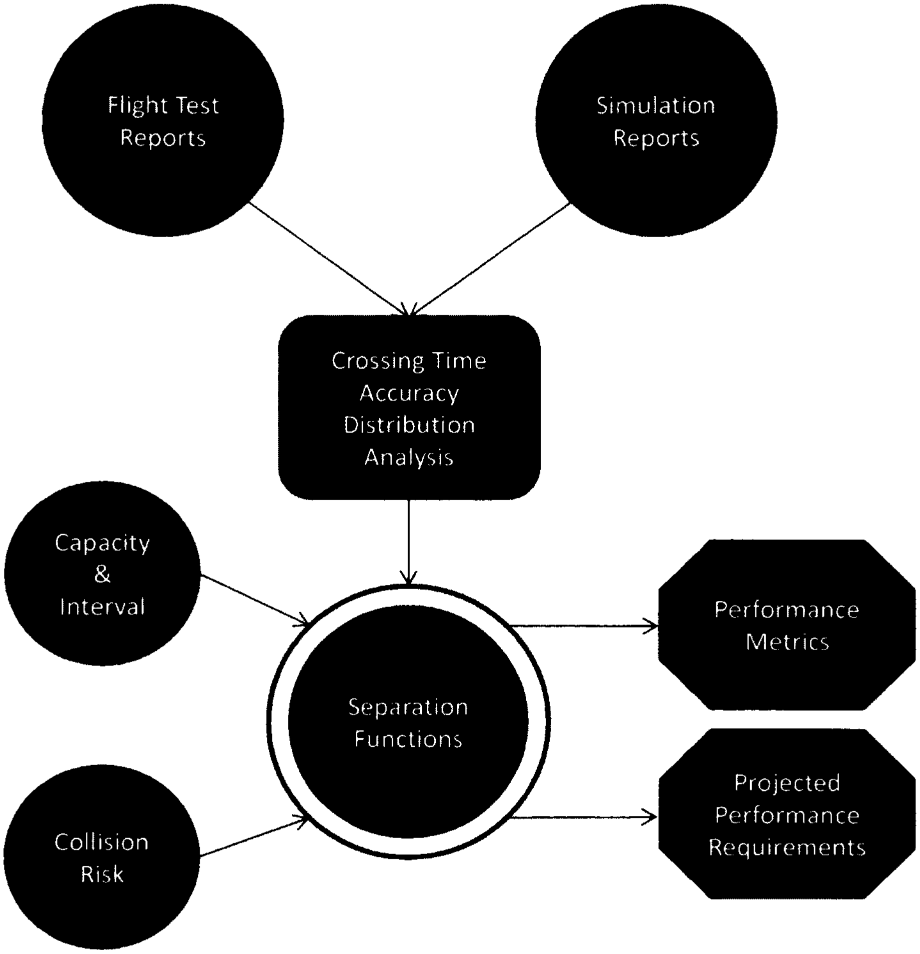

Figure 6: Research Process

Within the model, three symbols are used to differentiate the type of information presented. Circles represent uncertain data that must be collected in support of the study. A rectangle with rounded edges represents the result of combining two or more uncertain data types into a single uncertainty, providing categories of aircraft and flight management system performance expressed as parameters of a continuous probabilistic distribution. A double circle represents a deterministic function whereby if the inputs are known, the outputs are known precisely. For the purpose of this research, this symbol describes the functional relationship between the variables of interest. Finally, the outputs of the study are shown within octagons (Haimes, 2011, p. 179).

# 4. Discussion

## 4.1. Collision Risk

Numerous definitions of risk exist in literature and popular culture. The International Standards Organization defines risk as “the effect of uncertainty on objectives” (ISO, 2009). This definition allows broad application of the concept of risk, and allows for both positive and negative outcomes to be considered within the context of risk. Within the aviation community, definitions of risk are more narrowly focused and generally apply only to negative outcomes. The International Civil Aviation Organization defines “safety risk” in its *Safety Management Manual* as “The predicted probability and severity of the consequences or outcomes of a hazard” (ICAO, 2013, p. xii). With this term in mind, numerous authors of publications discussing collision risk refer to a “target level of safety.” This reference can be traced to the ICAO *Safety Management Manual* and its definition of “Acceptable level of safety performance,” which it defines as the “minimum level of safety performance of civil aviation in a State . . . as defined in its safety management system, expressed in terms of safety performance targets and safety performance indicators” (ICAO, 2013, p. xii). To provide one example, Campos and Marques frequently set a value of $5 \times 10^{-9}$ as the target level of safety and reference ICAO standards as being the source of this value (Campos & Marques, 2010, p. 1).

Whenever two or more aircraft operate in proximity to one another, there is some probability of collision. Experience has shown that in addition to the definitions presented in the preceding section regarding the severity of aircraft collisions, these events normally result in the loss of one or both aircraft involved as well as the passengers and crew members of those aircraft. While it is recognized that accidents between larger aircraft carrying more people are more severe than accidents between smaller aircraft with less loss of life, it is not the intention of this research to quantify the value of human life or to differentiate between accidents in which differing numbers of passengers might be involved. Instead, this research follows the conventions established in regulatory documents cited previously that consider any collision between aircraft a catastrophic event. The result of this practice is to equate collision risk solely with the probability of collision rather than an alternative approach that would establish a risk metric that considers the combination of an accident's total loss value in concert with the probability of the event.

The ICAO definitions lead aviation regulatory agencies such as the FAA in the United States to define their own performance targets for various activities. Within the FAA, the Air Traffic Organization is responsible for air traffic management services, and publishes a *Safety Management System Manual.* This document redefines risk as "The composite of predicted severity and likelihood of the potential effect of a hazard in the worst credible system state" (FAA, 2008a, p. 14). The manual goes on to categorize the severity of possible outcomes by assigning five classification levels. The most severe outcome is classified as "catastrophic," a category it defines as "conditions resulting in a collision between aircraft, obstacles, or terrain" (FAA, 2008a, p. 39). The manual then categorizes likelihood into five classification levels as well, and clearly indicates that the only region of acceptable risk occurs in the "extremely improbable" category. It goes on to define this level of likelihood as being a probability less than $1 \times 10^{-9}$ per operational flight hour (FAA, 2008a, p. 42).

### 4.1.1. The Nature of Collision Risk

Since the advent of RADAR and the implementation of distance-based separation standards, a common perception of collision risk is that it is the probability that the distance between two aircraft reaches zero. As a result of this understanding of collision risk, it is easy to believe that by increasing the required separation distance between aircraft, the resulting collision risk should be reduced, and vice versa. However, this intuition fails when applied to many applications. As an extreme example, consider the US Navy flight demonstration team, the Blue Angels. Six of their aircraft are routinely operated within inches of each other while performing complex aerial maneuvers, and yet they operate with acceptable collision risk and it is likely that they will continue to operate indefinitely without experiencing a serious collision. At another extreme, consider two aircraft that are separated by the required five nautical miles in an en route airspace environment, but are traveling in opposite directions on the same jet route at the same altitude. If each aircraft is traveling at 600 knots ground speed, closure between the aircraft is such that they will collide in 15 seconds if neither aircraft maneuvers to avoid the collision.

In a more general example, consider two pairs of aircraft traveling in opposite directions along parallel flight tracks at a routinely flown airspeed such as 480 KTAS, and separated longitudinally by five nautical miles. Now consider the influence of a 120 knot wind, a common jet stream speed experienced in the en route domain, on the available collision avoidance time. As depicted in Figure 7, the aircraft traveling with the wind have substantially less time separating them than aircraft traveling against the wind.

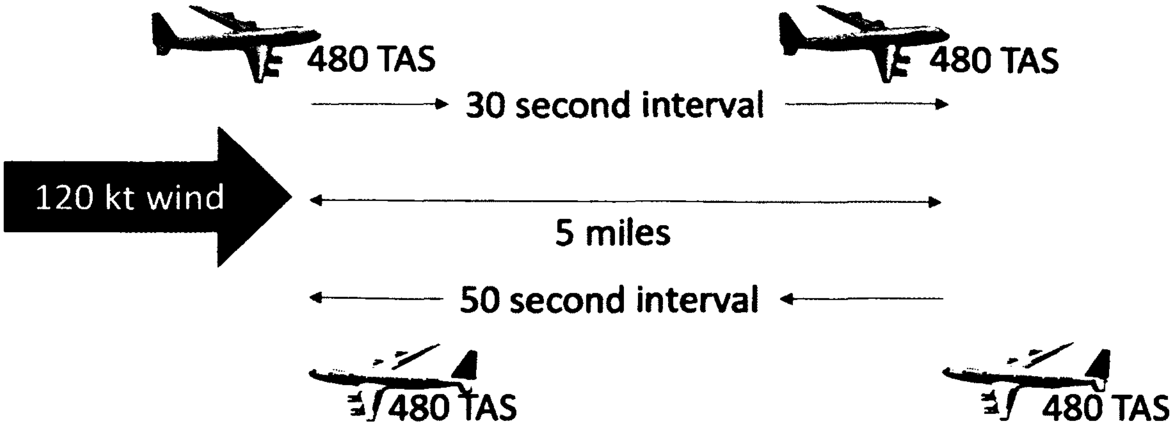

Figure 7: Effect of Wind on Separation Distance

This example provides insight into the nature of collision risk and collision avoidance. Since collision risk depends upon the amount of time available for conflict detection and resolution, it is not a function of the distance between aircraft, but the time. As a result, a more appropriate definition of collision risk is the probability that two aircraft will occupy the same point in space at the same time. It then follows that the objective of collision risk mitigation should be to provide sufficient time for operators to recognize a potential conflict and for at least one of the operators to take action to avoid a potential collision.

Further evidence of the validity of this reasoning with regard to collision avoidance is found in the design of the Traffic Alert and Collision Avoidance System (TCAS). This system is installed on commercial aircraft worldwide and uses a transponder interrogation technique to judge the relative position of proximate aircraft. The logic of the algorithms used in this system are based on the work of Dr. John S. Morrell, and his theory of collision avoidance which states the "concept is based on time, rather than distance, to the closest point of approach in an encounter" (FAA, 2000, p. 6). Dr. Morrell's development of a variable labeled "tau" in the TCAS algorithms refers to the time remaining before CPA and when a threshold value is reached, the system issues an advisory to the pilot to perform a collision avoidance maneuver. The use of a time-based metric as the basis for collision avoidance functions in TCAS is a compelling indication that the use of time over distance-based methods is emerging as a preferred tool. Further evidence of the acceptance of time-based collision avoidance with respect to TCAS is the existence of numerous mandates by nations around the world that require all aircraft capable of carrying 30 or more passengers to be equipped with TCAS, and a recent European Union mandate that requires aircraft carrying more than 19 passengers in European airspace to be equipped with the latest version of TCAS (Eurocontrol, 2011).

### 4.1.2. Acceptability of Collision Risk

The probability of collision is treated as a dependent variable in this research. However, for the purpose of recommendations formulated on the basis of the results reported herein, a probability of collision less than $1 \times 10^{-9}$ per operational flight hour will be treated as a constraint that must be met for any recommendation to be considered feasible. While the majority of international researchers use a more aggressive value as a target level of safety, the nature of this research is to develop a basis from which viable recommendations may be made for safety standards governing trajectory based operations in the United States and Europe. Therefore, to ensure appropriately conservative recommendations are formulated, and to conform to current guidance as published in the *FAA Air Traffic Organization's Safety Management System Manual*, the maximum value prescribed in that document is set as a basis for the recommendations provided by this research.

## 4.2. Research Motivation

A number of studies, demonstrations, and experiments have been conducted to evaluate potential benefits of trajectory based operations, such as increased capacity, reduced fuel consumption, reduced carbon emissions, and improved safety. While several studies have shown great promise in achieving some of these objectives, none of the studies have been able to demonstrate that the benefits can be achieved while satisfying existing distance-based separation standards. Similarly, studies that have achieved required separation minimums fail to show any measurable benefit over existing procedures. This perplexing outcome should not be surprising in light of basic optimization theory, as attempting to sequence aircraft by time while maintaining existing separation standards is effectively a case of operating the same system with a time restriction being added as an additional constraint. In order to achieve both the benefits of trajectory based operations *and* acceptable separation minimums, it is necessary to not only sequence aircraft by time, but also to separate them by time. This is true for two reasons. First, use of a distance-based standard results in varying amounts of time between aircraft separated by a uniform distance at each altitude and airspeed combination, and the variability is increased by changes in environmental conditions such as wind and temperature. In contrast, a time-based standard allows a uniform flow of traffic with equal time intervals that are independent of altitude, airspeed, and environmental conditions. Secondly, and most importantly, employing a time-based standard allows aircraft to be safely separated at distances that are significantly less than those required today under certain circumstances as described herein. These concepts are further illustrated through observation of test results and the theoretical example that follows.

Consider the results of the Required Time of Arrival (RTA) experiments conducted in the vicinity of Seattle International Airport using General Electric Flight Management Systems on Alaska Airlines B737 aircraft from 2010 to 2011. During initial simulation testing and flight trials, all aircraft were assigned required crossing times in whole minute intervals at the Olympia fix while the airport was in a south-flow configuration. This required aircraft to cross a meter fix called *Olympia* at 17,000 feet and at 270 KIAS (see Appendix A). At no time during the flight trials or simulations were any separation losses reported (Smith, 2011). However, during subsequent testing, with the airport operating in north flow configurations, aircraft were required to cross the same fix at 12,000 feet and 250 KIAS. Under these lower and slower conditions, simulation testing conducted in preparation for the flight tests resulted in frequent losses of the required 5 NM separation between aircraft when a one minute interval was assigned. As a result, a decision was made to employ a two minute interval for the live flight testing. These tests proved to be extremely successful with regard to the crossing time accuracy achieved, but the two minute intervals produced excessive spacing between aircraft, especially at the high and fast crossing points. In a summary table describing potential variations between high and low altitude crossings over a typical range of ground speeds with a maximum time error of 20 seconds, the report demonstrates the range between sequential aircraft could be as little as 1.3 NM at the low altitude fix if separated by only 1 minute and as high as 26.7 miles at the high altitude crossing if separated by 2 minutes (Teller, 2011, p. 41).

To view the problem from another perspective, consider two aircraft crossing a meter fix at 250 KIAS with a 30 knot headwind at two different altitudes: 19,000 feet, such as is the case on arrivals to Denver, and 12,000 feet, such as the arrival to Seattle. These two examples are also representative of the flight and simulation testing performed by the FAA in recent years. Due to reduced air density at 19,000 feet, on a standard day the aircraft travel at 337 KTAS, and due to the effect of the wind, 307 KGS. If they cross the fix with a 60 second interval between them, they are separated by 5.1 NM, satisfying existing separation criteria with sufficient time for collision avoidance. However, due to the comparatively higher air density at 12,000 feet, the same aircraft travel at 300 KTAS, and 270 KGS. If they cross the same fix with the same 60 second interval between them, they are separated by only 4.7 NM, and the exact same amount of collision avoidance time is considered inadequate solely due to a failure to meet an arbitrary distance-based separation standard. From the perspective of a person standing on the ground and looking straight up at the aircraft as they cross however, the same observation is made – two aircraft crossing with a 60 second interval. This situation is depicted in Figure 8 below:

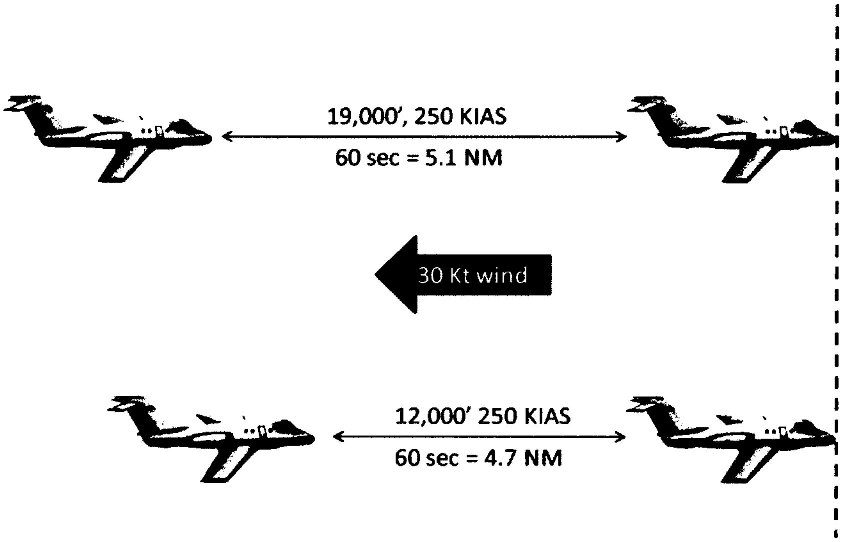

Figure 8: Separation Distance Variations with Equal Time Intervals

It is the assertion of this dissertation that because the time available for collision avoidance is equal for both pairs of aircraft, the risk of collision is also equal. It follows that in all cases represented by this example a time-based separation standard allows lower and slower aircraft to be sequenced with reduced distance between them, allowing a desired increase in system capacity while retaining an adequate safety margin. This potential benefit provides the motivation for the research described in the following sections.

## 4.3. Data Sources

Several flight and simulation experiments have been performed in recent years to assess the ability of a modern aircraft to cross a three dimensional fix in space at an assigned time. These experiments have been done in the United States and Europe by aviation regulatory authorities in partnership with airlines, flight management system manufacturers, and local air traffic controllers. The results of these experiments have been compiled into a data set for use in quantification of the nature and magnitude of the errors that should be expected when air traffic is managed using controlled time of arrival methods. This section describes the experiments that have been performed and discusses the data reported as a result of each experiment.

### 4.3.1. 2008 CASSIS Flight Trials

One of the first flight trials conducted to evaluate the time-based performance of aircraft was sponsored by Eurocontrol and executed at the Stockholm Arlanda International Airport in 2008. The flight trial consisted of three phases with the first phase being conducted in June, the second in September, and the final phase concluding in December. Boeing 737 aircraft and McDonnell-Douglas MD-80 aircraft served as test aircraft for all three periods and Airbus A300 and A330 aircraft participated in the final test period. Of note, the General Electric flight management system was in use on 737 aircraft. This system includes full phase Required Time of Arrival (RTA) functionality that computes a four dimensional trajectory for the aircraft and allows the flight crew to enter the assigned arrival time either manually or through receipt of a data link message. Once the RTA is entered, the FMS can be commanded to execute the RTA, allowing the aircraft autopilot system to be governed by the FMS as needed to cross the assigned fix on time. In stark contrast, the MD-80 aircraft has no time of arrival capability associated with its flight management system, requiring pilots to manually adjust speed to achieve the desired crossing time. Airbus aircraft participating in the third phase of the trial were equipped with a Honeywell flight management system that provided RTA functionality, but with limited time of arrival capability as compared to the General Electric system.

Arrival times were issued by air traffic control between 25 and 40 minutes prior to the estimated fix crossing time as determined by ground automation systems. Once a crossing time was assigned, aircraft progress was monitored via RADAR and trial aircraft were separated from non-participating aircraft as necessary through standard air traffic control practices. When multiple trial aircraft were predicted to arrive at or near the same time, crossing time assignments were issued with two or three minute intervals at the discretion of the controller.

The results of this trial included qualitative results generated from surveys of participating pilots and air traffic controllers and quantitative results of the crossing time performance. Quantitative results are also provided in the form of a summary table and histogram of crossing times for all aircraft. However, closer inspection of the data reveals there may be inadvertent sources of bias within the data. According to the report, "Prior to the trials, a tolerance of ± 30 seconds was seen as the appropriate tolerance for metering of traffic towards a TMA entry point" (Swedavia, 2009, p. 23). There is no justification for this value, but it seems to have become a success criterion in which flights arriving within 30 seconds were considered a success while those outside of this window were considered failures, effectively categorizing the data. Evidence of this possibility is easily seen by observing that 70 of the 308 flights are reported to have crossed the meter fix with exactly 0 seconds of error. A detailed histogram of the flight trial crossing times is shown in Figure 9 with 100 intervals of 1 second each.

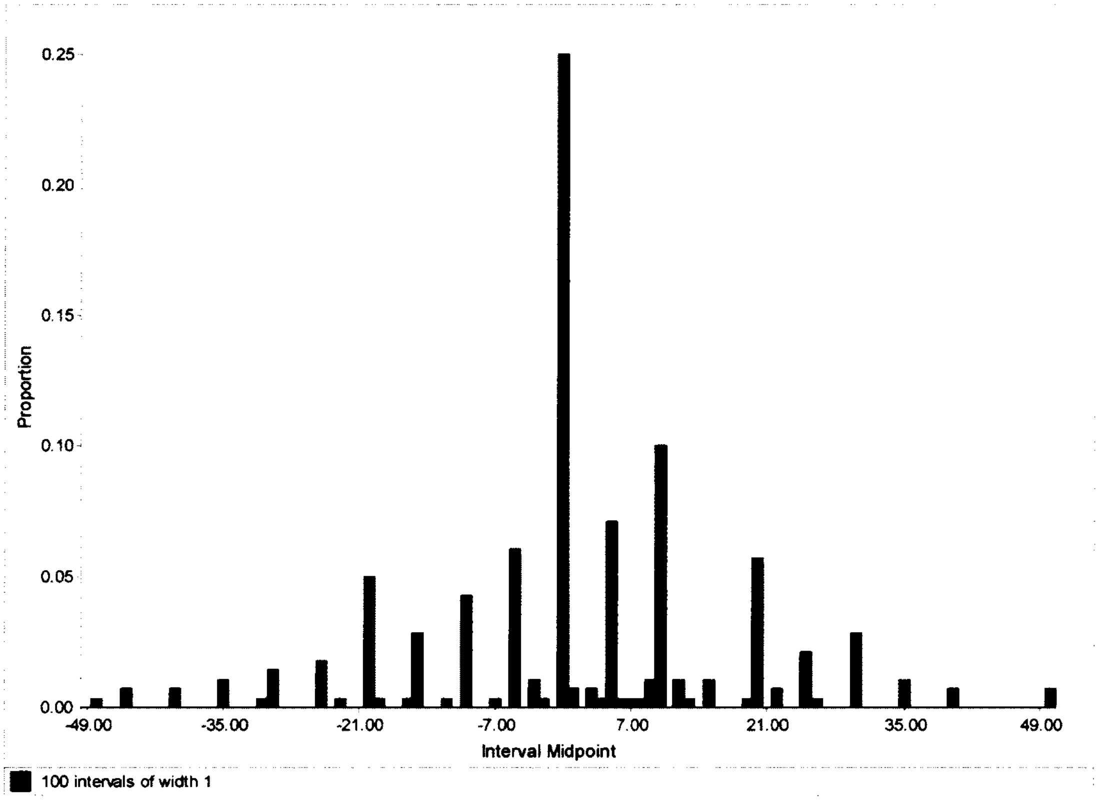

Figure 9: CASSIS I Crossing Time Errors

It can easily be seen from the spikes in the data that researchers displayed a strong tendency to round crossing time errors to the nearest five second interval. More importantly, 25% of the crossings are recorded as having zero crossing time error, implying that at least some of the researchers recorded crossing time errors of less than 30 seconds as successes, and attributed no crossing time error to these events.

As a result of the apparent bias associated with these data, the quantitative results have not been used as the basis for quantification of aircraft performance capability in this research. However, the general trend of the results is still of use in assessing the consistency of result trends with other experiments. Also, the CASSIS flight trials are the only known flight trials to date that have attempted to evaluate the ability of an aircraft being flown without an RTA function in the FMS, providing qualitative insight into the nature of the expected error times associated with manually flown aircraft.

### 4.3.2. 2009 CASSIS Flight Trials

With the results of the initial flight trials considered promising, a second round of flight trials was conducted in October and December of 2009. A similar lineup of aircraft were evaluated, including the Boeing 737 with a General Electric FMS, McDonnell Douglas MD-80 with no RTA capability, and Airbus A330 and A300 aircraft with a Honeywell FMS. However, Novair's Airbus A321 aircraft were also added and are reported to have utilized a Thales FMS.

Qualitatively, the report of the 2009 CASSIS flight trials indicates improved performance over the 2008 trials. Interestingly, the improvement seemed to be confined to the performance of the 737 aircraft, and the reduced standard deviation of arrival time errors for this aircraft is attributed to an avionics adjustment. The General Electric FMS includes a user setting referred to as a time error tolerance (TET) value, and allows the flight crew to select a value between 6 and 30 seconds. Since the algorithms are proprietary to General Electric, it is unclear what the exact influence of this setting is, but the 2009 setting of 10 seconds delivered better accuracy than the 30 second setting used in 2008.

Unfortunately, the quantitative results of the 2009 CASSIS flight trials indicate a bias similar to that of the 2008 trials as illustrated in Figure 10.

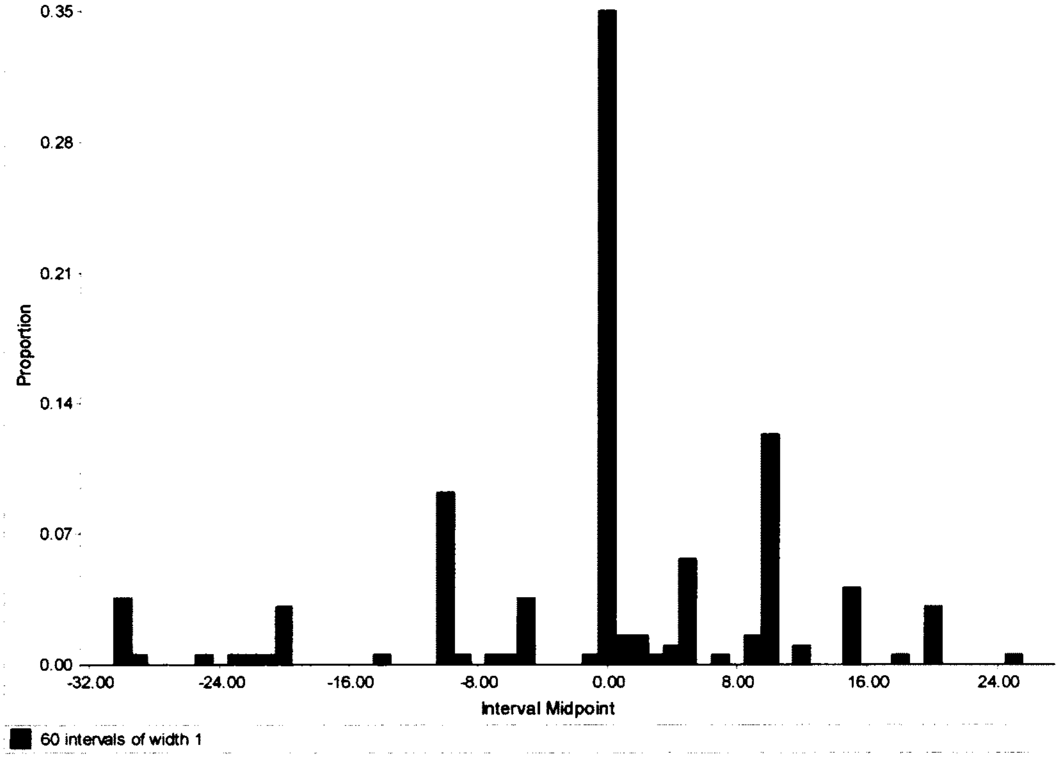

Figure 10: CASSIS II Crossing Time Errors

Once again, the results indicate a strong tendency to report crossing times in five second increments and approximately 35% of the 197 evaluated crossings were recorded to have achieved a perfect crossing time with zero error. While the general trend of improvement associated with the lower error tolerance on the General Electric FMS is noteworthy, the quantitative results of these trials are not used in this research as a basis for estimating the performance capability of modern aircraft. They are of value however in demonstrating the approximate range of values within which aircraft may perform, and as such, are included as an additional source of qualitative evidence supporting the findings of the current research effort.

### 4.3.3. 2010 FAA Human-in-the-Loop Simulation

Following the CASSIS flight trials, the FAA initiated a program to study Four Dimensional Flight Management System Required Time of Arrival capability in en route flight environments. An initial simulation was performed at Embry-Riddle Aeronautical University in June 2010 to investigate the feasibility of a flight trial and to develop candidate procedures for such a trial. However, no quantitative data is available from that study.

### 4.3.4. 2010 FAA Flight Trial

In October 2010, the FAA partnered with Alaska Airlines to conduct a flight trial to evaluate RTA concepts at Seattle-Tacoma International Airport. The flight trial included only Boeing 737 aircraft equipped with General Electric flight management systems and consisted of a small sample of flights. Over a seven day period, only 39 flights received time-based clearances and executed the clearances to completion such that data regarding crossing time errors could be evaluated (Smith, 2011). The results of this trial are provided in Appendix B.

### 4.3.5. 2011 FAA Human-in-the-Loop Simulation

In May of 2011, the FAA conducted another simulation to further explore and evaluate RTA concepts. This simulation was performed in the NextGen Integration and Evaluation Capability laboratory at the William J. Hughes Technical Center in Atlantic City, NJ. The aircraft simulated included the Boeing 737 with a General Electric FMS, Airbus A320 with a Honeywell Pegasus FMS that includes RTA functionality, and an Embraer 170 with a Honeywell Primus Epic FMS that does not provide RTA functionality and requires manual control by the pilot. In this simulation and in all subsequent FAA simulations, experienced pilots and controllers operated computer-based systems representative of actual air traffic control and aircraft systems. Aircraft systems included operational flight management systems driven by proprietary PC-based emulations of controls and displays necessary to operate the aircraft being simulated. A typical pilot interface is shown in Figure 11.

Of note, the time error tolerance value for all flights during this simulation was set to a value of 20 seconds. It is not clear why this setting was chosen, but subsequent testing considered a crossing time error of less than 20 seconds a "success" and greater than 20 seconds a "failure."

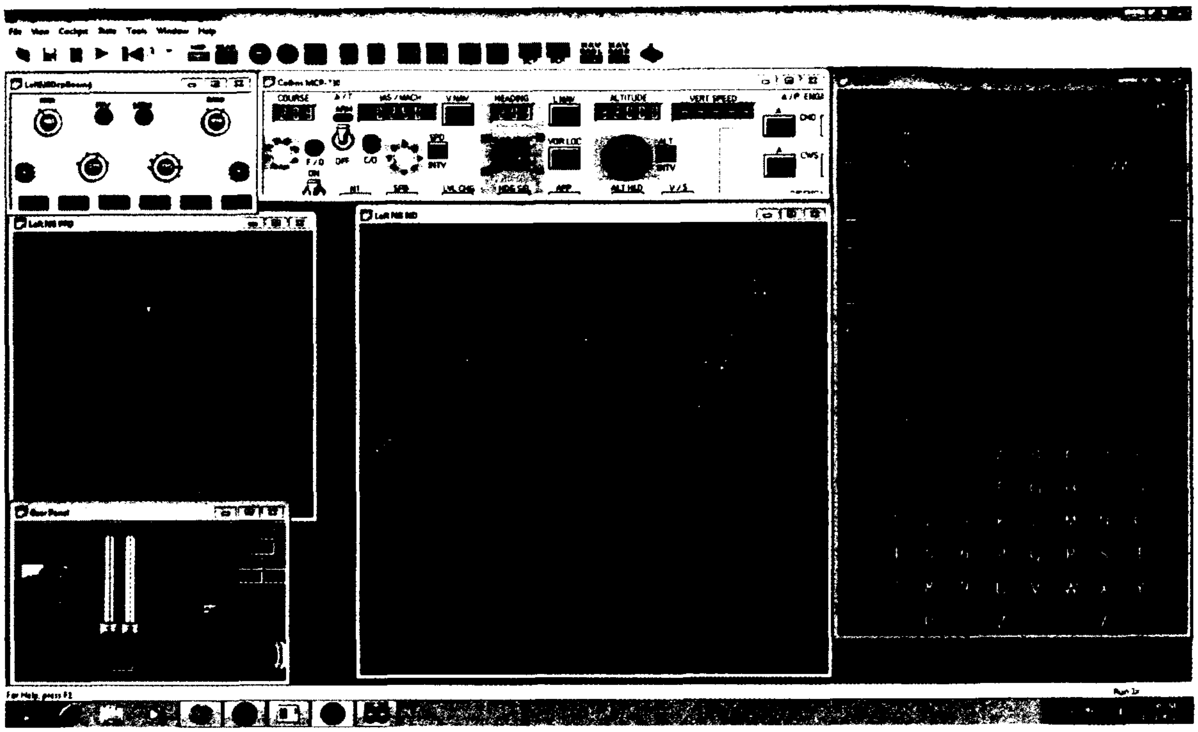

Figure 11: Typical Pilot Interface for B737 Aircraft with GE FMS

While a twenty second value was used as a criterion for categorization of results, detailed quantitative data sets were also recorded and has been made available for this research. The information is provided in Appendix C. A total of 87 crossing events were recorded during this testing.

### 4.3.6. 2011 FAA Flight Trial

In November and December of 2011, the FAA conducted a second flight trial in the vicinity of Seattle, and once again partnered with Alaska Airlines to evaluate the performance of Boeing 737 aircraft with General Electric Flight Management Systems. This flight trial was substantially more robust than any time of arrival control flight test conducted to that point, delivering 588 fully executed controlled time of arrival events. A time error tolerance of 20 seconds was used on all flights, and consistent with the previous simulation, success was categorized base on a 20 second evaluation criterion. Detailed performance information is available from this testing, and the complete data set is provided in Appendix D. This data set also has a significant influence on the performance estimates developed in subsequent sections of this document.

### 4.3.7. 2012 FAA Human-in-the-Loop Simulations

Following the second round of flight trials, the FAA continued research of controlled time of arrival concepts to further advance the concept of operations. The simulations were conducted in four parts between March and July of 2012, with each simulation being conducted over several days. An important aspect of these simulations is that the geographic operating environment used for testing was changed from Seattle to Denver. Due to the comparatively high altitude of the Denver airport, this resulted in experiments being conducted at high altitude, with a consistent altitude at the arrival crossing point of 19,000 feet and en route crossing points in high altitude airspace above flight level 290. This resulted in higher true air speeds at the crossing point due to lower air density than might be expected at a crossing point used to sequence aircraft into a sea level airport. A number of other details were adjusted during these simulations that are of particular interest to this research. The time error tolerance value on the General Electric flight management systems was set to 20 seconds for a portion of the flights, while a 10 second value was used for the remaining flights. Also important is a change in procedure by which times were assigned in six second increments rather than in whole minutes, providing air traffic managers with more flexibility in assigning crossing times. The six second increment was chosen to allow easy mental conversion of crossing time assignments for aircraft that enter time in minutes and seconds as well as those that enter time in tenths of a minute. Finally, the series of simulations was designed to explore new concepts, adding complexity to the process of achieving time-based crossings. The increased demand on flight crew and avionics partially explains some of the variance observed in the data. The results of these simulations have been provided by the FAA, Mitre, and MIT Lincoln Labs and are included in Appendix E.

Each phase of the 2012 simulations was designed to evaluate specific elements of time-based air traffic management. The first phase was initially designed to assess the spacing that resulted from variations in intervals assigned to sequential aircraft executing required time of arrival clearances. The tests were governed by an expectation that a 90 second interval would provide a safe and efficient balance between the 1 minute intervals used for the first flight trials and the 2 minute intervals used during the second trials. Results reported from this simulation conclude that 90 seconds "did yield a good balance between separation assurance and flow efficiency" (Teller, Alexander, Davis, & Phillips, 2012, p. 23). However, the report also acknowledges that this conclusion is in contrast to the results of previously cited experiments by Klooster and DeSmedt (2011), which were conducted with a comparatively low 8,000 foot crossing altitude. The consistent theme between the reports is that the distance observed between aircraft separated by time during simulation is solely a function of ground speed. Researchers for this phase of the experiment even developed a look up table to provide controllers with guidelines for how much time to assign between aircraft to achieve a desired distance-based interval based on their groundspeed. It is important to stress that in all simulations conducted to date, evaluation of separation between aircraft has not been based on a collision risk probability, but instead, by simple evaluation of the distance between aircraft sequenced by time. It is clear that results of this testing, and the conclusion that a 90 second interval provides a good balance would have been significantly different if a low altitude crossing point had been used at a sea level airport.

The second phase of testing was designed to evaluate alternatives for absorbing delay during high density traffic periods, a state referred to as "metering conditions." The methods tested the feasibility of using time-based clearances in conjunction with flight path offsets that effectively increased the distance flown by the aircraft as a means of delaying its arrival.

Phase three of the simulation tested the feasibility of integrating ground support tools being developed for air traffic management with the airborne capability of a flight management system. Specifically, the FAA's Three Dimensional Path Arrival Management (3D PAM) tool was used to generate offset waypoints for aircraft to extend their flight paths in a manner similar to what was tested during phase two. However, the concept of operations associated with 3D PAM includes issuing a Mach number and indicated airspeed for the pilot to transition to during the descent phase of flight in order to achieve the desired crossing time. Phase 3 testing showed that a dramatic increase in crossing time accuracy is achieved when this system is employed with an RTA crossing time assignment at the meter fix. Recall that the results of FAA tests with UPS in Louisville concluded that using a ground-based automation system to issue speed commands in attempt to guide aircraft to accurate crossing times was not feasible. The data generated during this testing provides compelling evidence to validate that conclusion. A comparison of the crossing time accuracy achieved by the ground automation system versus the airborne flight management system is presented in Figure 12 as a box plot allowing the magnitude of the difference between the two systems' performance to be better understood. In this graphic depiction, the top row of data describes the crossing time errors of flights that executed speed commands as issued by ground automation systems while the bottom row of data describes crossing time errors achieved by airborne flight management systems executing RTA clearances. The blue boxes are bounded by the 25th and 75th percentiles, also referred to as upper and lower quartiles, and the entire width of the blue box is known as the inter-quartile range. The black vertical bar in the center of the blue box is the median, or 50th percentile. The "whiskers" on either side of the box represent a range of 1.5 times the inter-quartile range. Values that lie outside this range are represented by red stars and may be outliers. These results deserve investigation and consideration for removal from the data set if the cause of the outliers can be determined, such as case in which a data entry error is found or a simulation malfunction event occurred. The horizontal axis represents time in seconds, with time zero representing the assigned crossing time for all flight events.

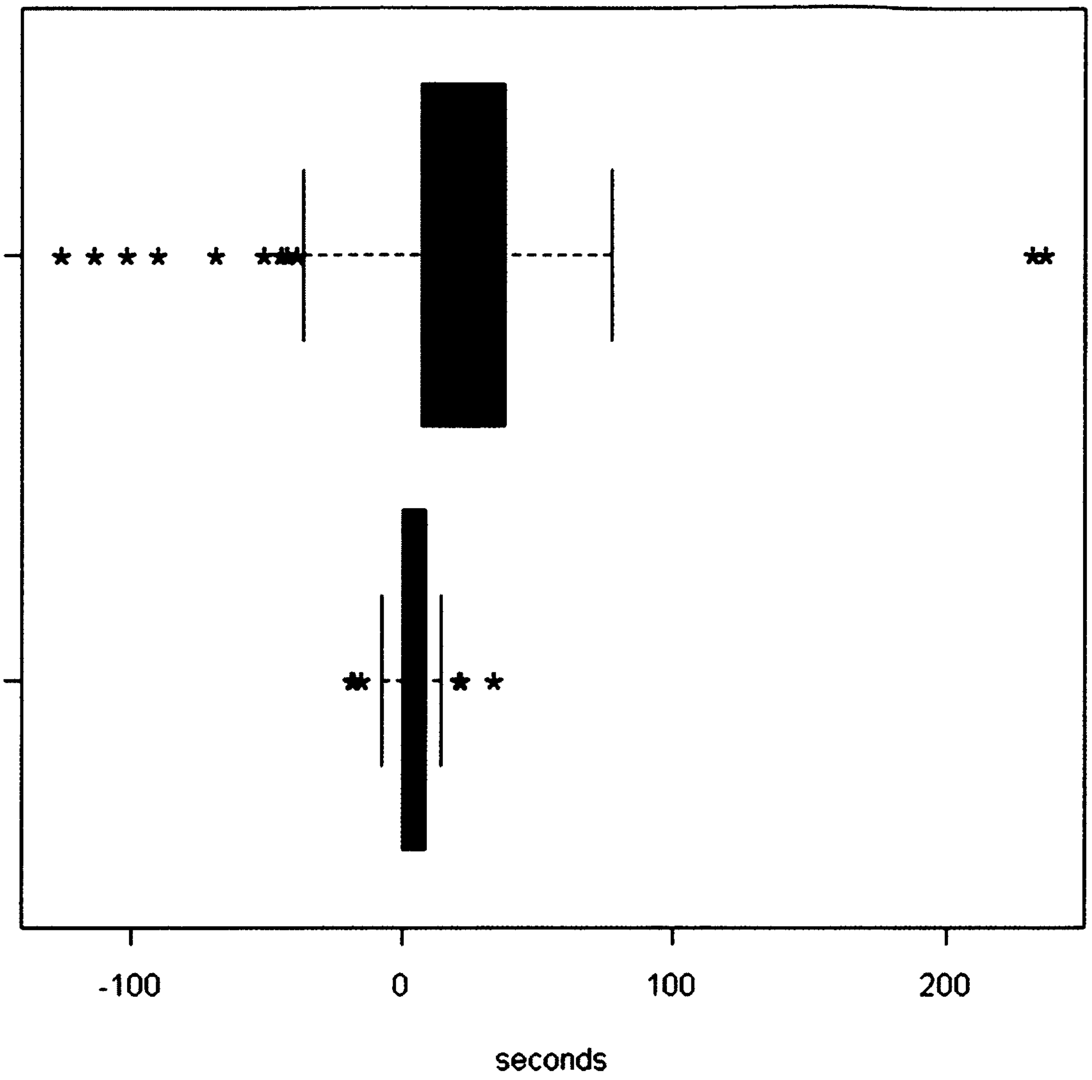

Figure 12: Comparison of Ground versus Airborne Automation System Performance

The final phase of testing in 2012 was designed to further evaluate the feasibility of integrating ground based automation systems with airborne RTA capabilities. This testing included a new capability, departure RTAs, wherein aircraft on the ground were issued crossing time assignments prior to takeoff for the same arrival meter fix as airborne en route aircraft. This application of the required time of arrival concept has not been documented in any previous research, and results indicate that while a number of new uncertainties associated with pre-takeoff ground operations emerged, performance of aircraft in meeting assigned crossing times is comparable to both en route and arrival applications.

### 4.3.8. 2013 FAA Human-in-the-Loop Simulations

The 2013 FAA simulations continued research initiated during the 2012 simulations and included two periods of testing in fiscal year 2013. The first testing took place on December 4th and 5th, 2012, and provided additional data collection opportunities for time-based operations in all phases of flight, including departures, en route, and arrival operations. The aircraft simulated included the Boeing 737 with a General Electric FMS, but differed slightly from previous tests in that the software version used was updated to a new version (U10.8A). The testing also included evaluation of Boeing 757 aircraft with Honeywell FMS using research prototype software referred to as "red label" software. Results indicate a significant advance in both functionality and performance of this software as compared to previous versions of Honeywell systems (Teller, Alexander, Davis, & Phillips, 2013).

A second phase of testing was conducted from July 8-12, 2013, and further expanded testing to include the same aircraft tested in Phase 1, but added two aircraft that had been used in previous testing for the purpose of additional data collection purposes. The Airbus A320 aircraft with a Honeywell Pegasus FMS and an Embraer 170 with a Honeywell Primus Epic FMS were simulated during these tests. This round of testing featured continued evaluation of departure RTA operations in which aircraft at an airport were assigned crossing times at fixes in the en route structure. The testing also provided a platform from which to evaluate the feasibility of a prototype system that can be handcarried by flight crew and used in the cockpit of an aircraft that is not equipped with a full-phase RTA capable FMS. This application is analogous to the use of a hand-held GPS, but with the added functionality of providing speed guidance calculations necessary to meet time of arrival control assignments. This type of system is generally referred to as an "electronic flight bag" (EFB) (Alexander, Davis, Phillips, & Teller, 2013, p. 5). As of the writing of this document, initial results have been reviewed, but final data set is not yet available and is therefore not included in this analysis.

# 5. Separation Function Derivation

The process of deriving a separation function for use as an engineering tool for management of trajectory based aviation operations is divided into several parts, with each portion of the research designed to develop the independent and dependent variables. The first step involves a review of previous efforts to model collision risk in the aviation environment. The next step is to conduct an analysis of data to develop insight as to the nature of the errors that should be expected when aircraft are required to cross three-dimensional points in the airspace system. Once that has been accomplished, a method must be developed to express this capability in the form of an implementable performance metric. Finally, an expression must be developed to calculate the probability of collision between aircraft, including aircraft with dissimilar performance capabilities. Once these steps are complete, the functional relationship developed to relate the performance capability of the aircraft, the probability of collision, and the interval between them can be applied to the management of air traffic.

## 5.1. Collision Risk Modeling

Numerous articles have been published over the past half century regarding methods by which collision risk may be estimated. Nearly all of these models are based on upon the seminal work of P.G. Reich in 1966, with subsequent models generalizing or building upon the initial model. Indeed, the International Civil Aviation Organization adopted a variation of Reich's model for use in its *Manual on Airspace Planning Methodology for the Determination of Separation Minima* (ICAO, 1998).

One of the key insights to the Reich model is that it is a distance-based model that assumes collision risk is a function of navigation position error. This approach to collision risk modeling is a natural outgrowth of the challenges faced by aviators in the two decades following World War II. Autopilot systems had not yet achieved a level of reliability that ensured precision in the vertical dimension, and position determination was limited to the fidelity of instruments that presented bearing and later, slant range information to pilots. In oceanic operations, the intended application of Reich's model, substantial navigation errors developed as pilots and navigators relied on principles of dead reckoning and celestial navigation to estimate position, frequently resulting in large cumulative errors that justified substantial separation distances between trans-oceanic tracks and between aircraft transiting along those tracks. Reich's modeling of this environment is based on his conceptualization of the problem in which two aircraft transiting the ocean on parallel tracks could each develop errors in their position estimate. If the tracks were from east to west, as in the North Atlantic, while both aircraft estimated their position as being along one of the tracks, the actual position of the northern aircraft could be somewhere south of the track. At the same time, the southern aircraft could be north of its estimated position. Reich theorized that if the sum of the two position errors was equal to the distance between the tracks, the two aircraft would be on the same effective track somewhere in the middle, and satisfying this condition would expose the aircraft to collision risk.

In the years that followed, the introduction of inertial navigation systems improved navigation performance, but position errors associated with these systems increase over time due to nuances of Schuler oscillations. This oscillatory cycle creates drift rate errors caused by the system's inability to distinguish between acceleration due to gravity and those due to aircraft maneuvers, leading to significant errors in position estimates over time (Fogg & Janus, 1990). Human errors operating these systems were also possible due to poor interface designs, with the most notable navigation error of this type being that of Korean Airlines Flight 007, which drifted over 200 miles off course and was shot down over Sakhalin Island in 1983 by a Soviet Su-15 (Degani, 2004).

The Reich model uses pair-wise comparisons of two aircraft and assumes there is a function to describe navigation system errors for each aircraft. It then considers the probability of each aircraft being off its intended course given some nominal separation distance. Reich did not have any data from which to construct a density function representing the probability of error distances, and so to overcome this limitation, he established an upper bound that he considered a maximum value likely to be encountered with an objective of developing a conservative standard with respect to collision risk.

In addition to navigation position errors in a horizontal plane, the Reich model considers deviations from intended course to be three dimensional, including a vertical component requiring a probability of collision to be developed for each dimension. This construct allows users to either focus on a single dimension, such as in the case of considering a reduction in vertical separation standards, or to combine the dimensional components for a complete quantification of the collision probability through convolution of multiple random variables.

A final important note with relevance to this research is that the ICAO version of the Reich model makes an important assumption influencing its longitudinal collision calculation. That is, commercial aircraft generally operate in a manner that results in relatively stable operating conditions with infrequent speed changes. Further, when speed changes are required, they are generally small changes in comparison to the overall speed of the aircraft, such as an when an aircraft changes a cost index or slows from an optimum cruise airspeed to a turbulent air penetration speed. The result of this assumption is a conclusion that a pair of aircraft operating in proximity to one another will not pass each other more than once in any given period of interest (ICAO, 1998).

Some of the baseline principles of the Reich model apply to the model developed for this research. To begin with, there is an assumption that an error distribution exists regarding the time-based performance of the aircraft. Inherent within this assumption is that any navigational position error that may exist will be accounted for through observation of the actual crossing time. To explain further, if the aircraft navigation system estimates the aircraft position as being at the designated crossing point exactly on time, but the actual aircraft position is behind the estimated position, the aircraft will be observed to cross the point late with some measurable time error as a result of the navigation error. Thus, any navigation error is inherently accounted for within the data recording crossing time errors and the distribution of navigation errors increases the variance of time-based errors.

Once the error distributions are quantified, the model developed for this research then uses the distribution from each aircraft to calculate a probability of collision. An assumption that no two aircraft will pass each other more than once in the longitudinal axis is also required, and consistent with the Reich model.

Substantial differences also exist between the respective methods as the premise of this research is that time, rather than distance, is the critical metric used to separate aircraft in trajectory based operations. More specifically, the assumption that collision probability is a function of a navigation error is changed. Instead, due to the precision of modern navigation systems that include GPS and conform to required navigation performance standards, this assumption is reversed to assume that navigational position error is negligible in the context of collision risk modeling. Similarly, redundant sources of altitude information along with automated features such as reliable altitude hold capability make the likelihood of a large height deviation, loosely defined as one greater than the height of the aircraft, negligible as well. A Reich model would consider these assumptions tantamount to a claim that there is zero collision risk since it assumes the probability of collision is a function of navigation position error. Referring once again to Figure 3, it is the claim of this research that the improvements in navigational accuracy have the opposite effect, and increase collision probability due to an increase in the density of traffic that are exactly on their intended course much in the same way early implementation of the first radio beacons increased the density of traffic traveling between terrestrial navigation aids. The logic driving this assumption is that in previous generations, two aircraft that inadvertently attempt to cross the same point in space at the same time might miss each other due to the navigation inaccuracies of legacy systems, deviating either vertically or laterally. With very little position error in their navigation systems, modern aircraft are much more likely to be precisely on their intended course and altitude, with the effect being that they fly through narrow tubes of air with higher probability of collision than aircraft of previous generations that would experience random navigation errors when flying under the same conditions.

Another substantial difference between the early Reich model and this research is the availability of a substantial data set documenting the performance of the aircraft. The robust nature of testing in both flight and simulation environments has allowed the development of probability density functions representing the time-based performance of existing modern aircraft equipped with RTA capable flight management systems. Additionally, this data allows the inductive process of projecting the degree of capability that will be necessary in future generations of air traffic management systems as demonstrated in subsequent sections of this document. Finally, in keeping with one of the rules set forth in Reich's original work, the important assumptions of accurate navigation, both vertically and laterally, provides a result that requires far less complexity in its calculus-based probability computations, and therefore becomes more easily understood and suitable for executive application.

## 5.2. Data Analysis

In order to develop an estimate of the collision risk that exists between aircraft operating in a trajectory based operations environment, a practical first step is to quantify the probability of an aircraft arrival time given that it is assigned a crossing time at some three dimensional fix. To accomplish this objective, the data reviewed in Chapter 4 can be analyzed to gain insight into the nature of this probability. This section will provide numerical and graphical representations of selected results of flight and simulation experiments from which information is available regarding the assigned and actual crossing times of aircraft conducting required time of arrival operations. Based on the results of this analysis, a generalization of performance levels will be inferred and used in subsequent portions of this research.

### 5.2.1. CASSIS I & II Data

Data collected during flight tests conducted at Stockholm's Arlanda International Airport included evidence of researcher bias toward recording some results in five second increments and a strong tendency to record arrivals judged to be successful as crossings with zero error. For this reason, the quantitative results of those trials are not used as part of the evidence supporting estimates of performance capability developed through this research. However, the CASSIS trials are of value in that they demonstrate general trends that are consistent with subsequent research, and that they included human pilots manually controlling an aircraft to a required time of arrival without the aid of FMS automation. Due to the biases noted, it would not be reasonable to directly compare the numeric results of the CASSIS trials to other trials, but since the bias appears to have been applied equally to all participating aircraft, it might be reasonable to draw a comparison between aircraft equipped with automation capability and aircraft that are not so equipped within this trial itself. Table 1 provides descriptive statistics of these two groups of aircraft for the purpose of allowing comparison between the results reported for each group. The Boeing aircraft with a General Electric FMS and the Airbus aircraft with a Honeywell FMS both have RTA capable systems, while the McDonnell Douglas MD-80 aircraft has no RTA capability.

Table 1. Automated and Manual RTA Performance Comparison for CASSIS Flight Trials

| | Aircraft with FMS RTA | MD-80 with No FMS RTA |
|---|---|---|
| Number of Crossings | 333 | 127 |
| Earliest Crossing | -70 seconds | -85 seconds |
| Latest Crossing | 95 seconds | 110 seconds |
| Mean | 0.45 late | -4.6 seconds |
| Median | 0 | 0 |
| Standard Deviation | 19.2 seconds | 30.6 seconds |

As indicated in Table 1, 127 arrivals were flown manually, providing the largest data set available to describe the performance of manually flown aircraft in this environment. It can be seen that pilots who manually flew their aircraft to comply with required time of arrival clearances had a tendency to arrive early, and the standard deviation of their arrival times was roughly one-third larger than those with automated systems.

### 5.2.2. Seattle Flight Trials Data

Two flight demonstrations of required time of arrival concepts were conducted in the vicinity of Seattle, Washington between November 2010 and December 2011. The first of these events was limited in scope to exploring time of arrival control operational concepts with existing airborne and ground-based air traffic management systems. The second event is the most robust flight trial to date, assessing the crossing time performance of nearly 600 Alaska Airlines Boeing 737 aircraft with General Electric Flight Management Systems during routine arrivals to the Seattle-Tacoma International airport. A statistical summary of the data collected during these trials is presented in

Table 2: Summary of Seattle Flight Trials Data

| | 2010 | 2011 | Combined |
|---|---|---|---|
| Number of Crossings | 39 | 588 | 627 |
| Earliest Crossing | -39 seconds | -47 seconds | -47 seconds |
| Latest Crossing | 16 seconds | 73 seconds | 73 seconds |
| Mean | -5.9 seconds | 9.0 seconds | 8.1 seconds |
| Median | -7 seconds | 9 seconds | 9 seconds |
| Standard Deviation | 12.1 seconds | 11.4 seconds | 12 seconds |

The most noticeable difference between the two experiments is the difference in mean and median crossing times, with the 2010 flights demonstrating a tendency to arrive early while the 2011 flights showed the opposite tendency. However, the small sample size in 2010, combined with the introductory nature of the procedures for both aircrew as well as air traffic controllers suggests little relative weight should be placed on the results of the first trial. The displacement of the mean crossing time error to the left in 2010, indicating a tendency for the aircraft to arrive early, could also be explained by constraints in the test procedures. Unlike the 2011 test where arrivals from all directions were evaluated with the airport in any operational runway configuration, the 2010 flights were limited to arrivals from the south only. Furthermore, these southerly arrivals were only evaluated when the airport was in a south flow configuration in which the prevailing surface winds were from the south, dictating the use of runways 16 left, right, and center. Since prevailing high altitude winds in the Pacific Northwest are from the north and west, it is likely that these aircraft experienced a substantial change in winds during their descent phase, beginning with a headwind, and then changing to a tailwind at some point during the arrival. If this occurred, due to the difficulties associated with forecasting and modeling wind in such a dynamic environment, it is plausible that these arrivals experienced wind conditions in which the headwind components experienced were less than expected (or conversely, tailwind components greater than expected). If this occurred, the effect would be to "push" the aircraft toward the crossing point at a higher than expected ground speed, and with the throttles already at idle, there would be little capability for the aircraft to further reduce thrust and few other options available to reduce true airspeed to compensate for the errors. This possibility, or a similar anomaly, could explain the predominantly early arrival times observed over this small sample.

For the purpose of fitting the data to a probability distribution, since arrivals of the type flown during the first trial were also a subset of the second trial, the two flight trials have been combined into a single data set. The results of fitting the data to three candidate distributions is shown graphically in Figure 13. Goodness-of-Fit tests indicate a Johnson SU distribution or a Logistic distribution represents the data well. A Gaussian distribution is also shown for comparison purposes.

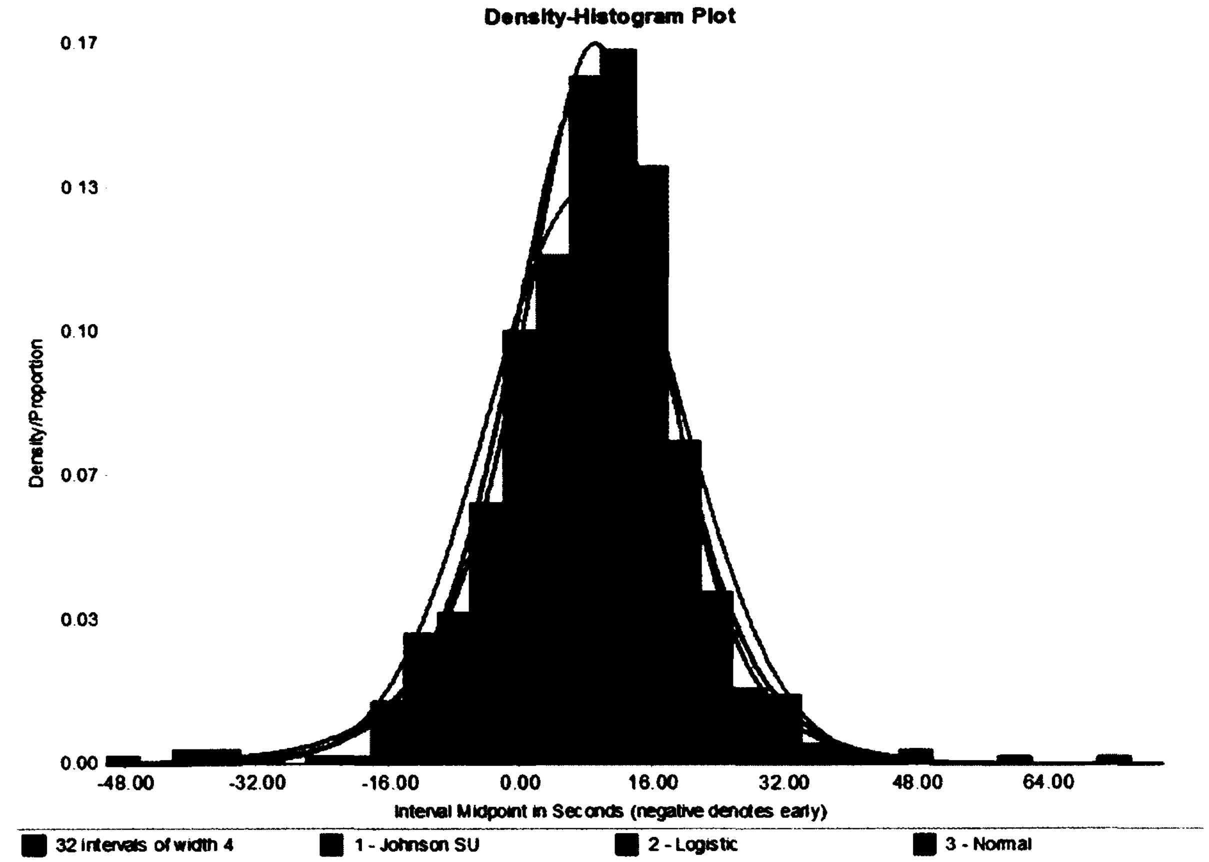

Figure 13: Seattle Flight Test Crossing Time Error Distribution

It is important to note that all of these results were obtained from aircraft operating the same flight management system, built by General Electric. The tendency for these aircraft to arrive late on a consistent basis can have serious safety implications if operated in an airspace system in which other flight management systems produced by different manufacturers tend to deliver aircraft with opposite tendencies. The possible safety implications of failing to control the mean crossing time error through regulation are demonstrated in a paper delivered at the ICMIE Conference in Budapest in 2013 (Bell, et al., 2013).

### 5.2.3. Simulation Testing

Required time of arrival concepts have been tested in a series of simulations sponsored by the FAA and conducted at the William J. Hughes Technical Center in Atlantic City, NJ, and at the Mitre Corporation in Mclean, VA. Relevant details of these tests are described in Section 4.3, and raw data gathered during this testing are presented in the Appendices. Aircraft types modeled include numerous variants of Boeing 737 and 757, Airbus A320, and Embraer E170. The flight management systems tested include the General Electric system used in both European and US flight trials, the Honeywell Pegasus FMS, and the Honeywell Primus Epic FMS. Of note, some of the more recent tests of the Honeywell Pegasus FMS included research software provided by Honeywell. Experiments were also conducted using an electronic flight bag, a hand-held tablet device used to calculate speeds required to achieve a required time of arrival, and envisioned for use by pilots of aircraft that are not equipped with an RTA-capable FMS.

While the simulation testing was conducted to address specific research questions, the focus of this section is to present numeric and graphical depictions of the crossing time error data gathered during this testing for subsequent use in estimating the performance levels that are currently possible with today's state-of-the art systems as well as to inform projections as to what may be possible with regard to future designs. The complete data sets from which this information is drawn are included in the appendices.

#### 5.2.3.1. FY-11 Simulation Data

The May 2011 simulation testing was conducted at the NextGen Integration and Evaluation Capability and Target Generation Facility at the William J. Hughes Technical

Center in Atlantic City, NJ. The study was conducted in preparation for the second round of flight trials in Seattle, WA in late 2011. As such, the bulk of the testing focused on the Boeing 737 aircraft with General Electric flight management systems which represented all of the aircraft flown by Alaska Airlines, the FAA's commercial airline partner for the flight trial. However, additional information was collected on the Airbus A320 and the Embraer E170 aircraft.

Selected parameters of the data collected during this simulation are shown numerically in Table 3 below.

Table 3: FY-11 Simulation Crossing Time Error Data Summary

| | B737 | A320 | E170 | Total |
|---|---|---|---|---|
| Number of Crossings | 68 | 14 | 5 | 87 |
| Earliest Crossing | -47 seconds | -29 seconds | -60 seconds | -60 seconds |
| Latest Crossing | 38 seconds | 51 seconds | 90 seconds | 90 seconds |
| Mean | 5.8 seconds | 4.9 seconds | 33 seconds | 7.1 seconds |
| Standard Deviation | 13 seconds | 25 seconds | 58 seconds | 21 seconds |

Unlike previous flight trials both in Europe and the US that had demonstrated a tendency for aircraft to arrive early, all aircraft demonstrated the opposite tendency in this simulation, a performance that was repeated in the subsequent flight trial. The very small sample size of the E170 aircraft being flown manually expands the minimum and maximum errors and contributes to the comparatively large standard deviation observed during this trial. If the five manually flown arrivals are removed from the data set, the mean crossing time shifts to 5.6 seconds with a 15.5 second standard deviation. It is also important to note that the time error tolerance setting on the FMS was set to 20 seconds for all aircraft participating in this testing.

Since the objective of this section is to gain insight into the capability of aircraft equipped with flight management systems to capture required arrival times, the histogram presented in Figure 14 only the B737 and A320 data, and attempts to fit a distribution to these observations.

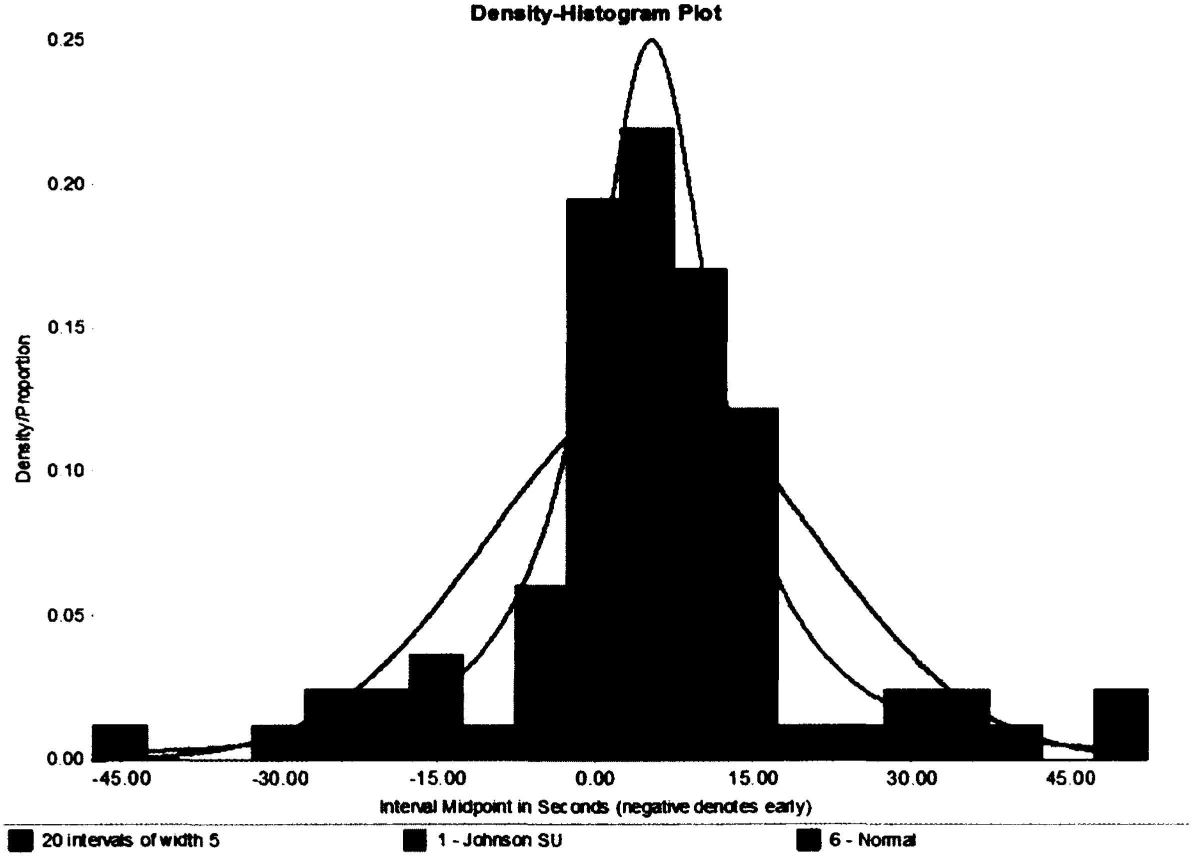

Figure 14: FY-11 Simulation Results

In a result similar to that seen in the data for the Seattle flight trial results, a Johnson SU distribution appears to be the best-fitting distribution. A normal distribution is once again displayed for comparison purposes.

#### 5.2.3.2. FY-12 & FY-13 Simulation Data

Following the second round of Seattle flight trials, a series of simulations were conducted at the Mitre Idea Lab in Mclean, VA. These simulations were designed to build on the results of the previous testing by exploring the application of required time of arrival capabilities to a number of other emerging technologies and procedures associated with *NextGen.* These human-in-the-loop simulations are described in the reports of their findings as "real-time simulation that integrates the human participants and interactions, typically embedded in complex human-machine systems . . . to explore, evaluate, and document candidate procedures and processes in medium fidelity operational environments" (Alexander, et al., 2013). Four simulation periods were conducted during FY-12 and two periods during FY-13. Results from each of the first five of these six test periods have been studied and included in the analysis performed for this research. Initial analysis of preliminary data from the final test period appear to be consistent with previous research, but these results are not included. The complete data sets from all five simulations used for this analysis are included in the appendices.

One of the most interesting and relevant findings over the course of these simulations is the effect of changing the time error tolerance setting on the General Electric FMS from an initial value of twenty seconds, as used in previous simulations and flight tests, to a value of ten seconds. While the exact influence this setting has on the internal algorithms is not known due to the proprietary nature of that information, the effect of the change is clear. The following table illustrates the data collected for all crossings simulated during these tests using each of the values.

Table 4: Time Error Tolerance Performance Data for Simulation

| | 20 Second TET | 10 Second TET |
|---|---|---|
| Number of Crossings | 90 | 222 |
| Earliest Crossing | -47 seconds | -34 seconds |
| Latest Crossing | 38 seconds | 81 seconds |
| Mean | 5.3 seconds | 3.1 seconds |
| Standard Deviation | 12.6 seconds | 11.4 seconds |

The reduced mean crossing time error and lower standard deviation associated with the smaller time error tolerance setting is consistent with the findings of the CASSIS flight trials that used 30 second and 10 second values. The results above include all crossing times for all flights with recorded data regardless of the phase of flight or application being tested. The insight of showing clear performance improvement is important evidence of the influence of the algorithm design and the potential for improved future performance through adjustment of significant variables within these algorithms.

Another important insight obtained through data analysis is the relative performance of aircraft executing time-based clearances in level cruise flight versus aircraft executing time-based clearances to meter fix crossings in the arrival phase. The difference between these two flight environments is dramatic. In level cruise flight, many of the most important variables are relatively constant, allowing for the possibility of very accurate crossing time performance. In contrast, the descending flight environment associated with the arrival phase, or similarly, the climbing environment associated with departures, includes a transition through a dynamic environment in which numerous variables such as wind, temperature, and pressure are simultaneously and continuously changing. The continuous nature of the changing parameters makes modeling of the environment challenging, and the expected result is a lower accuracy threshold. Aircraft engine parameters during this phase also contribute to the expectation of reduced accuracy. During the descent phase, arrivals are typically flown with engines at or near the flight idle power setting to minimize fuel burn. With a constant low thrust setting on the engines, common practice is to maintain airspeed by adjusting rate of descent. However, when a three dimensional flight profile must be maintained with strict adherence to crossing altitudes at geographic reference points, if engine thrust is not adjusted, airspeed will vary in response to random variables, with the strongest influence apparently being from that of local winds. It is also important to understand that jet engines are unresponsive at low power settings, and small throttle adjustments result in negligible changes in engine thrust. The practical effect of this characteristic is that in order to maintain a precise speed in a descent, large throttle movements would be necessary to make the small speed corrections necessary to overcome inevitable time errors that emerge during descent as a result of the differences between the environment modeled within the FMS and that actually experienced by the aircraft in the real world. Designing an FMS algorithm to perform speed corrections with the frequency and magnitude required for highly accurate time of arrival performance is not desired by commercial air carriers as it has two immediate costs. The first is increased engine wear associated with engine speed modulation, leading to higher total operating costs. The second is associated with diminished comfort and confidence of the passengers who are not accustomed to rapid changes in engine setting that are easily detected due to the audible changes in engine pitch and volume.

While departure events were executed with clearances to en route fixes, the vast majority of data collected during simulation involves level flight and descents in the arrival phase.Table 5 illustrates a breakdown of the data collected during the third and fourth simulations in which aircraft executed a time-based clearance during level cruise flight to an en route waypoint, followed immediately by a second time-based clearance to an arrival meter fix. Because these aircraft performed identical maneuvers under the same simulated environmental conditions, it is the most direct comparison available between these two operational performance envelopes.

Table 5: Comparison of Level vs. Descending Flight Performance

| | Cruise Flight | Descending Flight |
|---|---|---|
| Number of Crossings | 113 | 109 |
| Earliest Crossing | -18 seconds | -34 seconds |
| Latest Crossing | 41 seconds | 41 seconds |
| Mean | 5.6 seconds | 4.7 seconds |
| Mode | 0 seconds | 6 seconds |
| Median | 5 seconds | 5 seconds |
| Standard Deviation | 8.8 seconds | 10.5 seconds |

Due to the vast differences in operating environments, and the substantial challenges associated with the descending phase of flight, it is a somewhat surprising result that performance in level flight is roughly equal to that of descending flight. The explanation for the similarity is found within anecdotal descriptions provided by FMS system engineers of the algorithms that govern the corrections commanded by the flight management systems and the designed response to errors. Regardless of the environment, the FMS is not likely to command a thrust change to correct for minor variations in speed discrepancies as the aircraft experiences environmental conditions that vary from those forecasted and programmed into the system. This logic routinely allows for offsetting discrepancies to cancel each other out, such as when the headwind initially experienced is slightly greater than forecast, but slightly less than forecast at a subsequent portion of the flight. A system that is tuned too finely would apply two corrections in such cases, whereas the current configuration makes no correction while achieving the same end result of an on-time crossing. However, when a pre-determined threshold difference between the speed calculated to achieve an on-time crossing time and actual speed is reached, the system applies a correction to overcome the environmental uncertainty with a thrust change. The thresholds at which these corrections are made are not necessarily symmetric. The resulting performance is a random distribution that provides some insight into the nature of the corrections and error tolerances programmed into the systems.

Perhaps the most interesting characteristic of the system however, is a comparison of the distribution of simulated cruise crossing time errors with those of descending flight. Due to the nature of the models employed by the flight management system, which input expected wind values at some number of discrete flight levels and then apply some method of interpolation to estimate wind speeds at intermediate altitudes, the flight management system does not perfectly model winds in descending flight even in a simulated environment. For comparison purposes, the descending flight data set is presented graphically in Figure 15.

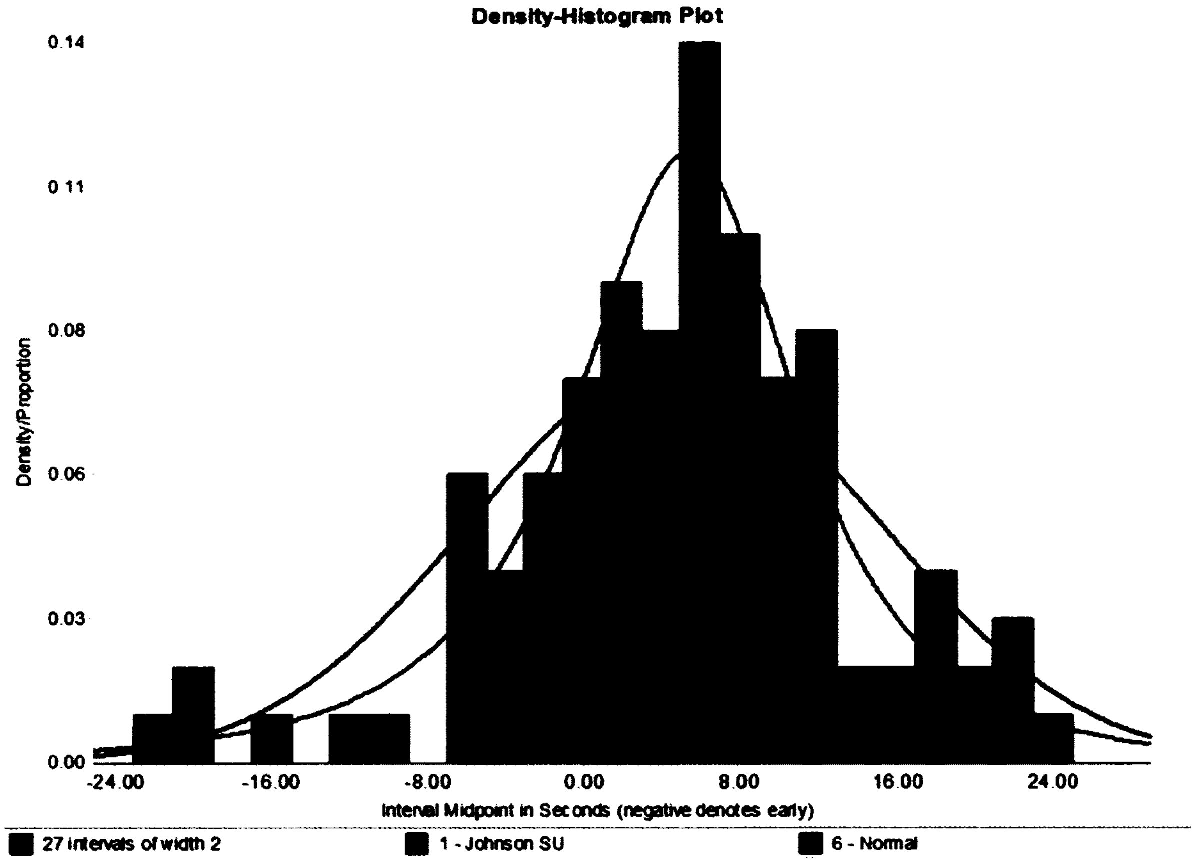

Figure 15: Crossing Time Error for Descending Flight

Note that once again, a Johnson SU distribution is the best-fitting model available. Consistent with previous graphical depictions, a normal distribution is also provided for reference.

Observing the data for level cruise flight reveals an interesting feature of the performance of the flight management systems when tested in simulation. In these operations, the aircraft demonstrates the ability to consistently arrive within a half second of the assigned crossing time on a substantial number of flights, while demonstrating a distribution that is virtually identical to descending flight for all other crossings. Throughout the simulation periods, environmental conditions were adjusted such that during some events the FMS was programmed with wind values that matched the simulation environment while in others events the simulation environment winds were deliberately set to values that differed from those programmed in the FMS. It has been hypothesized that the spike in the data observed at zero seconds is a result of executing flights with perfect wind information, but investigation of the simulation records provides no correlation to allow that hypothesis to be accepted, or more precisely in statistical analysis, for an alternative hypothesis to be rejected. These results suggest that additional research should be conducted to determine whether this spike is an artifact of simulation, or is the result of some performance characteristic of the FMS. From the non-zero crossing times, the evidence seems convincing that when the system is exposed to any variations from the forecasted values of the variables it models, it makes corrections in exactly the same manner during level flight as it does during the descent phase. More importantly, it is clear that despite the advantages of operating in an environment with relatively constant environmental conditions and at an engine setting that would allow for significantly more accurate performance with virtually undetectable throttle movements, the FMS does not take advantage of these opportunities for increased precision, and no correction is made until the single threshold error value is reached. Once that threshold is reached, a correction is applied (possibly a single correction) to compensate for the differences between the modeled conditions and actual conditions. The result for all crossings is a probabilistic distribution that is virtually identical to that observed during descending flight, but is slightly skewed toward zero due to the number of zero error crossings observed in simulation. These results are illustrated graphically in Figure 16 to clearly depict the "spike" at a zero crossing time error.

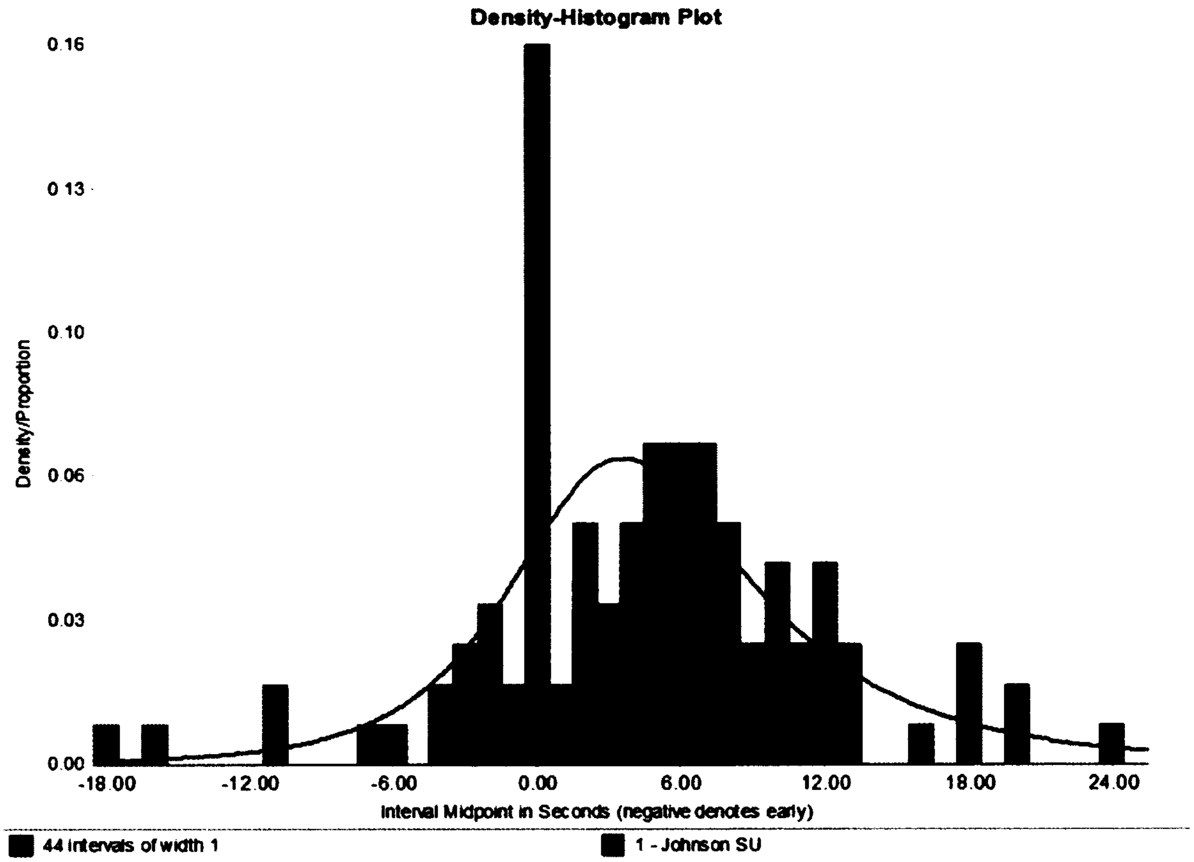

Figure 16: Crossing Time Error for Cruise Flight

It is important to note that these results were not collected and recorded by human observers as was the case during the CASSIS trials, and is not the result of researcher bias. Instead, these results are derived from the reported output of the simulation hardware.

## 5.3. Performance Metrics

One of the research questions identified in Section 1.3 asks *how can the time-based performance of an aircraft be quantified as a metric that provides adequate design flexibility while maintaining sufficient control of underlying parameters of the error distribution?* This section answers that first research question.

The expected increases in air traffic density in the coming decades will require unprecedented levels of navigation precision in all four dimensions to achieve desired capacity increases and safety improvements. The method by which these precise standards are communicated both to industry as well as operational activities has not yet been specified. The following sub-sections develop a metric by which sufficient control may be exerted over key performance parameters using a clear format that provides a robust complement to existing required navigation performance standards.

### 5.3.1. Metric Format Alternatives

By observing the performance of modern aircraft equipped with flight management systems featuring required time of arrival functions, as well as the performance of aircraft without such equipage, trends in the data can be identified. From these trends, it is possible to create performance metrics that will describe the performance of any aircraft, including both current and future models, depending on the type of systems available on each aircraft. The objective of developing such a metric is two-fold. First, it establishes a convention by which the time-based performance of aircraft may be quantified for use in air traffic management functions such as sequencing and separating aircraft. This convention has the added benefit of providing a means by which human operators may develop intuition regarding the relative performance levels of various aircraft operating in the airspace they control. Second, it provides guidelines for industry with respect to the design of avionics intended to support trajectory based operations. With these objectives in mind, it is useful to consider similar existing performance standards found in aviation regulations to establish a precedent from which new performance standards may be developed.

One alternative is to express a window of time in which an aircraft that is assigned a crossing time is expected to arrive along with some confidence level. This is the method by which time of arrival control standards have been expressed at the regulatory level to date. Initial time of arrival control standards did not require manufacturers to include a time of arrival control function on flight management systems, but specified that if such a function is included, it "shall control the time of arrival at a specified lateral fix in the flight plan with a 95% accuracy of 30 seconds" (RTCA, 2003, p. 24). The weakness of this standard is that it fails to control the shape of the underlying distribution. This flaw allows for the possibility that manufacturers who attempt to optimize the efficiency of a single aircraft descent profile will design algorithms that meet the standard, but lead to asymmetric control schemes resulting in consistently early or late arrivals. If multiple manufacturers produce systems that achieve certification through individual system testing, there is a potential for unacceptable collision risk to be introduced into the system if those systems are then combined operationally within the airspace system with other certified systems that display opposite tendencies (Bell, et al., 2013).

A more robust alternative is to develop a simple category system to express the relative performance of all aircraft. This practice is common within the aviation discipline and numerous examples exist within the Code of Federal Regulations (CFR) governing aviation activities in the United States. One such example is found in Title 14 CFR §97.3 of these regulations and describes aircraft as falling into one of five categories based on their approach airspeed. This category system serves as the basis for determining the minimum weather conditions under which an aircraft may execute an instrument approach to a runway for landing (GPO, 2012). A standard of this nature has been proposed for time of arrival control avionics and flight standards using a similar five category system to provide limits on the mean and standard deviation of expected crossing time errors (Bell, 2013).

A final method by which aircraft performance can be described is accomplished by setting a performance value. This method was pioneered to express navigational position accuracy and is described through the application of a Required Navigation Performance, denoted by RNP-X, where X is a variable describing the aircraft navigation performance. The method by which this is accomplished is depicted graphically in Figure 17 and explained in detail below.

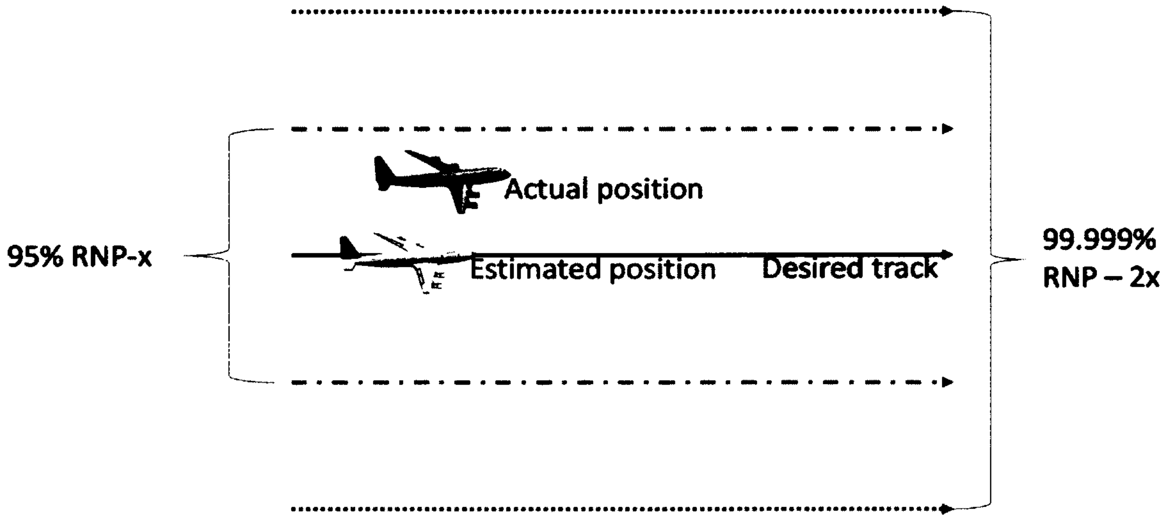

Figure 17: Required Navigation Performance Metrics

The figure shows the estimated position of an aircraft with regard to some desired track as determined by the navigation system. This estimated position is what is reported to air traffic control either by voice report, through a digital data link system, or by the emerging Automatic Dependent Surveillance – Broadcast (ADS-B) system. However, the actual position of the aircraft may be at some other point. The actual position of the aircraft is its true position, and can be determined through independent observation by air traffic control via sources such as RADAR or visual observation. RNP-X values are used to describe the likelihood of the discrepancy between estimated and actual position in probabilistic terms. By definition, the value of X describes the 95% confidence interval within which the aircraft is likely to be contained, expressed in terms of nautical miles. Additionally, the RNP definition states that the probability of the actual position being more than two times the value of X from its estimated position is $1 \times 10^{-5}$. For example, if a system is certified as RNP-4, there is a 95% probability that the aircraft will be within 4 miles of the desired track, and 99.999% probability that it will be within 8 miles (Nakamura, 2000).

### 5.3.2. Required Time Performance

As discussed in the previous section, there are significant safety concerns over the use of a standard that provides nothing more than bookend values of desired time-based performance. The use of a simple categorical standard is a preferred alternative due to its implicit control over key parameters of the error distribution. However, there are drawbacks to using a categorical standard as well. Namely, an aircraft that demonstrates performance that is just barely good enough to achieve certification in some category is treated identically to another aircraft whose performance falls just short of the next highest category. There is no graduated level of performance within any category, and therefore no benefit to any performance improvement within a category. Additionally, a category system that attempts to govern performance by controlling specific parameters of a distribution limits industry design flexibility as failure to meet the specification for any parameter results in a failure to meet the desired certification, regardless of how much the system might exceed performance requirements in other parameters.

The concept of a Required Time Performance standard is attractive for a number of reasons. In both name and function, it serves as a complement to existing standards used to describe navigation performance. Further, it allows incremental benefits to be realized with incremental gains in performance that are not arbitrarily constrained by a category system. Thus, aircraft and avionics manufacturers can assess the cost and practicality of achieving a desired time-based performance level and make informed decisions with regard to the tradeoffs associated with various algorithm design strategies. Finally, strategic documents defining the vision of *NextGen* have identified development of this standard as a pre-requisite to initiation of trajectory based operations (JPDO, 2011). The challenge of developing an RTP standard is in finding a way to adequately control the parameters of the underlying error distribution as a categorical standard does.

As a pre-requisite to providing a performance metric in an RTP format, the nature of the underlying distribution must be justified. Since the event of interest is that of all future time-based arrivals at any possible three-dimensional fix, the population being estimated is effectively infinite. An inductive mode of reasoning allows a finite sample of sufficient size to be used to infer the nature of that population. The research process depends upon employment of the central limit theorem in an attempt to generalize the time-based performance of aircraft. If the resources necessary for flight and simulation testing were not limited, an infinite series of tests could be developed to further explore the time-based performance of aircraft until the data set became saturated such that the addition of more data points would no longer influence the statistics describing aircraft performance. The central limit theorem asserts that if the mean value of each of these tests is fitted to a probability distribution, regardless of the underlying distribution from which the data itself originated, the result will be a normal distribution (Bertsekas & Tsitsiklis, 2002). It is this theorem that justifies the use of a normal distribution to describe the long-term expected performance of aircraft despite reported results indicating that individual test results are best represented by something other than a normal distribution.

With a normal distribution serving as the basis for an RTP standard, the RTP standard itself can be fully developed. In the same way that the Required Navigation Performance is communicated, the RTP standard is formulated with a variable value associated with it. If Y is assigned as a variable to represent this value in a *RTP-Y* format, the value of Y can be set as follows:

$$Y = 2(\mu + \sigma) \tag{1}$$

where $\mu$ represents the mean and $\sigma$ represents the standard deviation of the long-term expected crossing time error distribution of an aircraft.

To illustrate the effect of formulating Y as depicted in Equation (1), consider a normal distribution such as the one illustrated in Figure 18 that might describe the long-term performance of some aircraft. The key parameters of this sample distribution are a mean of 0 seconds and a standard deviation of 10 seconds.

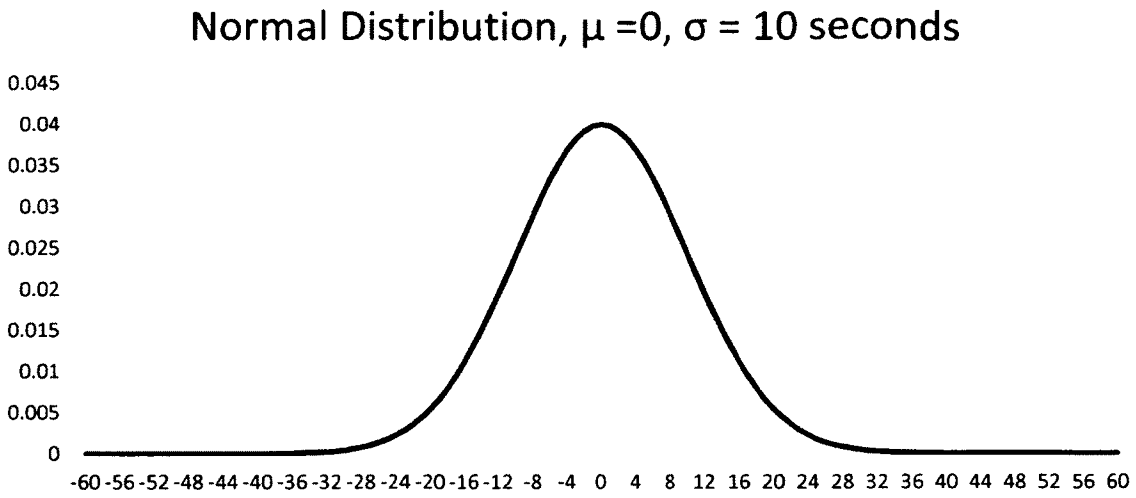

Figure 18: Example RTP-20 Crossing Time Error Distribution

It can be shown that the 95% confidence interval of this distribution ranges from -19.6 seconds to +19.6 seconds, roughly equal to the success criteria used in the evaluation of the Seattle flight trials. Since the 95% confidence interval of a normal distribution is approximately equal to two standard deviations, the value of Y approximates the 95% confidence interval when the mean of the distribution is zero. If the distribution in Figure 18 represented the performance of some aircraft, it would be certified under this proposal to a level of RTP-20. However, if certification testing showed the aircraft had a tendency to arrive late as has been observed in numerous tests to date, such as a case in which the mean crossing time error was +3 seconds, the Y value would increase such that the aircraft would be certified as RTP-26. If the manufacturer wished to design the system such that it meets a performance specification of RTP-20, conceivably to allow the aircraft to participate in operations requiring this level of performance, and for some reason did not wish to adjust the mean crossing time error, Figure 19 illustrates how design changes that reduce the standard deviation of test results would allow this certification level to be achieved. The burden on the manufacturer would then be to show the standard deviation to be seven seconds or less. Assuming this is technically feasible, a comparison of these two potential distributions provides important insight for the sections that follow.

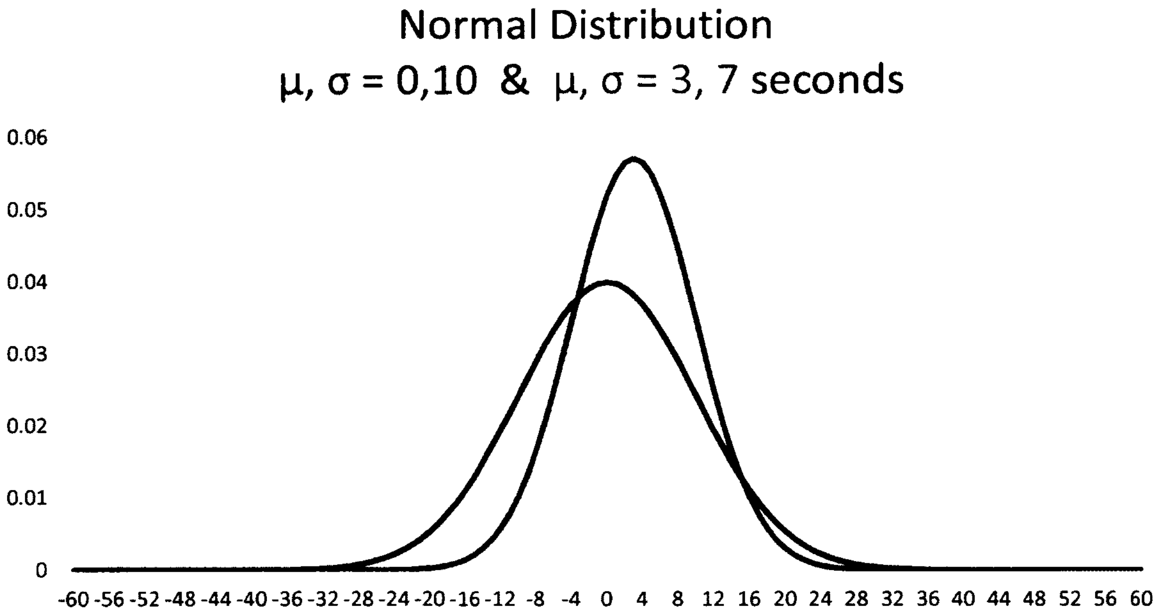

Figure 19: Two Alternative RTP-20 Distributions

Note that while the mean crossing time of the second distribution, shown in red, has noticeably shifted to the right, the tail of that same distribution drops more rapidly and approaches zero faster than the initial distribution with a zero mean. It can be shown that with regard to the dispersion of expected crossing times, a zero mean crossing time error is the limiting case when calculating the end points of the largest 95% confidence interval for any combination of mean and standard deviation values. From the perspective of a manufacturer, this function of Y results in a mathematical penalty for any deviation from the mean that must be overcompensated for with a reduction in standard deviation in order to achieve certification at a desired *RTP-Y* level. The importance of this feature of the standard will be further described in the following section.

## 5.4. Collision Probabilities

The second research question identified in section 1.3 asks *how can the probability of collision be determined for aircraft operating in a time-based operational environment?* This section answers that question demonstrating a method by which collision probability may be calculated using stochastic modeling techniques.

### 5.4.1. Scope of Calculations

The calculations developed for the purpose of this research are limited to aircraft operating in proximity to one another under two different scenarios. The first is a low aspect scenario in which both aircraft are assigned crossing times at some three-dimensional fix, and approach the fix along the same course, or nearly the same course. This is a routine operation that takes place on a nearly continuous basis in controlled airspace all over the world. An example of this type of operation can be seen in the Olympia 7 arrival to Seattle-Tacoma International Airport shown in Appendix A. The fix labeled *Olympia* is a meter fix that is used as a flow control point for southerly arrivals and is one of the points used for testing during both Seattle flight trials. Aircraft arriving from the south may first fly over the point labeled *Battleground* and then fly the prescribed course to *Olympia.* If two sequential aircraft fly this same profile, and both are assigned crossing times at *Olympia*, there is some probability that they will arrive at *Olympia* at the same time, resulting in a collision. However, it is also possible for a collision to occur at some other point along the route prior to reaching *Olympia.* If each aircraft arrival is considered independently, and the closest aircraft is assigned to cross the fix at some time prior to the furthest aircraft, it is possible that the aircraft assigned to cross the fix first will cross at some time after the second aircraft. If this is the case, the second aircraft must have passed the first aircraft somewhere prior to the crossing. Two previously discussed assumptions become important to the calculations that follow. First, the navigation error of each aircraft is assumed to be negligible such that the approach to the crossing fix is considered to be a tube of air that only one aircraft can fly through at a time. Secondly, it is assumed that if one aircraft overtakes another, this event will happen no more than once. The result of this formulation is conservative from a risk estimation perspective in that the event of the second aircraft arriving before the first leads to an assumption that a collision must have taken place at some point prior to the fix crossing. In this example, the collision would occur somewhere between *Battleground* and *Olympia.*

It is acknowledged that these assumptions may not be true in practice. The scenario described above may occur as described, and due to the random nature of navigation errors, one aircraft may pass the other with some horizontal or vertical clearance that does not result in a collision. Similarly, it is possible that the aircraft beginning further from the point is flying higher and faster than the closer aircraft, and may pass the closer aircraft with vertical clearance by design. If these variations are included in the collision risk calculations, each event considered would reduce the probability of collision by some amount. However, by not including them, the probability of collision will always be less than or equal to the value obtained by the calculations described herein.

The second scenario considered is the high aspect crossing case that occurs when two aircraft cross the same point at an intersection of two flight paths or at the merge point between two converging flight paths. This geometry can be seen once again on the arrival to Seattle such as a case in which only one aircraft arrives from *Battleground* while the other aircraft arrives from *Newberg.* In this case, the probability of collision is solely a function of crossing time error as the two tracks are not coincidental until reaching *Olympia.* Consistent with the previous description of low aspect geometries, the method of calculating the probability of collision provided in this research will be conservative in nature, slightly overstating the risk of collision between merging traffic by assuming that collisions will not be avoided due to chance errors in navigation. Since the calculated collision probability is treated as a constraint that must be satisfied for operational feasibility, future research efforts may achieve more aggressive results if constraints imposed by the assumptions of this effort are relaxed, leading to more complex time-based collision risk models that allow for further increases in system capacity. However, the objective of this research is limited to development and demonstration of a general method by which collision probability may be assessed in the most frequently experienced encounters in the airspace system, and therefore additional geometries such as vertical crossings are beyond the scope of this research.

### 5.4.2. Collision Probability Calculations

In the calculations that follow, it is assumed that the aircraft are not initially co-located, in which case a collision occurs at time 0. Instead, this research assumes that the aircraft are minimally separated by some amount that satisfies either current distance-based or a future time-based separation standard.

To introduce variables used in the development of these models, consider two aircraft, represented by j and k, where aircraft j is initially closest to the crossing point. The aircraft may then be assigned clearances to cross some three-dimensional fix at specific times, $T_j$ and $T_k$, with some interval, I, scheduled between them and I being expressed in units of time such that $I \geq 0$. The actual arrival times will be represented by lower case $t_j$ and $t_k$, respectively, with the difference between assigned and actual crossing time being referred to as crossing time errors. These crossing time errors are assumed to be distributed according to some function $f_j(t)$ and $f_k(t)$ respectively. Additionally, let $l_n$ represent the length and $v_n$ represent the ground speed of any aircraft n. The exposure time at the crossing point may then be defined by a variable $\delta_n$ as follows:

$$\delta_n = \frac{l_n}{v_n}$$

In this formulation, $\delta_n$ represents the amount of time between the leading edge of the aircraft n arriving at the crossing point and the trailing edge exiting the crossing point.

For convenience of expression regarding the equations to follow, two additional variables, $\alpha$, and $\beta$, are introduced to describe certain aspects of the time between the arrival of aircraft j at the crossing point and the relevant exposure times of aircraft j and k. The formulation and use of these variables will be further described in the sections that follow:

$$\alpha = t_j - \delta_k$$

$$\beta = t_j + \delta_j$$

### 5.4.2.1. Low Aspect Collision Probability

For two aircraft traveling along the same or nearly the same three-dimensional track to an assigned crossing point, it is possible that the aircraft will each exhibit crossing time errors such that they arrive at the same point in space at the same time anywhere along the track between their point of origination and the crossing point.

If the first crossing time is assigned to aircraft j, and a subsequent crossing time is assigned to aircraft k, there are three possible events that could take place. First, aircraft k's arrival time, $t_k$, could occur before the arrival time of aircraft j, $t_j$. In this case, aircraft k must have passed aircraft j, and since modern navigation systems demonstrate very little position error, it is conservative to assume that aircraft k collided with aircraft j at some point prior to reaching the crossing point. Second, $t_k$ could occur sometime after $t_j$, but before aircraft j has exited the crossing point, a time defined as β. This would result in a collision at, or very near, the crossing point. Finally, $t_k$ could arrive at some time after β, resulting in a crossing without a collision. The following equation summarizes these three scenarios and lays the groundwork for a stochastic model describing the probability of collision in this geometry.

$$P(Collision) = P(t_k \leq \beta)$$

Now suppose each aircraft has demonstrated its ability to capture time-based clearances through some certification process. It is reasonable to believe that the expected errors expressed by the probability density functions $f_j(t)$ and $f_k(t)$ are independent of each other. If this is true, the scenario can be depicted graphically with both density functions on a timeline as illustrated in Figure 20. These density functions have been chosen arbitrarily for the purpose of illustration only.

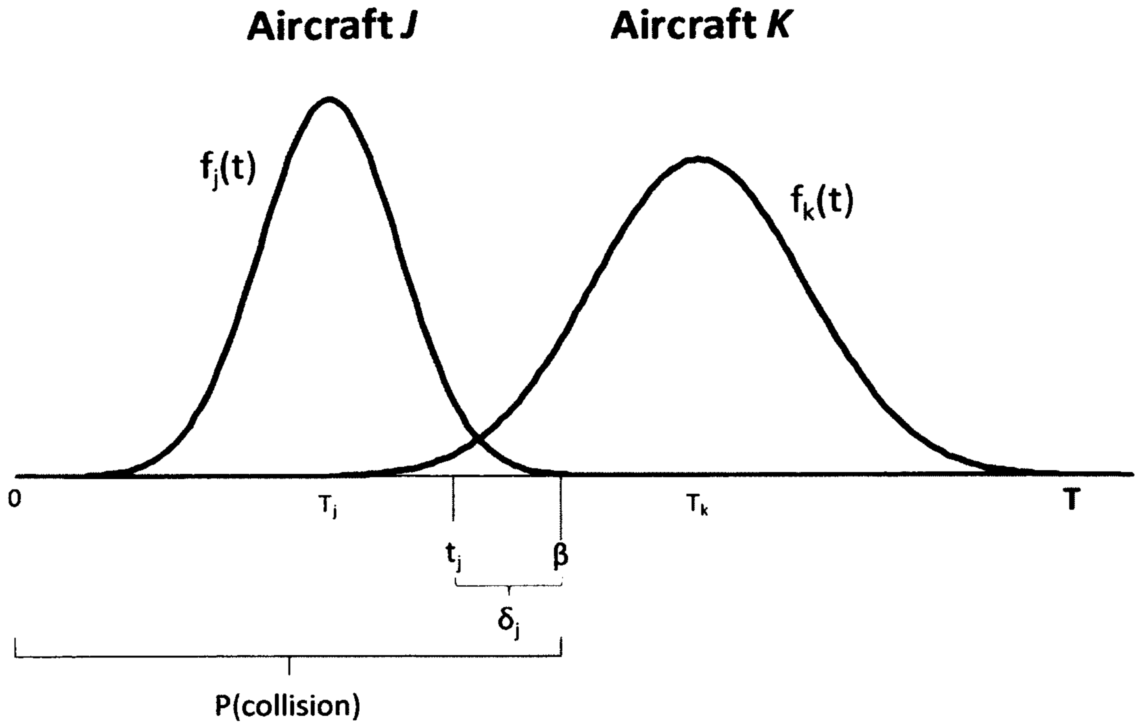

Figure 20: Two Aircraft Crossing-Time Error Distributions

Of interest is the probability that aircraft k arrives at the same time as aircraft j, or at any time prior to aircraft j exiting the crossing point, time β. This probability is calculated by integrating over all possible arrival times of aircraft j and the probability of aircraft k arriving at or earlier than β. Thus, the probability is calculated according to the following equation:

$$P[t_k \le \beta] = \int_0^{\infty} f_j(t)\,dt \left[\int_0^{\beta} f_k(t)dt\right] \tag{2}$$

The function $F_k(t)$ is commonly used to denote the probability distribution function of k, and it can be seen that the probability of aircraft k arriving at or before β is by definition the distribution function of k. This allows Equation (2) to be simplified to the following expression.

$$P[t_k \leq \beta] = \int_0^{\infty} f_j(t) * F_k(t)dt \tag{3}$$

As discussed in section 5.3.2, the long term crossing time errors for any aircraft are expected to take on the characteristics of a normal distribution. This allows the functions of j and k to be described entirely by their means, $\mu_j$ and $\mu_k$, and standard deviations, $\sigma_j$ and $\sigma_k$. Further, if the distribution of aircraft j errors is expressed as $S = N(\mu_s, \sigma_s)$, and the distribution of aircraft k errors is expressed as $R = N(\mu_r, \sigma_r)$, then a new function can be introduced as

$$Z = R - S$$

In this expression, aircraft j's crossing time is arbitrarily set as time $t_j = 0$. It follows that $\mu_s = \mu_j + \delta_j$ and $\mu_r = \Gamma + \mu_k$. Once again assuming the performance of each aircraft is statistically independent, it can be inferred that the variable Z is also a normal random variable and the properties of normal distribution functions allows the following relationship to be expressed (Haldar & Mahadevan, 2000):

$$P[t_k \leq \beta] = P[Z \leq 0]$$

Using the customary Greek letter $\Phi$ to denote the cumulative distribution function of the standard normal distribution, it can now be seen that equation (3) can be used to define the probability of collision as

$$P[Z \leq 0] = \phi\left[\frac{0 - (\mu_r - \mu_s)}{\sqrt[2]{{\sigma_r}^2 + {\sigma_s}^2}}\right] = \phi\left[\frac{\mu_s - \mu_r}{\sqrt[2]{{\sigma_r}^2 + {\sigma_s}^2}}\right] \tag{4}$$

### 5.4.2.2. High Aspect Collision Probabilities

The event of a collision occurring at a crossing point such as the merge point or intersection of two routes requires a more complex function to account for the elimination of collision probability prior to arrival at the crossing point. When the only common point of flight is the intersection of two flight paths, there are only two possible collision scenarios. Aircraft j can arrive while aircraft k is exposed in the intersection, or vice versa. Graphical depictions are useful for visualizing the mathematical relationships that describe these events. The vectors in Figure 21 represent any aircraft, n, of any length and groundspeed, and thus their magnitude is $\delta_n$. Similarly, all other variables used in the following formulation are consistent with those defined in the previous sections.

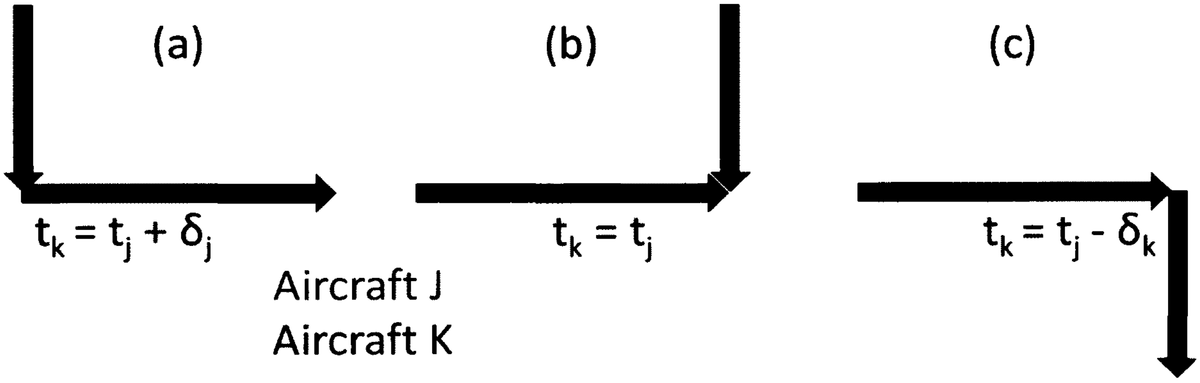

Figure 21: Range of Possibilities for High-Aspect Collision Geometries

In Figure 21, scenarios (a) and (c) represent the limiting cases of the two collision possibilities while scenario (b) depicts the midpoint between the two extremes. In scenario (a), aircraft j arrives at some time $t_j$, and the last moment in time that a collision can occur is if aircraft k's arrival time, $t_k$, occurs as the trailing edge of aircraft j is about to exit the crossing point. Scenario (b) simply depicts the arrival of both aircraft at exactly the same moment in time. Finally, scenario (c) depicts a case in which aircraft k arrives prior to aircraft j. In this scenario, $t_k$ must occur such that $t_j$ will occur while aircraft k is still exposed at the crossing point.

The collision risk model for high aspect geometries is subsequently derived from the limiting cases illustrated in scenarios (a) and (c). Of interest is the probability that $t_k$ occurs earlier than the time depicted in scenario (a) and later than the time depicted in scenario (b). Figure 21 depicts this range of time on the same timeline used in Figure 20.

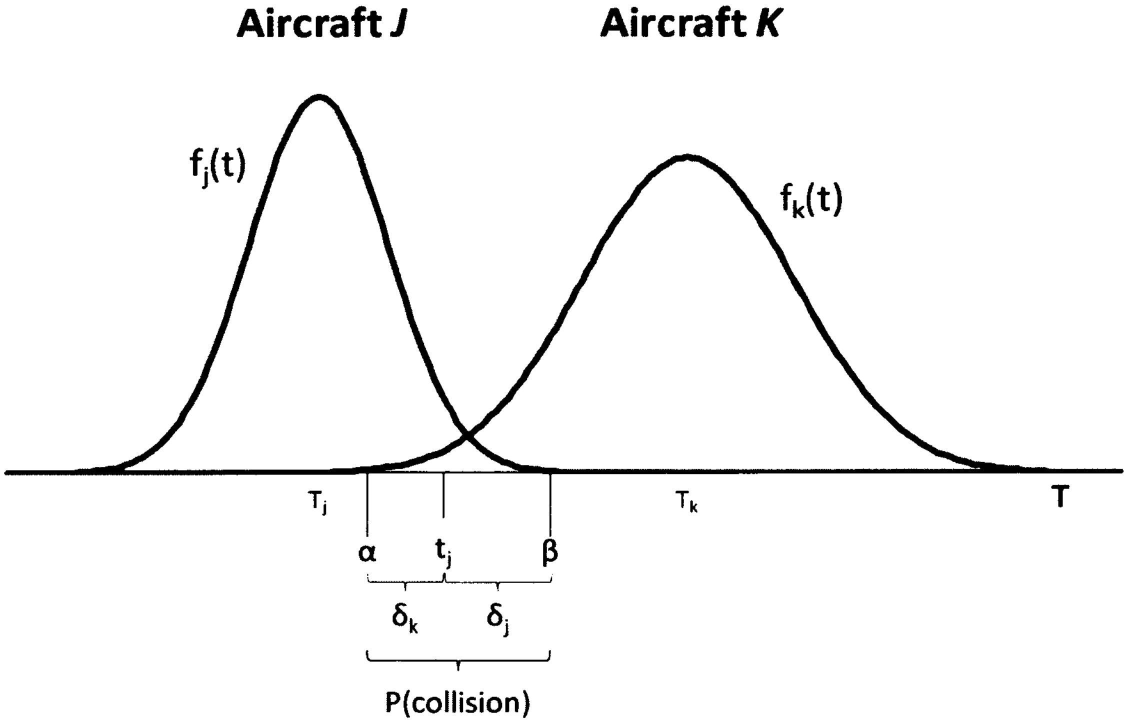

Figure 22: Graphic depiction of Possible High-Aspect Collision Times

To develop a collision risk model for this geometry, the probability that $t_k$ is less than or equal to β is once again necessary. However, from this value, the probability that $t_k$ is less than or equal to α must be considered as well, and this value must be subtracted. The process of deriving this model is shown through the series of equations presented below:

$$P(collision) = P(\alpha \leq t_k \leq \beta)$$

$$= P(t_j) * P(\{t_k \leq \beta\}) - P(t_j) * P(\{t_k \leq \alpha\})$$

$$= P(t_j) * [P(\{t_k \leq \beta\}) - P(\{t_k \leq \alpha\})]$$

$$= \int_0^{\infty} f_j(t)dt \left[\int_0^{\beta} f_k(t)dt - \int_0^{\alpha} f_k(t)dt\right] \tag{5}$$

With these two models, it is possible to calculate a collision risk between any two aircraft scheduled to cross a point in space with some interval between them. The next question to be considered is how the interval should be managed. That question is the addressed in the following section as the application of these models to the management of air traffic in a trajectory based operations environment is demonstrated.

## 5.5. Interval Analysis

The final research question to be addressed is *how can the density of air traffic be increased to meet expected demand while maintaining an acceptable level of collision risk?* This section provides an answer to that question. The method developed is to apply the separation functions developed through this research to collision risk models that may be used to determine how the interval between sequential aircraft influences the collision risk and the capacity of the system. To accomplish this, the models are formulated with two aircraft of variable performance capability, as indicated by an assumed *RTP-Y* certification level, operating in an uncertain environment. In this way, the results of the analysis may be easily applied to represent any two sequential aircraft scheduled to cross a fix with some amount of time between them. Once the model is constructed, it may be used as a tool to provide specific recommendations for standards governing four dimensional trajectory based operations as demonstrated in the following sections.

### 5.5.1. Aircraft Operating Environment Modeling

A unique characteristic of aviation operations is the dynamic nature of the environment in which the aircraft operate. There are numerous variables that must be considered in order for a model to be meaningful in its representation of aircraft operations. The variables involved include airspeed, wind, pressure, air density, and temperature.

Some of the variables used in the model developed to support this research are selectable by the user. These variables include the headwind component, the altitude in thousands of feet, the sea level temperature, and the interval assigned between sequential aircraft in seconds. A temperature lapse rate of 3.5 degrees per 1,000 feet is assumed to apply from sea level to flight level 450, the highest altitude currently modeled, and a flight level temperature is calculated for any altitude selected by the user. The default sea level temperature is set to 59 degrees Fahrenheit, the value specified for sea level in the 1976 US Standard Atmosphere (NOAA, NASA, & USAF, 1976). The temperature is also converted to degrees Kelvin (K) for use in other airspeed calculations described below. The air density at the selected altitude is then calculated using data from tables included in the US Standard Atmosphere document.

Airspeed expressions were discussed in section 2.3. The model developed through this research considers the differences between indicated, equivalent, and calibrated airspeed to be negligible, and calibrated airspeed is used to represent any aircraft speed restriction expressed in nautical miles per hour such as the ones specified on the standard arrival to Seattle depicted in Appendix A. Once a calibrated airspeed is selected, a true airspeed is then calculated. The formula for this conversion is shown below.

$$TAS = CAS \sqrt[2]{\frac{\rho_0}{\rho}}$$

where $\rho_0$ is the air density a sea level on a standard day, 1.225 kg/m$^3$, and $\rho$ is the density of the air in which the aircraft is flying. Ground speed may then be determined by simply subtracting any headwind component (or adding a tailwind component) to the true airspeed. As a final speed reference, Mach number is then calculated using the following expression.

$$Mach = \frac{TAS}{\left(a_0 \sqrt[2]{\frac{T}{T_0}}\right)}$$

Where $a_0$ is the standard speed of sound at sea level, 661.47 knots; T is the static air temperature in degrees Kelvin; and $T_0$ is the temperature at standard sea level, 288.15 K.

One final parameter is calculated by the model to allow comparisons to be drawn between current distance-based separation standards and time-based separation standards proposed herein. If each aircraft were to arrive at the specified crossing point exactly at its assigned time and at the designated airspeed, it is possible to determine the physical distance between the aircraft using the same calculations the Traffic Management Advisor uses in its stream class setting. This value is calculated by the model via the following equation.

$$Separation\ Distance\ (NM) = \left[\frac{Ground\ Speed\ \left(\frac{NM}{hr}\right)}{3600\ \left(\frac{seconds}{hr}\right)}\right] * Interval(seconds)$$

With these user inputs and calculations completed, the user may then enter the mean and standard deviation of the crossing time error distribution for each aircraft. Based on these inputs, the model generates a graphical depiction of the mathematical model similar to that shown in Figure 20. Additionally, the model calculates the probability of collision for the selected parameters using either Equations (4) or (5), depending on the aspect ratio of the intersection.

### 5.5.2. Application of the Performance Metric

In Section 5.3.2 a performance metric was developed in an *RTP-Y* format. This section will use the interval analysis model to demonstrate the application of this metric and the limiting case of a zero mean crossing time error.

The following parameters are drawn from either the US Standard Atmosphere, requirements for the Standard Arrival to Seattle shown in Appendix A, or as calculated by the model based on the user input values.

Table 6: Sample Values from Interval Analysis Model

| | |
|---|---|
| Calibrated Airspeed | 250 knots |
| Altitude | 12,000 feet |
| True Airspeed | 300 knots |
| Headwind | 0 |
| Sea Level Temp | 59 deg F |
| Ground Speed | 300 knots |
| Interval | 60 seconds |
| Separation Distance | 5 NM |

It can be observed that if the procedures for the arrival to Seattle are followed exactly, and the 5 NM separation standard is also exactly adhered to, the resulting time-based interval will be 60 seconds. This is simply a coincidence and this relationship does not hold true at crossing points associated with all arrivals.

Using this data set, consider two aircraft whose time-based performance is certified at RTP-14. To begin with, this performance will be assumed to have been achieved by identical aircraft demonstrating a zero mean crossing time error and a seven second standard deviation, roughly the best performance level demonstrated by any aircraft to date. It can be shown by applying Equation (4) using values from Table 6, the collision probability is 6.8 x $10^{-10}$. The scenario is depicted graphically in Figure 23.

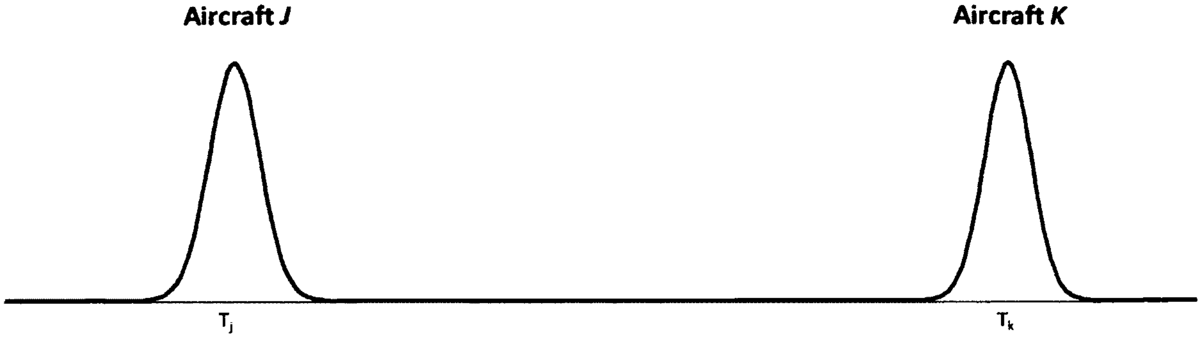

Figure 23: Sample Crossing Time Error, Initial Scenario

Now consider a variation of the scenario in which Aircraft j achieves an RTP-14 performance certification with a mean crossing time error of 2 seconds late and a standard deviation of 5 seconds, while aircraft k remains unchanged. The new probability of collision is lowered to 7.8 x $10^{-12}$. The reason for this reduction becomes clear when the relationship between the tails of each distribution are observed in the graphic depiction of the new scenario shown in Figure 24. The red curve depicts the new density function with a mean crossing time error of two seconds late, and the corresponding steeper vertical drop toward a zero value that is reached prior to the original curve.

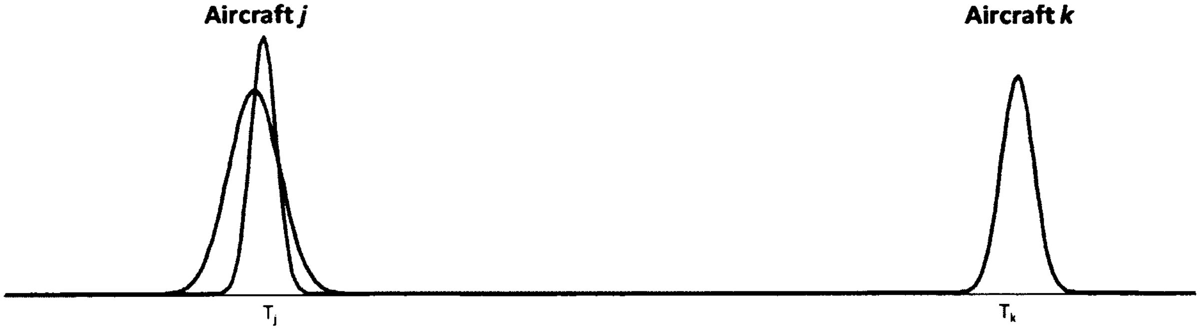

Figure 24: Sample Crossing Time Error, Updated Scenario

The scenario depicted in Figure 24 can be generalized to any sequence of aircraft with known *RTP-Y* values such that the highest probability of collision is calculated when both aircraft are treated as if their *RTP-Y* value is achieved with a zero mean crossing time error.

### 5.5.3. Relating Interval to Capacity

As described in previous sections, a number of strategies have been developed in recent years to increase the efficiency by which delays are absorbed during peak operating hours. However, the objective of programs such as *NextGen* and *Single European Sky* is to increase capacity rather than to simply reduce the cost of delays introduced when demand exceeds capacity. In order to accommodate current demand during peak operational periods, as well as projected future demand, the density of air traffic will need to be increased by some measurable amount. From Figure 2, it can be seen that demand is projected to be approximately 1.5 times greater than current demand by 2030, with the expected number of passengers increasing from about 800 million to roughly 1.2 billion. It can be concluded from the methods demonstrated in this research that a feasible approach to accommodating rising demand by increasing traffic density while maintaining an acceptable level of risk is available to air traffic management authorities. This section will demonstrate such application.

Consider the following example. If an operation currently involves acceptance of 60 arrivals per hour, in the future it will need to accommodate 90 arrivals per hour to meet an expected demand that is 1.5 times greater than current demand. Another way of stating this same problem is that if the operation currently accepts one arrival every 60 seconds, future demand will require acceptance of one arrival every 40 seconds. The collision risk models allow determination of how accurate flight management systems must be to allow aircraft to operate with this level of separation while maintaining an acceptable probability of collision.

Using the same general data from Table 6, but with the time-based interval changed to 40 seconds, the collision risk increases to $2.7 \times 10^{-5}$, an unacceptably high risk as defined by relevant regulatory documents. However, if the crossing time error performance of the aircraft is improved, the risk can be reduced. Through application of the methods described in this paper, it can be shown that if the aircraft could be certified to an RTP-9.4 performance level, the collision risk would be returned to an acceptable level, in this case $8.8 \times 10^{-10}$. Given the nature of "book end" standards that have been considered to date, it is interesting to note that this level of performance would be equal to a window of ±9.2 seconds with 95% confidence. As an alternative, if regulators wish to express *RTP-Y* standards with Y being constrained to an integer value, the same interval analysis model can be used to show that if both aircraft are certified to a level of RTP-10, the minimum interval that can be safely assigned between the aircraft is 43 seconds.

One final variation on this example is worth highlighting. Suppose that instead of identical aircraft, the aircraft are dissimilar. Recall that two aircraft separated by 60 seconds were shown to achieve an acceptable low-aspect collision risk if they are both certified as RTP-14. If aircraft j is such an aircraft, but due to enhanced algorithm design, aircraft k is able to meet requirements for certification at the RTP-10 level, the interval between the two aircraft may be safely reduced to 52 seconds. The important insight is that incremental gains are possible as any aircraft that is able to deliver improved performance in a trajectory based operations environment will contribute a measurable benefit to the system as a whole.

While no publically available data provides evidence that current aircraft are capable of achieving performance exceeding RTP-14, innovative designs powered by economic incentive may allow accomplishment of this performance level in the near future, allowing tomorrow's aircraft to operate in higher density environments while enjoying today's margin of safety.

# 6. Recommendations and Future Research

There are a number of recommendations that emerge from this research, and additional questions that arise suggesting the need for additional research. This section briefly summarizes recommendations that emerge as a result of this effort and provides suggestions for additional studies that will enhance these initial findings.

## 6.1. Time-Based Performance Metric

The need to develop a performance metric that is robust enough to ensure control of key parameters of crossing time error distributions has been made clear in recent literature, and is reinforced in this document. The safety of the flying public must be accounted for in the development of complex systems such as *NextGen*, and the precision that will be necessary to meet the stated objectives of such programs demands development of robust standards for future trajectory based operations.

The *RTP-Y* metric proposed in this research provides numerous advantages over previously considered alternatives. Its format is virtually identical to that of existing required navigation performance standards, allowing seamless integration with those standards and providing a comparatively intuitive method of quantifying performance. The simplicity of the formula used to compute the value of Y does not imply that the standard is not robust. As demonstrated in the previous section, a standard in this format provides adequate control over the critical parameters of the error distribution and allows for conservative estimates of collision risk in an operational setting as well as a clear metric by which industry may engineer future flight management system algorithms.

The combination of RTP and RNP performance standards has the potential to provide greater effects than either standard might allow for in isolation. As an example, their combined use allows a new solution to the problem of existing capacity shortfalls in the oceanic regions. Most of the world's oceanic airspace currently uses time-based longitudinal separation standards in conjunction with distance-based lateral separation standards. The use of distance-based collision risk models such as the one pioneered by Reich in the mid 1960's are simply not applicable to the time-based longitudinal separation standards. This flaw has led some regulatory agencies, including the FAA, to attempt a conversion from time-based to distance-based standards for procedurally separated aircraft, a decision partly influenced by the simple fact that they have yet to find a credible method by which to assess collision risk in the longitudinal axis. In fact, when current distance-based collision risk models are applied to aircraft separated by time, the result is that collision risk becomes a function of environmental conditions such that collision risk is quite literally determined by which way the wind blows. More seriously, this practice leads to a requirement for transition from existing procedural separation methods to tactical air traffic control methods due to extreme distance-based compression effects that result from frequent entry and exit from jet stream wind conditions common to the oceanic environment. This progression, which effectively parallels the conversion of time-based to distance-based standards in the 1940's due to the emergence of RADAR, is considered infeasible by many experts in the field due to the lack of independent surveillance sources and communication challenges in the oceanic realm. Furthermore, it is a conversion that goes in the opposite direction from the vision described by both US and European air traffic management systems that advocate trajectory-based operations as a foundational tool.

Reich models may still be applied effectively for calculation of the distance required between oceanic tracks to ensure an acceptable probability of collision between aircraft operating on parallel tracks. In this application, the use of an RNP performance metric fills a gap Reich considered intractable, that being the quantification of positional error via an evidence-based probabilistic distribution. Models developed by Campos and Marques appear to be at the leading edge of such developments. The power of an RTP metric is that it provides a similar quantification of crossing time errors in the longitudinal axis and allows for collision risk assessments that unlock reductions in separation standards that are unlikely to be achieved with distance-based standards alone.

## 6.2. Dual Time of Arrival Control Standards

A number of proposals have been presented to RTCA and Eurocontrol regarding standards for time of arrival control. One such proposal involves setting dual standards for certification of flight management systems. While the initial proposals are flawed in terms of their logic and are based on little more than intuition and round numbers, the idea of a dual standard itself might be worthy of consideration.

The initial proposal for a dual standard suggests that an aircraft assigned a required time of arrival in the descent phase, intuitively associated with aircraft arriving at airports for landing, must be capable of arriving within ±10 seconds with a 95% accuracy. Aircraft executing a required time of arrival in level cruise flight, where the density of traffic is expected to be lower, would be required to arrive within ±30 seconds with a 95% accuracy. The flaw in this proposal is that the modeling of the descent phase is far more complex and subject to more restrictive constraints. It is an easy case to make that if an aircraft is able to demonstrate crossings within 10 seconds of the assigned time in descent, it can easily achieve this same level of performance in level flight. It is this logic, supported by the data collected during recent testing, that has led to the development of a single performance metric in this research. However, it seems possible that far greater accuracy could be achieved in level flight for two reasons. First, the environment itself is far less dynamic, with relatively constant environmental variables that require only small airspeed changes to overcome differences between expected and actual conditions. Second, level cruise flight is typically flown with jet engines operating at relatively high rpm where changes in thrust associated with small throttle movements are significant and sufficient to effect speed changes necessary to keep a continuously updated estimated arrival time equal to that of the assigned arrival time. Today's flight management systems do not seem to distinguish between the level and descending environment, and appear to apply the same error tolerance thresholds before attempting to make corrections for errors. If this is the case, the time error tolerance in level flight may be adjustable to a level that allows time-based performance that significantly exceeds any demonstrated capability to date, allowing for tighter intervals between sequential aircraft. The lack of superior demonstrated performance in level flight is not unexpected as there has yet to be motivation for industry to provide more accurate time-based performance in level flight. Further, all indications from regulatory agencies to date have proposed standards indicating a lower level of performance will be expected in level flight.

## 6.3. Accuracy in Descending Flight

Most of the time of arrival control testing has been focused on the arrival phase of flight, and as described in the previous section, the design of the flight management systems and the dynamic nature of the environment suggest that the arrival phase is the limiting case with regard to the accuracy with which assigned crossing times may be captured. It should be expected that manufacturers of flight management systems design their algorithms to the specification of their customers, the aircraft manufacturers and operators. It is clear that the objective of each system is to optimize the flight profile of the individual aircraft by minimizing the total fuel burned during any phase of flight. In the descent phase, this leads designers to produce algorithms that calculate a descent point at which the throttles can be set at or near idle thrust and speed maintained by trading potential energy associated with the aircraft altitude for kinetic energy in the descent. However, what is optimum for a single aircraft may not be optimum for the airspace system, and a prisoner's dilemma may exist regarding algorithm design.

There are important limitations on the design of flight procedures in the arrival phase. There are many variants of commercial aircraft, each with unique aerodynamic properties, and as a result, the optimum descent airspeed for each aircraft may be different. When a comparatively slow aircraft precedes a faster aircraft, one of the two is forced to fly at a sub-optimum speed or to accept vectors from air traffic controllers to achieve required spacing. Another important concept is that jet engines operating at idle thrust are unresponsive to small throttle movements, making precise speed control virtually impossible if a three-dimensional flight profile is prescribed. These two constraints pose substantial challenges for airspace designers and air traffic managers.

If these limitations could be overcome, it would be possible to achieve far greater accuracy in terms of time of arrival control. One method by which this could be possible is for aircraft to fly descents at higher power settings. This would necessarily involve beginning the descent further from the destination, but by requiring this type of descent profile, aircraft would descend with engines operating at a higher power setting, allowing for the possibility of making speed changes to overcome the uncertainties associated with descending flight. This method of approach is not without precedent. In what is arguably the most precise time-based flight environment in the world, carrier based jets operated by the US Navy fly power on approaches so that the engines are operated at a power setting that allows precise control over important parameters of their approach. Future research may find that the benefits of avoiding vectors for spacing and speed constraints associated with dissimilar sequential arrivals, as well as the ability to avoid delays at peak periods due to the increased capacity associated with improved RTP values may outweigh the marginal cost of introducing power on approaches.

## 6.4. Refining the Time-Based Collision Risk Model

Since the introduction of Reich's distance-based collision risk model in 1966, numerous enhancements and updates have been published to support changes in airspace design, such as the reduction in distance between oceanic tracks in the North Atlantic region in 1981 (ICAO, 1998). Similarly, it is expected that enhancements to the initial time-based models presented in this document may be enhanced to account for vertical encounters such as sequencing a high, fast aircraft that is further away from a crossing point than a lower, slower aircraft, but has an earlier ETA. The exclusion of these scenarios from the initial collision risk models could lead to questions regarding the operational applicability of this research. By enhancing the collision risk models to account for the vertical geometry, confidence in the results may be increased sufficiently to allow the introduction of time-based operational procedures into the airspace system. Alternatively, recommendations for modifications to the existing airspace system itself such that these geometries do not arise by design might prove to be more palatable for regulatory authorities.

## 6.5. Revising the logic driving FMS algorithms

The exact nature of the logic driving today's FMS algorithms is unknown as these models are proprietary in a highly competitive industry. However, general descriptions of the function of the algorithms by industry representatives indicates that the logic is based on a process whereby the FMS calculates the speed at which it must fly to achieve a desired crossing time. Adjustments to engine thrust are not made until the difference between calculated ground speed and required ground speed reaches some pre-determined threshold value. As a result, a small speed discrepancy, if it persists over a large period of time, could lead to large cumulative crossing time errors over long duration flights. As an alternative, since it is known that the FMS calculates and frequently updates an ETA at the RTA fix, the logic of the correction scheme could be adjusted to take advantage of this information. Rather than adjusting engine thrust as a result of a speed discrepancy, the algorithm could be updated to adjust engine thrust to modify speed when a time discrepancy is reached, and a time-based threshold could be applied. By applying this type of logic, the aircraft would be capable of overcoming any uncertain environmental condition encountered in flight, so long as the speed correction required remained within the operational speed envelope of the aircraft. If the general understanding of the FMS design is correctly understood, this change would allow substantial benefit in terms of air traffic management, especially if data communication capabilities could provide air traffic managers not only with an ETA a various fixes, but also with a minimum and maximum achievable time at those fixes. If this information could be made available, air traffic managers could influence automated crossing time assignments such that aircraft are scheduled to arrive near the mid-point between their minimum and maximum arrival times, providing maximum flexibility to the aircraft for overcoming environmental uncertainty, and leading to improved crossing time accuracy.

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# APPENDICES

## APPENDIX A: Olympia Eight Arrival

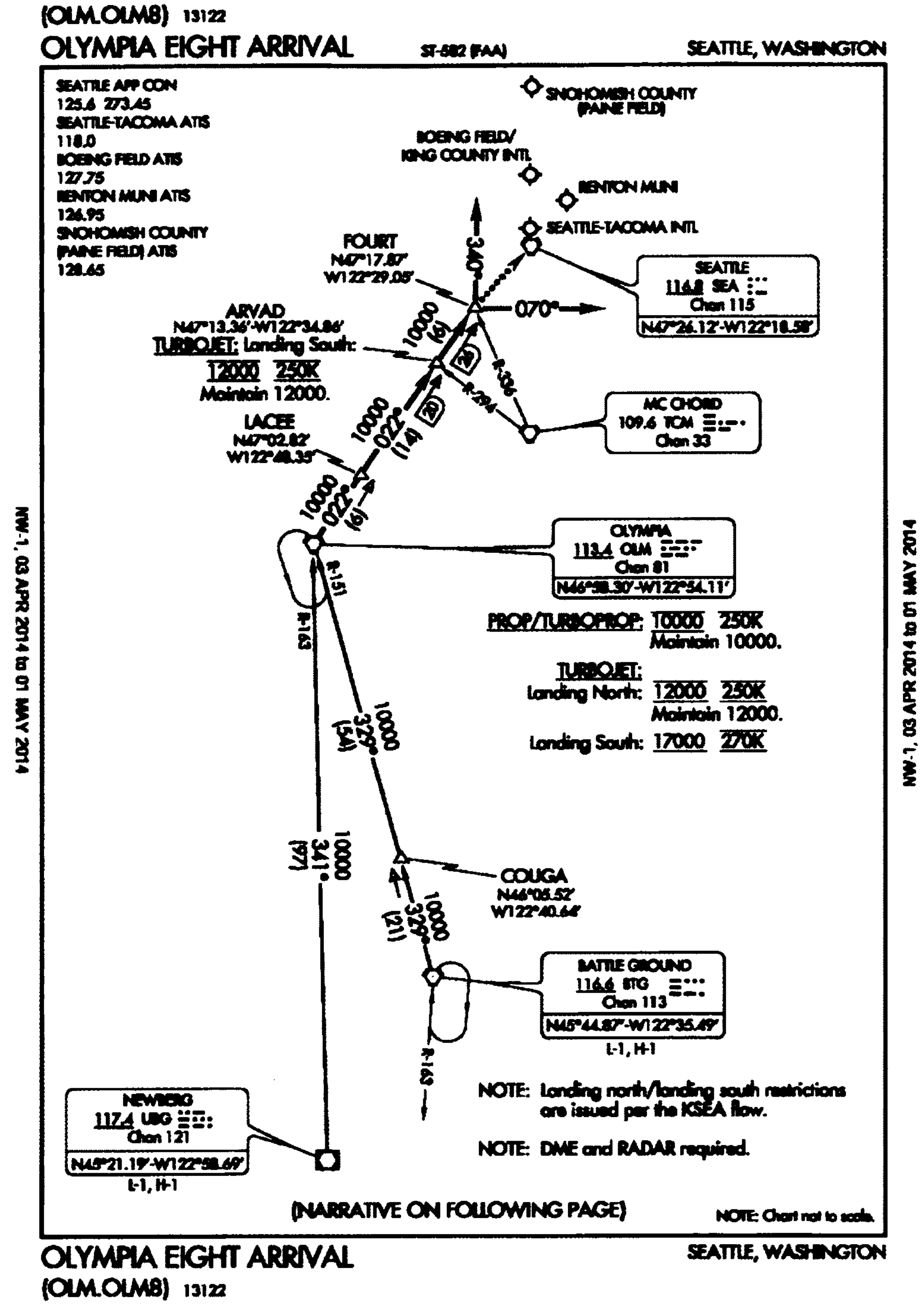

Figure 25: Standard Terminal Arrival to Seattle-Tacoma International Airport
(Not For Navigational Use: AirNav.com, 2013, reprinted by permission of AirNav.com)

# APPENDIX B: 2010 FAA Flight Trial Results

| Event | RTA Event | AC Type | TET | CI | TMA STA | Assigned | Time of Assign | Crossing | Error |
|---|---|---|---|---|---|---|---|---|---|
| 1 | RTA7 | B737 | 20 | 45 | 21:26 | 21:26 | 20:54:15 | 21:25:45 | -15 |
| 2 | RTA12 | B737 | 20 | 15 | 19:21 | 19:21 | 18:55:00 | 19:21:07 | 7 |
| 3 | RTA13 | B737 | 20 | 15 | 20:08 | 20:08 | 19:36:35 | 20:07:55 | -5 |
| 4 | RTA15 | B737 | 20 | 15 | 20:13 | 20:13 | 19:42:12 | 20:13:12 | 12 |
| 5 | RTA16 | B737 | 20 | 45 | 20:15 | 20:15 | 19:45:47 | 20:14:48 | -12 |
| 6 | RTA17 | B737 | 20 | 15 | 21:19 | 21:19 | 20:47:12 | 21:19:04 | 4 |
| 7 | RTA18 | B737 | 20 | 15 | 21:38 | 21:38 | 21:09:43 | 21:37:53 | -7 |
| 8 | RTA19 | B737 | 20 | 15 | 21:58 | 21:58 | 21:27:30 | 21:57:46 | -14 |
| 9 | RTA22 | B737 | 20 | 15 | 23:13 | 23:13 | 22:39:59 | 23:13:09 | 9 |
| 10 | RTA34 | B737 | 20 | 15 | 18:56 | 18:56 |  | 18:55:50 | -10 |
| 11 | RTA35 | B737 | 20 | 15 | 19:30 | 19:30 | 19:03:50 | 19:29:47 | -13 |
| 12 | RTA36 | B737 | 20 | 15 | 19:33 | 19:33 | 19:05:50 | 19:32:45 | -15 |
| 13 | RTA39 | B737 | 20 | 15 | 21:18 | 21:18 | 20:54:00 | 21:17:49 | -11 |
| 14 | RTA41 | B737 | 20 | 15 | 22:30 | 22:30 | 22:04:30 | 22:29:54 | -6 |
| 15 | RTA42 | B737 | 20 | 15 | 23:28 | 23:28 | 23:04:00 | 23:27:44 | -16 |
| 16 | RTA43 | B737 | 20 | 15 | 22:59 | 22:59 | 22:39:00 | 22:58:59 | -1 |
| 17 | RTA44 | B737 | 20 | 45 | 19:05 | 19:05 | 18:36:00 | 19:05:11 | 11 |
| 18 | RTA45 | B737 | 20 | 15 | 19:38 | 19:38 | 19:15:00 | 19:38:05 | 5 |
| 19 | RTA47 | B737 | 20 | 15 | 20:01 | 20:01 | 19:30:00 | 20:01:06 | 6 |
| 20 | RTA49 | B737 | 20 | 15 | 20:54 | 20:54 | 20:24:25 | 20:54:12 | 12 |
| 21 | RTA53 | B737 | 20 | 15 | 23:10 | 23:10 | 22:38:39 | 23:09:53 | -7 |
| 22 | RTA55 | B737 | 20 | 15 | 19:08 | 19:08 | 18:38:00 | 19:07:53 | -7 |
| 23 | RTA57 | B737 | 20 | 15 | 19:59 | 19:59 | 19:31:00 | 19:58:54 | -6 |
| 24 | RTA58 | B737 | 20 | 15 | 21:01 | 21:01 | 20:36:00 | 21:01:16 | 16 |
| 25 | RTA60 | B737 | 20 | 15 | 22:20 | 22:20 | 21:50:20 | 22:19:48 | -12 |
| 26 | RTA62 | B737 | 20 | 15 | 22:36 | 22:36 | 22:14:45 | 22:35:50 | -10 |
| 27 | RTA65 | B737 | 20 | 45 | 19:23 | 19:23 | 18:50:47 | 19:22:53 | -7 |
| 28 | RTA66 | B737 | 20 | 45 | 20:00 | 20:00 | 19:28:50 | 19:59:43 | -17 |
| 29 | RTA67 | B737 | 20 | 45 | 19:56 | 19:56 | 19:25:36 | 19:55:49 | -11 |
| 30 | RTA68 | B737 | 20 | 45 | 20:13 | 20:13 | 19:43:15 | 20:12:52 | -8 |
| 31 | RTA69 | B737 | 20 | 45 | 21:17 | 21:17 | 20:43:30 | 21:16:47 | -13 |
| 32 | RTA70 | B737 | 20 | 15 | 22:01 | 22:01 | 21:26:30 | 22:00:58 | -2 |
| 33 | RTA71 | B737 | 20 | 15 | 21:31 | 21:31 | 20:56:19 | 21:30:43 | -17 |
| 34 | RTA72 | B737 | 20 | 45 | 21:52 | 21:52 | 21:19:23 | 21:52:10 | 10 |
| 35 | RTA73 | B737 | 20 | 15 | 23:19 | 23:19 | 22:49:20 | 23:19:04 | 4 |
| 36 | RTA46 | B737 | 20 | 15 | 19:34 | 19:34 | 19:06:00 | 19:34:06 | 6 |
| 37 | RTA37 | B737 | 20 | 15 | 20:00 | 20:00 | 19:35:00 | 19:59:38 | -22 |
| 38 | RTA40 | B737 | 20 | 15 | 21:20 | 21:20 | 20:55:00 | 21:19:29 | -31 |
| 39 | RTA56 | B737 | 20 | 15 | 20:01 | 20:01 | 19:34:00 | 20:00:21 | -39 |

# APPENDIX C: 2011 FAA Simulation Results

| Flt | ACID | Type | CI | Meter | TMA Analysis | | | TMA | Δt | FMS | FMS Analysis | | | RTA | | Cross Fix - | | Cross Fix - | | Cross Fix - | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | ETA | Δt | STA | ETA | | ETA | First | ETA | Last | Time | Assn | Time | Δt | Alt | ΔAlt | Speed | ΔSpd | |
| s1d1r1f1 | ASA 487 | B737 | 15 | NO | 0:33:27 | 00:01 | 0:33:26 | 0:33:27 | 00:25 | 0:33:02 | 0:30:50 | 0:33:02 | 0:33:23 | 0:10:40 | 0:33:00 | 0:32:58 | -2 | 17,544 | 544 | 270 | 0 | |
| s1d1r1f2 | ASA 313 | B738 | 15 | NO | 0:30:53 | 00:04 | 0:30:57 | 0:30:53 | 00:07 | 0:31:00 | 0:29:31 | 0:31:00 | 0:30:41 | | 0:31:00 | 0:31:02 | 2 | 17,500 | 500 | 275 | 5 | |
| s1d1r1f3 | ASA 507 | B737 | 15 | NO | 0:29:25 | 00:12 | 0:29:13 | 0:29:25 | 00:15 | 0:29:10 | 0:27:46 | 0:29:10 | 0:29:33 | 0:07:31 | 0:29:00 | 0:29:04 | 4 | 17,493 | 493 | 270 | 0 | |
| s1d1r2f1 | ASA 457 | B737 | 15 | NO | 0:33:36 | 00:02 | 0:33:34 | 0:33:36 | 02:28 | 0:36:04 | 0:33:50 | 0:36:04 | 0:38:44 | 0:05:17 | 0:34:00 | 0:34:38 | 38 | 18,519 | 1519 | 287 | 17 | |
| s1d1r2f2 | ASA 363 | B738 | 15 | NO | 0:38:48 | 00:05 | 0:38:53 | 0:38:48 | 01:12 | 0:40:00 | 0:37:33 | 0:40:00 | 0:41:34 | 0:09:08 | 0:39:00 | 0:39:03 | 3 | 18,653 | 1653 | 270 | 0 | |
| s1d1r2f3 | ASA 531 | B737 | 15 | NO | 0:38:02 | 00:06 | 0:38:08 | 0:38:02 | 00:09 | 0:37:53 | 0:35:48 | 0:37:53 | 0:40:13 | 0:08:55 | 0:37:00 | 0:37:03 | 3 | 18,469 | 1469 | 297 | 27 | |
| s1d1r3f1 | ASA 345 | B737 | 15 | NO | 0:31:44 | 00:11 | 0:31:55 | 0:31:44 | 00:19 | 0:31:25 | 0:29:10 | 0:31:25 | 0:32:22 | 0:10:18 | 0:32:00 | 0:32:15 | 15 | 17,591 | 591 | 273 | 3 | |
| s1d1r3f2 | ASA 611 | B738 | 15 | NO | 0:28:44 | 00:01 | 0:28:45 | 0:28:44 | 00:05 | 0:28:39 | 0:27:16 | 0:28:39 | 0:28:39 | 0:08:40 | 0:28:00 | 0:28:12 | 12 | 17,662 | 662 | 274 | 4 | |
| s1d1r3f3 | ASA 465 | B737 | 15 | NO | 0:28:04 | 00:13 | 0:28:17 | 0:28:04 | 00:22 | 0:27:42 | 0:25:33 | 0:27:42 | 0:28:53 | 0:05:16 | 0:27:00 | 0:27:04 | 4 | 17,496 | 496 | 284 | 14 | |
| s1d1r4f1 | ASA 487 | B737 | 15 | NO | 0:40:21 | 00:14 | 0:40:35 | 0:40:21 | 00:05 | 0:40:26 | 0:40:26 | 0:40:26 | 0:45:03 | 0:12:24 | 0:41:00 | 0:41:07 | 7 | 18,515 | 1515 | 282 | 12 | |
| s1d1r4f2 | ASA 313 | B738 | 15 | NO | 0:39:37 | 00:04 | 0:39:41 | 0:39:37 | 02:45 | 0:36:52 | 0:36:43 | 0:36:52 | 0:39:10 | 0:03:03 | 0:39:00 | 0:39:02 | 2 | 18,687 | 1687 | 278 | 8 | |
| s1d1r4f3 | ASA 507 | B737 | 15 | NO | 0:36:55 | 00:07 | 0:37:02 | 0:36:55 | 00:12 | 0:37:07 | 0:35:21 | 0:37:07 | 0:39:11 | 0:06:35 | 0:37:00 | 0:36:58 | -2 | 18,449 | 1449 | 278 | 8 | |
| s1d2r1f1 | ASA 457 | B737 | 15 | NO | 0:34:05 | 00:00 | 0:34:05 | 0:34:05 | 02:55 | 0:37:00 | 0:34:23 | 0:37:00 | 0:39:20 | 0:05:49 | 0:35:00 | 0:35:01 | 1 | 12,015 | 15 | 253 | 3 | |
| s1d2r1f2 | ASA 363 | B738 | 15 | NO | 0:39:02 | 00:05 | 0:38:57 | 0:39:02 | 02:27 | 0:41:29 | 0:38:40 | 0:41:29 | 0:42:53 | 0:11:25 | 0:39:00 | 0:39:04 | 4 | 12,015 | 15 | 252 | 2 | |
| s1d2r1f3 | ASA 531 | B737 | 15 | NO | 0:38:43 | 00:52 | 0:37:51 | 0:38:43 | 00:23 | 0:39:06 | 0:36:27 | 0:39:06 | 0:41:28 | 0:07:59 | 0:38:00 | 0:37:57 | -3 | 12,016 | 16 | 253 | 3 | |
| s1d2r2f1 | ASA 345 | B737 | 15 | NO | 0:30:51 | 00:00 | 0:30:51 | 0:30:51 | 01:04 | 0:31:55 | 0:29:38 | 0:31:55 | 0:32:57 | 0:09:36 | 0:31:00 | 0:31:07 | 7 | 12,016 | 16 | 253 | 3 | |
| s1d2r2f2 | ASA 611 | B738 | 15 | NO | 0:29:02 | 00:04 | 0:29:06 | 0:29:02 | 00:32 | 0:29:34 | 0:28:00 | 0:29:34 | 0:29:34 | 0:08:19 | 0:29:00 | 0:29:06 | 6 | 12,926 | 926 | 248 | -2 | ATC Alt Restrict |
| s1d2r2f3 | ASA 465 | B737 | 15 | NO | 0:28:14 | 00:01 | 0:28:15 | 0:28:14 | 00:09 | 0:28:23 | 0:26:06 | 0:28:23 | 0:29:25 | 0:05:58 | 0:28:00 | 0:28:06 | 6 | 12,017 | 17 | 253 | 3 | |
| s1d2r3f1 | ASA 487 | B737 | 15 | NO | 0:41:25 | 00:08 | 0:41:17 | 0:41:25 | 00:29 | 0:41:54 | 0:39:20 | 0:41:54 | 0:44:05 | 0:11:45 | 0:42:00 | 0:41:53 | -7 | 12,016 | 16 | 253 | 3 | |
| s1d2r3f2 | ASA 313 | B738 | 15 | NO | 0:38:32 | 00:02 | 0:38:30 | 0:38:32 | 00:57 | 0:39:29 | 0:37:28 | 0:39:29 | 0:39:59 | 0:09:44 | 0:39:00 | 0:38:50 | -10 | 12,015 | 15 | 253 | 3 | |
| s1d2r3f3 | ASA 507 | B737 | 15 | NO | 0:37:19 | 00:26 | 0:36:53 | 0:37:19 | 00:08 | 0:37:27 | 0:34:26 | 0:37:27 | 0:37:40 | 0:11:17 | 0:37:00 | 0:37:00 | 0 | 12,016 | 16 | 253 | 3 | |
| s1d2r4f1 | ASA 457 | B737 | 15 | NO | 0:27:39 | 00:05 | 0:27:34 | 0:27:39 | 01:16 | 0:28:55 | 0:26:39 | 0:28:55 | 0:29:44 | 0:06:39 | 0:28:00 | 0:29:25 | 85 | 12,012 | 12 | 250 | 0 | **RTA Cancelled** |
| s1d2r4f2 | ASA 363 | B738 | 15 | NO | 0:31:24 | 00:39 | 0:32:03 | 0:31:24 | 00:22 | 0:31:46 | 0:30:00 | 0:31:46 | 0:31:46 | 0:15:02 | 0:33:00 | 0:33:06 | 6 | 12,016 | 16 | 253 | 3 | *Vector to RTA* |
| s1d2r4f3 | ASA 531 | B737 | 15 | NO | 0:30:30 | 00:05 | 0:30:25 | 0:30:30 | 00:19 | 0:30:49 | 0:28:17 | 0:30:49 | 0:31:23 | 0:08:21 | 0:31:00 | 0:31:16 | 16 | 12,016 | 16 | 252 | 2 | |
| s1d2r5f1 | ASA 345 | B737 | 15 | NO | 0:31:51 | 00:07 | 0:31:58 | 0:31:51 | 00:07 | 0:31:58 | 0:29:06 | 0:31:58 | 0:33:26 | 0:07:57 | 0:32:00 | 0:32:09 | 9 | 11,945 | -55 | 252 | 2 | |
| s1d2r5f2 | ASA 611 | B738 | 15 | NO | 0:28:59 | 00:03 | 0:29:02 | 0:28:59 | 00:27 | 0:29:26 | 0:27:42 | 0:29:26 | 0:29:26 | 0:07:22 | 0:29:00 | 0:29:08 | 8 | 11,953 | -47 | 253 | 3 | |
| s1d2r5f3 | ASA 465 | B737 | 15 | NO | 0:28:14 | 00:00 | 0:28:14 | 0:28:14 | 00:10 | 0:28:24 | 0:25:59 | 0:28:24 | 0:29:33 | 0:04:36 | 0:28:00 | 0:28:05 | 5 | 11,929 | -71 | 252 | 2 | |
| s1d3r1f1 | ASA 487 | B737 | 15 | NO | 0:41:19 | 00:03 | 0:41:16 | 0:41:19 | 00:09 | 0:41:10 | 0:38:45 | 0:41:10 | 0:44:08 | 0:07:36 | 0:41:00 | 0:40:57 | -3 | 18,517 | 1517 | 278 | 8 | |
| s1d3r1f2 | ASA 313 | B738 | 15 | NO | 0:39:36 | 00:04 | 0:39:40 | 0:39:36 | 00:11 | 0:39:25 | 0:37:12 | 0:39:25 | 0:39:32 | 0:06:39 | 0:39:00 | 0:39:00 | 0 | 18,684 | 1684 | 272 | 2 | |
| s1d3r1f3 | ASA 507 | B737 | 15 | NO | 0:37:07 | 00:01 | 0:37:06 | 0:37:07 | 00:39 | 0:36:28 | 0:34:29 | 0:36:28 | 0:37:56 | 0:05:28 | 0:37:00 | 0:37:11 | 11 | 18,531 | 1531 | 273 | 3 | |
| s1d3r1f4 | UAL 573 | A320 | 10 | NO | 0:42:35 | 00:00 | 0:42:35 | 0:42:35 | 00:43 | 0:43:18 | NA | 0:43:18 | NA | | 0:43:00 | 0:43:15 | 15 | 18,223 | 1223 | 261 | -9 | |
| s1d3r2f1 | ASA 457 | B737 | 15 | NO | 0:27:35 | 00:07 | 0:27:28 | 0:27:35 | 01:44 | 0:29:19 | 0:26:51 | 0:29:19 | 0:29:54 | 0:07:26 | 0:27:00 | 0:27:36 | 36 | 12,015 | 15 | 275 | 25 | |
| s1d3r2f2 | ASA 363 | B738 | 15 | NO | 0:31:00 | 01:04 | 0:32:04 | 0:31:00 | 00:53 | 0:31:53 | 0:29:46 | 0:31:53 | 0:32:20 | 0:08:48 | 0:31:00 | 0:31:10 | 10 | 12,023 | 23 | 252 | 2 | |
| s1d3r2f3 | ASA 531 | B737 | 15 | NO | 0:30:45 | 00:01 | 0:30:44 | 0:30:45 | 00:38 | 0:31:23 | 0:28:20 | 0:31:23 | 0:31:23 | 0:08:18 | 0:30:00 | 0:30:08 | 8 | 12,004 | 4 | 252 | 2 | |
| s1d3r2f4 | VRD 746 | A320 | 10 | NO | 0:33:20 | 00:10 | 0:33:10 | 0:33:20 | 02:16 | 0:35:36 | NA | 0:35:36 | NA | | 0:34:00 | 0:34:01 | 1 | 12,026 | 26 | 231 | -19 | |
| s1d3r3f1 | ASA 345 | B737 | 15 | NO | 0:38:57 | 00:01 | 0:38:56 | 0:38:57 | 01:22 | 0:40:19 | 0:37:32 | 0:40:19 | 0:45:01 | 0:07:37 | 0:39:00 | 0:39:06 | 6 | 18,516 | 1516 | 290 | 20 | |
| s1d3r3f2 | ASA 611 | B738 | 15 | NO | 0:36:10 | 00:01 | 0:36:11 | 0:36:10 | 00:13 | 0:35:57 | 0:34:17 | 0:35:57 | 0:36:21 | 0:08:11 | 0:36:00 | 0:36:01 | 1 | 18,671 | 1671 | 280 | 10 | |
| s1d3r3f3 | ASA 465 | B737 | 15 | NO | 0:34:47 | 00:05 | 0:34:42 | 0:34:47 | 00:13 | 0:35:00 | NA | 0:35:00 | NA | | 0:35:00 | 0:35:02 | 2 | 17,269 | 269 | 270 | 0 | **Manual RTA** |
| s1d3r3f4 | VRD 793 | A320 | 10 | NO | 0:42:59 | 00:05 | 0:43:04 | 0:42:59 | 01:30 | 0:44:29 | NA | 0:44:29 | NA | | 0:43:00 | 0:43:08 | 8 | 18,545 | 1545 | 270 | 0 | |
| s1d3r4f1 | ASA 507 | B737 | 15 | NO | 0:28:44 | 00:00 | 0:28:44 | 0:28:44 | 00:40 | 0:29:24 | 0:27:36 | 0:29:24 | 0:29:42 | 0:05:33 | 0:29:00 | 0:29:04 | 4 | 12,016 | 16 | 253 | 3 | |
| s1d3r4f2 | ASA 313 | B738 | 15 | NO | 0:30:07 | 00:08 | 0:30:15 | 0:30:07 | 00:45 | 0:30:52 | 0:29:04 | 0:30:52 | 0:30:52 | 0:06:13 | 0:30:00 | 0:30:10 | 10 | 12,016 | 16 | 253 | 3 | |
| s1d3r4f3 | UAL 573 | A320 | 10 | NO | 0:32:01 | 00:07 | 0:31:54 | 0:32:01 | 04:21 | 0:36:22 | NA | 0:36:22 | NA | | 0:34:00 | 0:34:14 | 14 | 11,999 | -1 | 250 | 0 | |
| s1d3r4f4 | SKW 6447 | E170 | NA | NO | 0:36:03 | 00:04 | 0:36:07 | 0:36:03 | 01:57 | 0:38:00 | NA | 0:38:00 | NA | | 0:39:00 | 0:48:00 | 540 | 11,991 | -9 | 250 | 0 | **Invalid Data** |
| s1d3r5f1 | ASA 457 | B737 | 30 | NO | 0:23:31 | 00:01 | 0:23:30 | 0:23:31 | 00:31 | 0:24:02 | 0:22:49 | 0:24:02 | 0:25:04 | 0:05:02 | 0:24:00 | 0:24:17 | 17 | 17,034 | 34 | 250 | -20 | |
| s1d3r5f2 | ASA 363 | B738 | 30 | NO | 0:30:22 | 00:02 | 0:30:20 | 0:30:22 | 00:24 | 0:29:58 | 0:28:14 | 0:29:58 | 0:30:48 | 0:06:51 | 0:30:00 | 0:30:03 | 3 | 17,688 | 688 | 277 | 7 | |
| s1d3r5f3 | VRD 746 | A320 | 10 | NO | 0:32:25 | 00:09 | 0:32:16 | 0:32:25 | 00:35 | 0:31:50 | NA | 0:31:50 | NA | | 0:35:00 | 0:35:05 | 5 | 17,022 | 22 | 270 | 0 | |
| s1d3r5f4 | SKW 6119 | E170 | NA | NO | 0:30:53 | 00:08 | 0:31:01 | 0:30:53 | 01:53 | 0:29:00 | NA | 0:29:00 | NA | | 0:33:00 | 0:38:00 | 300 | 18,342 | 1342 | 273 | 3 | **Invalid Data** |

| Flt | ACID | Type | CI | Meter | TMA Analysis |  |  | TMA | Δt | FMS | FMS Analysis |  |  | RTA |  | Cross Fix - |  | Cross Fix - |  | Cross Fix - |  | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  | ETA | Δt | STA | ETA |  | ETA | First | ETA | Last | Time | Assn | Time | Δt | Alt | ΔAlt | Speed | ΔSpd |  |
| s2d1r1f1 | ASA487 | B737 | 30 | NO | 0:39:50 | 01:00 | 0:40:50 | 0:39:50 | 00:58 | 0:38:52 | 0:38:52 | 0:38:52 | 0:44:22 | 0:07:11 | 0:41:00 | 0:40:36 | -24 | 12,016 | 16 | 281 | 31 |  |
| s2d1r1f2 | ASA 313 | B738 | 30 | NO | 0:38:28 | 00:19 | 0:38:47 | 0:38:28 | 00:25 | 0:38:03 | 0:37:30 | 0:38:03 | 0:39:57 | 0:11:08 | 0:39:00 | 0:38:57 | -3 | 12,016 | 16 | 254 | 4 |  |
| s2d1r1f3 | ASA 507 | B737 | 30 | NO | 0:36:12 |  | 0:36:25 | 0:36:12 | 00:23 | 0:36:35 | 0:34:49 | 0:36:35 | 0:38:11 | 0:10:05 | 0:36:00 | 0:36:06 | 6 | 12,016 | 16 | 253 | 3 |  |
| s2d1r1f4 | UAL 573 | A320 | 25 | NO | 0:41:14 | 01:54 | 0:43:08 | 0:41:14 | 01:30 | 0:42:44 | NA | 0:42:44 | NA |  | 0:43:00 | 0:42:45 | -15 | 11,989 | -11 | 250 | 0 |  |
| s2d1r2f1 | ASA 457 | B737 | 30 | NO | 0:27:14 | 00:11 | 0:27:25 | 0:27:14 | 02:12 | 0:29:26 | 0:26:35 | 0:29:26 | 0:29:36 | 0:02:12 | 0:27:00 | 0:27:17 | 17 | 17,497 | 497 | 264 | -6 |  |
| s2d1r2f2 | ASA 363 | B738 | 30 | NO | 0:30:20 | 03:45 | 0:34:05 | 0:30:20 | 00:08 | 0:30:12 | 0:29:16 | 0:30:12 | 0:31:16 | 0:10:45 | 0:34:00 | 0:34:02 | 2 | 20,059 | 3059 | 285 | 15 | *Vector to RTA* |
| s2d1r2f3 | ASA 531 | B737 | 30 | NO | 0:29:17 | 00:33 | 0:29:50 | 0:29:17 | 00:02 | 0:29:19 | 0:28:06 | 0:29:19 | 0:30:21 | 0:10:35 | 0:30:00 | 0:30:11 | 11 | 17,586 | 586 | 280 | 10 |  |
| s2d1r2f4 | SKW 6119 | E170 | ~ | NO | 0:29:50 | 02:04 | 0:31:54 | 0:29:50 | 01:10 | 0:31:00 | NA | 0:31:00 | NA | 24:46 | 0:32:00 | 0:33:13 | 73 | 18,696 | 1696 | 290 | 20 | **Speed/Vector** |
| s2d1r3f1 | ASA 465 | B737 | 45 | NO | 0:27:04 | 00:03 | 0:27:07 | 0:27:04 | 03:17 | 0:30:21 | 0:26:13 | 0:30:21 | 0:30:21 | 0:01:18 | 0:27:00 | 0:27:08 | 8 | 12,015 | 15 | 253 | 3 |  |
| s2d1r3f2 | ASA 611 | B738 | 45 | NO | 0:28:50 | 00:19 | 0:29:09 | 0:28:50 | 00:56 | 0:29:46 | 0:27:55 | 0:29:46 | 0:29:46 | 0:01:58 | 0:29:00 | 0:29:09 | 9 | 12,000 | 0 | 250 | 0 |  |
| s2d1r3f3 | VRD 793 | A320 | 45 | NO | 0:32:20 | 00:03 | 0:32:17 | 0:32:20 | 00:50 | 0:33:10 | NA | 0:33:10 | NA |  | 0:32:00 | 0:31:31 | -29 | 18,005 | 1005 | 255 | 5 | VNav Path Error |
| s2d1r3f4 | SKW 6229 | E170 | ~ | NO | 0:32:47 | 00:50 | 0:33:37 | 0:32:47 | 00:13 | 0:33:00 | NA | 0:33:00 | NA |  | 0:33:00 | 0:34:30 | 90 | 12,021 | 21 | 261 | 11 |  |
| s2d1r4f1 | ASA 457 | B737 | 45 | NO | 0:34:54 | 00:36 | 0:34:18 | 0:34:54 | 00:05 | 0:34:59 | 0:34:05 | 0:34:59 | 0:39:06 | 0:06:34 | 0:34:00 | 0:34:35 | 35 | 18,522 | 1522 | 274 | 4 |  |
| s2d1r4f2 | ASA 363 | B738 | 45 | NO | 0:37:24 | 00:04 | 0:37:20 | 0:37:24 | 00:16 | 0:37:08 | 0:36:59 | 0:37:08 | 0:41:21 | 0:05:36 | 0:38:00 | 0:38:12 | 12 | 18,669 | 1669 | 274 | 4 |  |
| s2d1r4f3 | ASA 531 | B737 | 45 | NO | 0:37:05 | 00:30 | 0:36:35 | 0:37:05 | 00:45 | 0:36:20 | 0:35:58 | 0:36:20 | 0:40:35 | 0:10:18 | 0:37:00 | 0:37:06 | 6 | 18,462 | 1462 | 280 | 10 |  |
| s2d1r4f4 | VRD 746 | A320 | 45 | NO | 0:42:02 | 00:30 | 0:41:32 | 0:42:02 | 05:04 | 0:36:58 | NA | 0:36:58 | NA |  | 0:44:00 | 0:44:51 | 51 | 15,890 | -1110 | 284 | 14 | VNav Path Error |
| s2d2r1f1 | ASA 345 | B737 | 15 | 1-3m | 0:44:40 | 03:14 | 0:47:54 | 0:44:40 | 00:24 | 0:44:16 | 0:43:57 | 0:44:16 | 0:48:08 | 0:23:53 | 0:48:00 | 0:47:59 | -1 | 17,610 | 610 | 270 | 0 |  |
| s2d2r1f2 | ASA 611 | B738 | 15 | 1-3m | 0:41:06 | 01:00 | 0:42:06 | 0:41:06 | 00:24 | 0:41:30 | 0:39:26 | 0:41:30 | 0:41:44 | 0:08:45 | 0:44:00 | 0:44:16 | 16 | 17,716 | 716 | 249 | -21 | *Vector to RTA* |
| s2d2r1f3 | ASA 465 | B737 | 15 | 1-3m | 0:41:33 | 02:10 | 0:43:43 | 0:41:33 | 00:12 | 0:41:21 | 0:38:10 | 0:41:21 | 0:43:39 | 0:10:35 | 0:42:00 | 0:42:12 | 12 | 17,578 | 578 | 256 | -14 | *Vector to RTA* |
| s2d2r1f4 | VRD 793 | A320 | 15 | 1-3m | 0:45:13 | 04:55 | 0:50:08 | 0:45:13 | 02:24 | 0:47:37 | NA | 0:47:37 | NA |  | 0:50:00 | 0:49:45 | -15 | 16,984 | -16 | 270 | 0 | *Vector to RTA* |
| s2d2r2f1 | ASA 507 | B737 | 15 | 1-3m | 0:53:31 | 04:31 | 0:58:02 | 0:53:31 | 01:07 | 0:54:38 | 0:52:07 | 0:54:38 | 0:57:07 | 0:25:42 | 0:58:00 | 0:57:58 | -2 | 12,014 | 14 | 253 | 3 | *Vector to RTA* |
| s2d2r2f2 | ASA 313 | B738 | 15 | 1-3m | 0:54:41 | 05:14 | 0:59:55 | 0:54:41 | 02:24 | 0:57:05 | 0:53:41 | 0:57:05 | 0:57:41 | 0:21:22 | 1:00:00 | 1:00:02 | 2 | 12,015 | 15 | 253 | 3 | *Vector to RTA* |
| s2d2r2f3 | UAL 573 | A320 | 15 | 1-3m | 0:57:41 | 04:12 | 1:01:53 | 0:57:41 | 04:06 | 1:01:47 | NA | 1:01:47 | NA |  | 1:02:00 | 1:01:40 | -20 | 11,989 | -11 | 250 | 0 |  |
| s2d2r2f4 | SKW 6447 | E170 | ~ | 1-3m | 0:58:35 | 05:29 | 1:04:04 | 0:58:35 | 00:25 | 0:59:00 | NA | 0:59:00 | NA |  | 1:04:00 | 1:05:00 | 60 | 12,053 | 53 | 243.6 | -6.4 |  |
| s2d2r3f1 | ASA 457 | B737 | 15 | 1-3m | 0:42:01 | 02:00 | 0:44:01 | 0:42:01 | 01:27 | 0:43:28 | 0:39:05 | 0:43:28 | 0:44:40 | 0:09:53 | 0:44:00 | 0:45:06 | 66 | 12,377 | 377 | 254 | 4 | **RTA Cancelled** |
| s2d2r3f2 | ASA 363 | B738 | 15 | 1-3m | 0:40:28 | 01:52 | 0:42:20 | 0:40:28 | 02:23 | 0:42:51 | 0:41:46 | 0:42:51 | 0:45:32 | 0:18:54 | 0:46:00 | 0:47:00 | 60 | 12,015 | 15 | 253 | 3 | **RTA Cancelled** |
| s2d2r3f3 | ASA 531 | B737 | 15 | 1-3m | 0:42:22 | 03:20 | 0:45:42 | 0:42:22 | 00:38 | 0:43:00 | NA | 0:43:00 | NA |  | 0:43:00 | 0:43:31 | 31 | 12,014 | 14 | 255 | 5 | ManRTA/Vector |
| s2d2r3f4 | VRD 746 | A320 | 15 | 1-3m | 0:45:02 | 02:21 | 0:47:23 | 0:45:02 | 03:42 | 0:48:44 | NA | 0:48:44 | NA |  | 0:49:00 | 0:49:30 | 30 | 12,000 | 0 | 250 | 0 | Vector by OLM |
| s2d2r4f1 | ASA 465 | B737 | 15 | 1-3m | 0:51 | 04:48 | 0:55:48 | 0:51:00 | 02:25 | 0:53:25 | 0:49:45 | 0:53:25 | 0:59:59 | 0:11:39 | 0:56:00 | 0:55:58 | -2 | 18,139 | 1139 | 269 | -1 |  |
| s2d2r4f2 | ASA 611 | B738 | 15 | 1-3m | 0:54:38 | 02:55 | 0:57:33 | 0:54:38 | 00:13 | 0:54:51 | 0:52:07 | 0:54:51 | 0:55:39 | 0:14:09 | 0:57:00 | 0:57:13 | 13 | 18,777 | 1777 | 277 | 7 | *Vector to RTA* |
| s2d2r4f3 | VRD 793 | A320 | 15 | 1-3m | 1:01:25 | 01:44 | 1:03:09 | 1:01:25 | 06:23 | 0:55:02 | NA | 0:55:02 | NA |  | 0:59:00 | 0:59:48 | 48 | 16,984 | -16 | 347 | 77 |  |
| s2d2r4f4 | SKW 6229 | E170 | ~ | 1-3m | 0:59:56 | 03:04 | 1:03 | 0:59:56 | 02:04 | 1:02:00 | NA | 1:02:00 | NA |  | 1:03:00 | 1:02:00 | -60 | 19,025 | 2025 | 270 | 0 |  |
| s2d3r1f1 | ASA 507 | B737 | 45 | 4-8m | 0:52:20 | 07:38 | 0:59:58 | 0:52:20 | 01:20 | 0:51:00 | 0:50:39 | 0:51:00 | 0:55:56 | 0:15:06 | 1:00:00 | 1:00:02 | 2 | 18,500 | 1500 | 253 | -17 | *Vector to RTA* |
| s2d3r1f2 | ASA 313 | B738 | 15 | 4-8m | 0:54:39 | 07:15 | 1:01:54 | 0:54:39 | 00:14 | 0:54:25 | 0:53:10 | 0:54:25 | 0:56:22 | 0:19:18 | 1:02:00 | 1:02:16 | 16 | 18,824 | 1824 | 273 | 3 | *Vector to RTA* |
| s2d3r1f3 | UAL 573 | A320 | 25 | 4-8m | 0:56:56 | 08:19 | 1:05:15 | 0:56:56 | 01:28 | 0:58:24 | NA | 0:58:24 | NA |  | 1:05:00 | 1:04:38 | -22 | 18,156 | 1156 | 266 | -4 |  |
| s2d3r1f4 | SKW 6447 | E170 | ~ | 4-8m | 0:43:06 | 05:16 | 0:48:22 | 0:43:06 | 03:06 | 0:40:00 | NA | 0:40:00 | NA |  | 0:48:00 | 0:48:15 | 15 | 18,718 | 1718 | 269 | -1 | *Vector to RTA* |
| s2d3r2f1 | ASA 457 | B737 | 15 | 4-8m | 0:41:36 | 04:38 | 0:46:14 | 0:41:36 | 00:45 | 0:42:21 | 0:39:15 | 0:42:21 | 0:44:06 | 0:13:00 | 0:46:00 | 0:46:25 | 25 | 12,013 | 13 | 249 | -1 | *Vector to RTA* |
| s2d3r2f2 | ASA 363 | B738 | 45 | 4-8m | 0:41:41 | 06:23 | 0:48:04 | 0:41:41 | 00:30 | 0:41:11 | 0:39:50 | 0:41:11 | 0:43:30 | 0:13:32 | 0:48:00 | 0:48:09 | 9 | 12,017 | 17 | 253 | 3 | *Vector to RTA* |
| s2d3r2f3 | VRD 746 | A320 | 45 | 4-8m | 0:43:42 | 08:02 | 0:51:44 | 0:43:42 | 01:35 | 0:45:17 | NA | 0:45:17 | NA |  | 0:52:00 | 0:52:34 | 34 | 12,157 | 157 | 250 | 0 | **RTA Cancelled** |
| s2d3r2f4 | SKW 6119 | E170 | ~ | 4-8m | 0:42:05 | 07:49 | 0:49:54 | 0:42:05 | 01:05 | 0:41:00 | NA | 0:41:00 | NA |  | 0:50:00 | 0:50:58 | 58 | 12,056 | 56 | 250 | 0 | *Vector to RTA* |
| s2d3r3f1 | ASA 345 | B737 | 15 | 4-8m | 0:54:52 | 06:08 | 1:01 | 0:54:52 | 03:47 | 0:58:39 | 0:54:19 | 0:58:39 | 1:05:38 | 0:15:10 | 1:01:00 | 1:00:13 | -47 | 12,017 | 17 | 224 | -26 |  |
| s2d3r3f2 | ASA 611 | B738 | 45 | 4-8m | 0:53:19 | 04:28 | 0:57:47 | 0:53:19 | 00:14 | 0:53:33 | 0:53:06 | 0:53:33 | 0:57:46 | 0:15:23 | 0:58:00 | 0:57:46 | -14 | 12,016 | 16 | 253 | 3 |  |
| s2d3r3f3 | ASA 465 | B737 | 45 | 4-8m | 0:49:15 | 06:42 | 0:55:57 | 0:49:15 | 02:24 | 0:51:39 | 0:50:11 | 0:51:39 | 1:01:35 | 0:10:45 | 0:56:00 | 0:55:33 | -27 | 12,012 | 12 | 239 | -11 |  |
| s2d3r3f4 | VRD 793 | A320 | 25 | 4-8m | 0:57:50 | 05:27 | 1:03:17 | 0:57:50 | 01:52 | 0:59:42 | NA | 0:59:42 | NA |  | 1:03:00 | 1:02:55 | -5 | 11,993 | -7 | 251 | 1 | **RTA Cancelled** |
| s2d3r4f1 | ASA 487 | B737 | 15 | 4-8m | 0:44:51 | 05:39 | 0:50:30 | 0:44:51 | 00:02 | 0:44:53 | 0:41:59 | 0:44:53 | 0:46:26 | 0:13:40 | 0:50:00 | 0:50:18 | 18 | 17,570 | 570 | 281 | 11 | *Vector to RTA* |
| s2d3r4f2 | ASA 313 | B738 | 15 | 4-8m | 0:41:40 | 06:34 | 0:48:14 | 0:41:40 | 00:15 | 0:41:55 | 0:40:00 | 0:41:55 | 0:42:11 | 0:12:47 | 0:48:00 | 0:48:15 | 15 | 17,754 | 754 | 277 | 7 | *Vector to RTA* |
| s2d3r4f3 | ASA 507 | B737 | 45 | 4-8m | 0:39:22 | 04:20 | 0:43:42 | 0:39:22 | 00:32 | 0:38:50 | 0:37:48 | 0:38:50 | 0:41:19 | 0:08:58 | 0:44:00 | 0:44:07 | 7 | 17,984 | 984 | 270 | 0 | *Vector to RTA* |
| s2d3r4f4 | UAL 573 | A320 | 10 | 4-8m | 0:44:40 | 08:06 | 0:52:46 | 0:44:40 | 01:33 | 0:46:13 | NA | 0:46:13 | NA |  | 0:53:00 | 0:52:57 | -3 | 17,200 | 200 | 270 | 0 | *Vector to RTA* |

# APPENDIX D: 2011 FAA Flight Trial Results

| ACID | Type | T E T | RTA Assignment | Cross Fix - Time | |
|---|---|---|---|---|---|
| | | | Time | Time | Δt |
| AS357 | B738 | 20 | 18:39:00 | 18:39:58 | 58 |
| AS601 | B739 | 20 | 21:37:00 | 21:37:06 | 6 |
| AS17 | B738 | 20 | 19:35:00 | 19:36:25 | NA |
| AS509 | B737 | 20 | 00:24:00 | 0:24:19 | 19 |
| AS469 | B739 | 20 | 19:04:00 | 19:04:24 | NA |
| AS503 | B734 | 20 | NaN | 22:12:11 | NA |
| AS303 | B738 | 20 | 19:53:00 | 19:53:04 | 4 |
| AS321 | B738 | 20 | 19:18:00 | 19:22:05 | NA |
| AS661 | B737 | 20 | 23:35:00 | 23:37:18 | NA |
| AS619 | B739 | 20 | 19:28:00 | 19:26:18 | NA |
| AS373 | B738 | 20 | 23:17:00 | 23:17:14 | 14 |
| AS679 | B737 | 20 | 21:32:00 | 21:31:26 | NA |
| AS21 | B739 | 20 | 18:25:00 | 18:24:43 | -17 |
| AS603 | B739 | 20 | 17:06:00 | 17:06:41 | NA |
| AS307 | B738 | 20 | 19:23:00 | 19:24:05 | NA |
| AS1 | B738 | 20 | 18:03:00 | 18:03:13 | 13 |
| AS493 | B737 | 20 | 17:35:38 | 17:45:09 | NA |
| AS517 | B737 | 20 | 18:32:00 | 18:31:53 | -7 |
| AS1 | B738 | 20 | 20:38:00 | 20:38:12 | 12 |
| AS679 | B739 | 20 | 22:33:54 | 22:33:05 | NA |
| AS515 | B737 | 20 | NaN | 17:57:08 | NA |
| AS357 | B738 | 20 | 18:42:00 | 18:42:17 | NA |
| AS503 | B737 | 20 | 22:27:57 | 22:21:32 | NA |
| AS527 | B737 | 20 | 18:28:00 | 18:27:55 | -5 |
| AS305 | B738 | 20 | 23:18:49 | 23:18:34 | -15 |
| AS509 | B737 | 20 | 00:20:00 | 0:20:09 | 9 |
| AS555 | B734 | 20 | 01:09:00 | 1:09:03 | 3 |
| AS539 | B734 | 20 | 17:23:00 | 17:23:05 | 5 |
| AS373 | B738 | 20 | 22:57:00 | 22:57:09 | 9 |
| AS365 | B738 | 20 | 19:53:00 | 19:53:06 | NA |
| AS227 | B738 | 20 | 19:20:00 | 19:19:36 | -24 |
| AS501 | B737 | 20 | 21:07:00 | 21:06:34 | NA |
| AS327 | B738 | 20 | 00:49:00 | 0:49:14 | 14 |
| AS461 | B738 | 20 | 00:27:00 | 0:26:58 | -2 |
| AS305 | B738 | 20 | 22:45:00 | 22:47:26 | NA |
| AS203 | B739 | 20 | 02:50:13 | 2:54:55 | NA |

| ACID | Type | T E T | RTA Assignment | Cross Fix - Time | |
|---|---|---|---|---|---|
| | | | Time | Time | Δt |
| AS517 | B737 | 20 | 18:24:13 | 18:25:06 | NA |
| AS461 | B738 | 20 | 23:24:02 | 23:23:15 | -47 |
| AS611 | B738 | 20 | 02:49:00 | 2:49:14 | 14 |
| AS531 | B737 | 20 | 03:47:00 | 3:46:41 | NA |
| AS307 | B738 | 20 | 19:06:00 | 19:07:28 | NA |
| AS755 | B739 | 20 | 04:15:00 | 4:15:13 | 13 |
| AS483 | B738 | 20 | 22:56:29 | 23:00:16 | NA |
| AS507 | B738 | 20 | 02:21:00 | 2:21:13 | 13 |
| AS313 | B738 | 20 | 02:35:00 | 2:35:09 | 9 |
| AS455 | B734 | 20 | 01:44:00 | 1:44:14 | 14 |
| AS661 | B737 | 20 | 23:42:00 | 23:43:30 | NA |
| AS673 | B737 | 20 | 02:57:08 | 2:57:17 | 9 |
| AS487 | B737 | 20 | NaN | 1:16:17 | NA |
| AS357 | B738 | 20 | 18:29:00 | 18:29:21 | 21 |
| AS529 | B737 | 20 | 21:33:00 | 21:33:36 | NA |
| AS679 | B737 | 20 | 21:14:00 | 21:16:13 | NA |
| AS743 | B738 | 20 | 04:05:14 | 4:05:38 | NA |
| AS373 | B738 | 20 | 22:58:00 | 22:58:18 | 18 |
| AS495 | B738 | 20 | 18:58:00 | 19:03:16 | NA |
| AS1 | B738 | 20 | 18:17:00 | 18:18:48 | NA |
| AS601 | B739 | 20 | 21:47:00 | 21:47:09 | 9 |
| AS23 | B738 | 20 | 01:40:00 | 1:40:26 | 26 |
| AS3 | B738 | 20 | 04:09:00 | 4:09:06 | 6 |
| AS509 | B737 | 20 | 00:04:00 | 0:09:05 | NA |
| AS355 | B737 | 20 | 03:23:00 | 3:23:16 | 16 |
| AS671 | B738 | 20 | 04:00:00 | 3:59:51 | -9 |
| AS345 | B737 | 20 | 03:32:00 | 3:32:42 | NA |
| AS39 | B738 | 20 | 03:57:17 | 3:57:35 | 18 |
| AS503 | B737 | 20 | 21:39:00 | 21:39:15 | 15 |
| AS3 | B738 | 20 | 03:54:00 | 3:54:06 | 6 |
| AS461 | B739 | 20 | 23:38:00 | 23:37:57 | -3 |
| AS555 | B734 | 20 | 01:00:00 | 1:00:20 | 20 |
| AS373 | B738 | 20 | 22:50:31 | 22:51:51 | NA |
| AS305 | B738 | 20 | 22:34:56 | 22:37:26 | NA |
| AS511 | B737 | 20 | 04:13:00 | 4:12:47 | -13 |
| AS527 | B737 | 20 | 18:13:57 | 18:14:09 | 12 |

| ACID | Type | T E T | RTA Assignment | Cross Fix - Time | |
|---|---|---|---|---|---|
| | | | Time | Time | Δt |
| AS603 | B738 | 20 | 17:13:00 | 17:13:35 | NA |
| AS611 | B738 | 20 | 02:29:02 | 2:29:14 | 12 |
| AS17 | B738 | 20 | 19:30:00 | 19:30:17 | 17 |
| AS743 | B738 | 20 | 03:49:00 | 3:48:49 | -11 |
| AS345 | B737 | 20 | 03:19:00 | 3:19:20 | 20 |
| AS233 | B738 | 20 | 03:23:25 | 3:24:41 | NA |
| AS661 | B737 | 20 | 00:05:00 | 0:05:08 | 8 |
| AS493 | B737 | 20 | 17:10:00 | 17:10:13 | 13 |
| AS313 | B734 | 20 | NaN | 2:41:11 | NA |
| AS619 | B739 | 20 | 19:31:00 | 19:31:03 | 3 |
| AS605 | B738 | 20 | NaN | 23:53:16 | NA |
| AS755 | B738 | 20 | 04:05:00 | 4:04:54 | -6 |
| AS483 | B738 | 20 | 23:03:00 | 23:03:05 | 5 |
| AS503 | B737 | 20 | 21:59:00 | 21:59:14 | 14 |
| AS327 | B738 | 20 | 00:44:00 | 0:44:46 | NA |
| AS487 | B734 | 20 | 01:13:41 | 1:14:05 | 24 |
| AS469 | B739 | 20 | 18:50:00 | 18:50:02 | 2 |
| AS227 | B738 | 20 | 19:07:25 | 19:07:26 | 1 |
| AS11 | B738 | 20 | 18:07:00 | 18:07:03 | 3 |
| AS671 | B739 | 20 | 03:54:41 | 3:54:38 | NA |
| AS601 | B739 | 20 | 21:45:00 | 21:45:03 | 3 |
| AS673 | B738 | 20 | 03:15:00 | 3:15:15 | 15 |
| AS533 | B734 | 20 | 20:57:00 | 20:57:14 | 14 |
| AS457 | B739 | 20 | 04:06:24 | 4:06:32 | 8 |
| AS23 | B739 | 20 | 01:42:00 | 1:42:15 | 15 |
| AS507 | B737 | 20 | 02:15:00 | 2:15:01 | 1 |
| AS1 | B738 | 20 | 18:01:00 | 18:01:03 | 3 |
| AS495 | B738 | 20 | 18:55:00 | 18:54:57 | -3 |
| AS679 | B737 | 20 | 22:19:00 | 22:19:01 | 1 |
| AS365 | B738 | 20 | 19:41:00 | 19:41:06 | 6 |
| AS307 | B734 | 20 | 18:59:00 | 18:59:03 | 3 |
| AS39 | B738 | 20 | 04:04:00 | 4:04:17 | 17 |
| AS553 | B734 | 20 | 03:06:00 | 3:06:08 | 8 |
| AS603 | B739 | 20 | 17:22:00 | 17:21:57 | -3 |
| AS307 | B738 | 20 | 19:06:00 | 19:06:02 | 2 |
| AS21 | B739 | 20 | 17:41:00 | 17:40:50 | -10 |
| AS743 | B738 | 20 | 03:45:00 | 3:45:12 | 12 |
| AS601 | B739 | 20 | 21:58:00 | 21:58:04 | 4 |
| AS1 | B738 | 20 | 17:46:00 | 17:45:56 | -4 |
| AS495 | B738 | 20 | 18:41:00 | 18:41:10 | 10 |

| ACID | Type | T E T | RTA Assignment | Cross Fix - Time | |
|---|---|---|---|---|---|
| | | | Time | Time | Δt |
| AS507 | B738 | 20 | 02:12:00 | 2:12:07 | 7 |
| AS455 | B734 | 20 | 01:48:00 | 1:48:16 | 16 |
| AS555 | B734 | 20 | 01:21:00 | 1:21:15 | 15 |
| AS327 | B738 | 20 | 00:45:00 | 0:45:18 | 18 |
| AS39 | B738 | 20 | 03:34:00 | 3:34:13 | 13 |
| AS313 | B738 | 20 | 02:31:32 | 2:31:55 | NA |
| AS461 | B739 | 20 | 23:36:00 | 23:36:13 | 13 |
| AS671 | B739 | 20 | 03:48:00 | 3:48:02 | 2 |
| AS321 | B738 | 20 | 19:03:00 | 19:04:33 | NA |
| AS661 | B737 | 20 | 00:26:00 | 0:26:02 | 2 |
| AS509 | B737 | 20 | 23:59:00 | 23:59:08 | 8 |
| AS373 | B738 | 20 | 22:50:00 | 22:50:08 | NA |
| AS19 | B738 | 20 | 04:34:00 | 4:34:19 | 19 |
| AS605 | B738 | 20 | 23:46:00 | 23:46:40 | NA |
| AS483 | B738 | 20 | 23:03:00 | 23:02:10 | NA |
| AS229 | B738 | 20 | 19:54:00 | 19:53:59 | -1 |
| AS619 | B739 | 20 | 19:21:13 | 19:21:20 | 7 |
| AS501 | B737 | 20 | 20:50:00 | 20:50:07 | 7 |
| AS305 | B734 | 20 | 22:48:00 | 22:48:01 | 1 |
| AS529 | B737 | 20 | 21:32:00 | 21:32:14 | 14 |
| AS355 | B738 | 20 | 03:32:00 | 3:32:48 | 48 |
| AS755 | B738 | 20 | 04:03:00 | 4:03:09 | 9 |
| AS517 | B737 | 20 | 18:33:00 | 18:37:34 | NA |
| AS503 | B738 | 20 | 21:46:00 | 21:46:37 | 37 |
| AS11 | B738 | 20 | 17:29:00 | 17:29:00 | 0 |
| AS23 | B739 | 20 | 01:27:00 | 1:27:13 | 13 |
| AS3 | B738 | 20 | 03:58:39 | 3:58:20 | NA |
| AS493 | B734 | 20 | 17:24:00 | 17:24:12 | 12 |
| AS469 | B739 | 20 | 18:54:00 | 18:53:47 | NA |
| AS611 | B738 | 20 | 02:29:00 | 2:28:28 | NA |
| AS455 | B738 | 20 | 01:25:01 | 1:25:08 | 7 |
| AS501 | B737 | 20 | 20:40:00 | 20:40:09 | 9 |
| AS603 | B738 | 20 | 17:19:00 | 17:18:55 | -5 |
| AS357 | B738 | 20 | 18:36:00 | 18:36:17 | 17 |
| AS679 | B739 | 20 | 21:12:00 | 21:11:50 | -10 |
| AS661 | B737 | 20 | 23:42:00 | 23:42:08 | 8 |
| AS305 | B738 | 20 | 22:27:00 | 22:26:54 | -6 |
| AS529 | B737 | 20 | 21:25:00 | 21:24:58 | -2 |
| AS307 | B738 | 20 | 18:54:00 | 18:54:05 | 5 |
| AS527 | B737 | 20 | 18:19:00 | 18:19:02 | 2 |

| ACID | Type | T E T | RTA Assignment | Cross Fix - Time | |
|---|---|---|---|---|---|
| | | | Time | Time | Δt |
| AS327 | B738 | 20 | 00:29:58 | 0:29:44 | -14 |
| AS743 | B738 | 20 | 03:57:00 | 3:55:18 | NA |
| AS555 | B734 | 20 | 00:43:00 | 0:42:56 | -4 |
| AS531 | B734 | 20 | 03:57:00 | 3:56:43 | NA |
| AS483 | B738 | 20 | 22:42:00 | 22:41:59 | -1 |
| AS671 | B739 | 20 | 03:38:00 | 3:38:11 | 11 |
| AS469 | B739 | 20 | 18:41:00 | 18:40:59 | -1 |
| AS461 | B738 | 20 | 23:26:00 | 23:25:56 | -4 |
| AS303 | B734 | 20 | 19:45:44 | 19:46:38 | NA |
| AS313 | B738 | 20 | 02:27:00 | 2:26:55 | -5 |
| AS601 | B739 | 20 | 21:57:00 | 21:56:54 | -6 |
| AS453 | B739 | 20 | 20:07:00 | 20:06:59 | -1 |
| AS517 | B737 | 20 | 18:14:00 | 18:13:59 | -1 |
| AS493 | B734 | 20 | 17:21:00 | 17:21:14 | 14 |
| AS605 | B738 | 20 | 23:36:00 | 23:36:08 | 8 |
| AS619 | B739 | 20 | 19:04:00 | 19:04:00 | 0 |
| AS461 | B734 | 20 | 23:10:00 | 23:10:05 | 5 |
| AS453 | B738 | 20 | 20:07:11 | 20:07:14 | 3 |
| AS373 | B738 | 20 | 22:36:00 | 22:36:05 | 5 |
| AS493 | B737 | 20 | 16:51:00 | 16:51:11 | 11 |
| AS601 | B739 | 20 | 21:36:00 | 21:36:03 | 3 |
| AS679 | B739 | 20 | 21:19:00 | 21:21:14 | NA |
| AS603 | B738 | 20 | 16:55:00 | 16:55:02 | 2 |
| AS611 | B738 | 20 | 02:30:00 | 2:30:09 | 9 |
| AS661 | B739 | 20 | 00:06:00 | 0:06:15 | 15 |
| AS509 | B737 | 20 | 23:43:00 | 23:43:24 | 24 |
| AS313 | B737 | 20 | 02:23:00 | 2:23:07 | 7 |
| AS11 | B738 | 20 | 17:40:00 | 17:40:14 | 14 |
| AS631 | B738 | 20 | 02:15:00 | 2:15:20 | 20 |
| AS227 | B738 | 20 | 18:55:00 | 18:55:08 | 8 |
| AS511 | B737 | 20 | 03:58:00 | 3:57:59 | -1 |
| AS345 | B737 | 20 | 03:11:00 | 3:12:07 | NA |
| AS515 | B734 | 20 | 17:31:00 | 17:30:53 | -7 |
| AS501 | B737 | 20 | 20:24:00 | 20:24:06 | 6 |
| AS671 | B739 | 20 | 03:42:03 | 3:42:21 | 18 |
| AS17 | B738 | 20 | 19:43:00 | 19:43:06 | 6 |
| AS555 | B734 | 20 | 00:44:00 | 0:44:00 | 0 |
| AS355 | B737 | 20 | 03:09:00 | 3:08:59 | -1 |
| AS303 | B738 | 20 | 19:43:00 | 19:42:48 | -12 |
| AS529 | B738 | 20 | 21:10:00 | 21:09:47 | -13 |

| ACID | Type | T E T | RTA Assignment | Cross Fix - Time | |
|---|---|---|---|---|---|
| | | | Time | Time | Δt |
| AS503 | B737 | 20 | 21:46:00 | 21:46:02 | 2 |
| AS233 | B738 | 20 | 03:16:00 | 3:16:10 | 10 |
| AS743 | B738 | 20 | 04:11:00 | 4:11:17 | 17 |
| AS307 | B734 | 20 | 19:07:00 | 19:07:10 | 10 |
| AS233 | B738 | 20 | 03:18:00 | 3:18:24 | 24 |
| AS303 | B734 | 20 | 20:46:25 | 20:46:36 | NA |
| AS685 | B739 | 20 | 17:31:19 | 17:33:18 | NA |
| AS509 | B737 | 20 | 23:44:00 | 23:44:05 | 5 |
| AS611 | B739 | 20 | 02:27:19 | 2:27:29 | 10 |
| AS501 | B737 | 20 | 20:24:00 | 20:24:20 | 20 |
| AS671 | B739 | 20 | 03:50:00 | 3:50:09 | 9 |
| AS603 | B738 | 20 | 16:52:00 | 16:52:15 | 15 |
| AS481 | B734 | 20 | 20:12:35 | 20:12:14 | NA |
| AS673 | B738 | 20 | 03:02:00 | 3:02:06 | 6 |
| AS529 | B738 | 20 | 21:16:00 | 21:16:18 | 18 |
| AS661 | B739 | 20 | 00:06:00 | 0:06:05 | 5 |
| AS487 | B737 | 20 | 01:09:00 | 1:09:22 | 22 |
| AS457 | B738 | 20 | 03:33:01 | 3:35:48 | NA |
| AS511 | B737 | 20 | 04:05:00 | 4:05:18 | 18 |
| AS555 | B734 | 20 | 00:48:00 | 0:48:13 | 13 |
| AS507 | B737 | 20 | 01:54:01 | 1:54:40 | 39 |
| AS455 | B738 | 20 | 01:37:00 | 1:37:28 | 28 |
| AS503 | B737 | 20 | 21:38:00 | 21:38:13 | 13 |
| AS495 | B738 | 20 | 18:36:00 | 18:36:06 | NA |
| AS527 | B737 | 20 | 17:55:00 | 17:55:09 | 9 |
| AS17 | B738 | 20 | 19:57:00 | 19:57:21 | 21 |
| AS517 | B737 | 20 | 18:07:09 | 18:07:06 | -3 |
| AS321 | B738 | 20 | 18:50:00 | 18:50:10 | 10 |
| AS23 | B739 | 20 | 02:00:16 | 1:59:20 | NA |
| AS307 | B734 | 20 | 18:48:00 | 18:48:20 | 20 |
| AS229 | B738 | 20 | 21:56:09 | 21:56:23 | 14 |
| AS453 | B738 | 20 | 20:26:00 | 20:26:08 | 8 |
| AS679 | B739 | 20 | 21:33:00 | 21:32:54 | -6 |
| AS493 | B734 | 20 | 17:06:00 | 17:06:10 | 10 |
| AS313 | B738 | 20 | 02:39:49 | 2:40:06 | 17 |
| AS605 | B738 | 20 | 23:51:00 | 23:51:08 | 8 |
| AS345 | B737 | 20 | 03:24:00 | 3:23:43 | NA |
| AS605 | B738 | 20 | 23:40:00 | 23:40:13 | 13 |
| AS461 | B734 | 20 | NaN | 23:21:08 | NA |
| AS457 | B734 | 20 | 03:37:00 | 3:38:21 | NA |

| ACID | Type | TET | RTA Assignment | Cross Fix - Time | |
|---|---|---|---|---|---|
| | | | Time | Time | Δt |
| AS455 | B734 | 20 | 01:34:00 | 1:34:18 | 18 |
| AS673 | B738 | 20 | 02:58:32 | 2:58:42 | 10 |
| AS357 | B738 | 20 | 18:29:00 | 18:29:02 | 2 |
| AS685 | B739 | 20 | 17:18:00 | 17:18:10 | 10 |
| AS515 | B737 | 20 | 17:37:00 | 17:37:04 | NA |
| AS531 | B734 | 20 | 03:35:00 | 3:36:33 | NA |
| AS365 | B738 | 20 | 19:53:00 | 19:52:58 | -2 |
| AS305 | B737 | 20 | 22:46:00 | 22:46:03 | 3 |
| AS679 | B739 | 20 | 21:32:00 | 21:31:55 | -5 |
| AS501 | B737 | 20 | 20:26:48 | 20:29:21 | NA |
| AS233 | B738 | 20 | 03:20:00 | 3:23:23 | NA |
| AS553 | B738 | 20 | 03:15:00 | 3:15:40 | NA |
| AS481 | B734 | 20 | 20:21:00 | 20:21:08 | 8 |
| AS487 | B737 | 20 | 00:57:00 | 0:56:54 | -6 |
| AS453 | B738 | 20 | 20:19:00 | 20:19:07 | 7 |
| AS17 | B738 | 20 | 19:30:17 | 19:30:29 | NA |
| AS529 | B737 | 20 | 21:22:23 | 21:22:22 | -1 |
| AS509 | B737 | 20 | 23:53:00 | 23:52:54 | -6 |
| AS1 | B738 | 20 | 18:30:00 | 18:27:31 | NA |
| AS555 | B734 | 20 | 00:54:00 | 0:54:45 | NA |
| AS633 | B739 | 20 | 00:51:00 | 0:51:11 | 11 |
| AS503 | B737 | 20 | 21:37:00 | 21:37:20 | 20 |
| AS611 | B738 | 20 | 02:41:00 | 2:41:17 | 17 |
| AS539 | B734 | 20 | 16:46:00 | 16:46:02 | 2 |
| AS469 | B737 | 20 | 18:36:00 | 18:39:46 | NA |
| AS517 | B737 | 20 | 18:21:00 | 18:21:15 | NA |
| AS661 | B738 | 20 | 23:49:00 | 23:49:00 | 0 |
| AS327 | B738 | 20 | NaN | 0:38:21 | NA |
| AS355 | B737 | 20 | 03:25:00 | 3:31:10 | NA |
| AS321 | B738 | 20 | 18:51:11 | 18:51:23 | 12 |
| AS487 | B738 | 20 | 00:59:00 | 0:59:05 | 5 |
| AS483 | B738 | 20 | 22:33:00 | 22:33:04 | 4 |
| AS17 | B738 | 20 | 19:53:00 | 19:53:03 | 3 |
| AS303 | B734 | 20 | 19:37:00 | 19:37:11 | 11 |
| AS679 | B738 | 20 | 21:39:00 | 21:39:30 | 30 |
| AS345 | B737 | 20 | NaN | 3:31:04 | NA |
| AS229 | B738 | 20 | 19:43:00 | 19:43:13 | 13 |
| AS493 | B738 | 20 | 17:05:00 | 17:05:11 | 11 |
| AS527 | B737 | 20 | 18:02:00 | 18:02:07 | 7 |
| AS373 | B738 | 20 | 22:39:09 | 22:39:16 | 7 |

| ACID | Type | TET | RTA Assignment | Cross Fix - Time | |
|---|---|---|---|---|---|
| | | | Time | Time | Δt |
| AS685 | B738 | 20 | 17:48:00 | 17:48:13 | 13 |
| AS619 | B739 | 20 | 19:08:00 | 19:08:14 | 14 |
| AS503 | B737 | 20 | 21:46:00 | 21:45:56 | -4 |
| AS673 | B738 | 20 | 02:45:00 | 2:45:19 | 19 |
| AS469 | B734 | 20 | 18:36:00 | 18:35:58 | -2 |
| AS495 | B738 | 20 | 18:28:00 | 18:28:12 | 12 |
| AS539 | B734 | 20 | 16:51:00 | 16:51:01 | 1 |
| AS501 | B737 | 20 | 20:35:00 | 20:34:48 | -12 |
| AS555 | B734 | 20 | 00:46:00 | 0:46:12 | 12 |
| AS533 | B737 | 20 | 20:08:09 | 20:07:38 | NA |
| AS327 | B738 | 20 | 00:29:00 | 0:28:59 | -1 |
| AS603 | B739 | 20 | 17:07:00 | 17:07:14 | 14 |
| AS23 | B739 | 20 | 01:30:00 | 1:30:10 | 10 |
| AS39 | B738 | 20 | 03:40:00 | 3:40:42 | NA |
| AS661 | B738 | 20 | 23:45:00 | 23:45:18 | 18 |
| AS511 | B737 | 20 | 04:03:00 | 4:03:00 | 0 |
| AS355 | B737 | 20 | 03:08:00 | 3:08:02 | 2 |
| AS531 | B734 | 20 | 03:37:00 | 3:37:09 | 9 |
| AS307 | B734 | 20 | 18:45:00 | 18:45:09 | 9 |
| AS605 | B738 | 20 | 23:31:00 | 23:30:59 | -1 |
| AS529 | B737 | 20 | 21:25:00 | 21:25:12 | 12 |
| AS461 | B738 | 20 | 23:23:00 | 23:23:09 | 9 |
| AS453 | B739 | 20 | 20:00:00 | 20:00:16 | 16 |
| AS507 | B738 | 20 | 01:57:00 | 1:57:03 | 3 |
| AS509 | B737 | 20 | 23:38:00 | 23:37:49 | -11 |
| AS305 | B737 | 20 | 22:35:00 | 22:34:48 | -12 |
| AS233 | B738 | 20 | 03:22:22 | 3:22:26 | 4 |
| AS1 | B738 | 20 | 18:21:00 | 18:20:56 | -4 |
| AS313 | B739 | 20 | 02:28:00 | 2:28:05 | NA |
| AS455 | B734 | 20 | 01:32:00 | 1:32:00 | 0 |
| AS601 | B739 | 20 | 21:19:08 | 21:19:16 | 8 |
| AS553 | B734 | 20 | 03:10:00 | 3:10:04 | 4 |
| AS527 | B737 | 20 | 17:55:00 | 17:55:05 | 5 |
| AS509 | B737 | 20 | 23:40:00 | 23:39:59 | -1 |
| AS357 | B738 | 20 | 18:26:00 | 18:26:02 | 2 |
| AS501 | B737 | 20 | 20:20:00 | 20:20:12 | 12 |
| AS515 | B737 | 20 | 17:25:00 | 17:25:14 | 14 |
| AS453 | B734 | 20 | 20:03:00 | 20:03:12 | 12 |
| AS345 | B737 | 20 | 03:24:00 | 3:24:25 | NA |
| AS619 | B739 | 20 | 18:58:00 | 18:58:12 | 12 |

| ACID | Type | T E T | RTA Assignment | Cross Fix - Time | |
|---|---|---|---|---|---|
| | | | Time | Time | Δt |
| AS601 | B739 | 20 | 21:36:00 | 21:36:18 | 18 |
| AS555 | B734 | 20 | 01:01:00 | 1:01:13 | 13 |
| AS233 | B738 | 20 | 03:12:22 | 3:12:26 | 4 |
| AS23 | B739 | 20 | 01:23:00 | 1:23:30 | 30 |
| AS685 | B739 | 20 | 17:36:00 | 17:36:10 | 10 |
| AS1 | B738 | 20 | 18:07:00 | 18:07:16 | 16 |
| AS611 | B738 | 20 | 02:17:00 | 2:17:04 | NA |
| AS11 | B738 | 20 | 18:23:01 | 18:23:17 | 16 |
| AS503 | B737 | 20 | 21:34:00 | 21:34:07 | 7 |
| AS227 | B738 | 20 | 19:04:00 | 19:04:13 | 13 |
| AS461 | B734 | 20 | 23:36:06 | 23:36:15 | 9 |
| AS517 | B737 | 20 | 18:00:00 | 18:00:09 | 9 |
| AS307 | B734 | 20 | 18:47:00 | 18:47:12 | 12 |
| AS3 | B738 | 20 | 04:00:00 | 4:00:05 | 5 |
| AS373 | B738 | 20 | 22:34:00 | 22:34:10 | 10 |
| AS305 | B737 | 20 | 22:22:00 | 22:22:04 | 4 |
| AS39 | B738 | 20 | 03:42:00 | 3:42:31 | 31 |
| AS671 | B739 | 20 | 03:51:00 | 3:51:01 | 1 |
| AS495 | B738 | 20 | 18:23:00 | 18:23:19 | 19 |
| AS605 | B738 | 20 | 23:31:00 | 23:31:12 | 12 |
| AS529 | B738 | 20 | 21:24:00 | 21:24:20 | 20 |
| AS755 | B738 | 20 | 03:53:00 | 3:53:07 | 7 |
| AS553 | B734 | 20 | 03:27:00 | 3:27:06 | 6 |
| AS507 | B738 | 20 | 01:55:00 | 1:55:48 | NA |
| AS493 | B734 | 20 | 16:49:00 | 16:49:05 | NA |
| AS603 | B738 | 20 | 16:52:00 | 16:52:01 | 1 |
| AS533 | B734 | 20 | 20:23:00 | 20:23:18 | 18 |
| AS743 | B738 | 20 | 03:49:00 | 3:49:26 | 26 |
| AS511 | B737 | 20 | 03:53:00 | 3:53:24 | 24 |
| AS365 | B738 | 20 | 19:37:00 | 19:37:20 | 20 |
| AS661 | B738 | 20 | 23:36:00 | 23:36:04 | 4 |
| AS17 | B738 | 20 | 19:21:00 | 19:21:12 | 12 |
| AS673 | B738 | 20 | 02:37:00 | 2:37:17 | 17 |
| AS487 | B737 | 20 | 00:55:00 | 0:55:06 | 6 |
| AS679 | B739 | 20 | 21:18:00 | 21:18:18 | 18 |
| AS17 | B738 | 20 | 19:27:00 | 19:26:58 | -2 |
| AS461 | B734 | 20 | 23:11:00 | 23:11:38 | 38 |
| AS469 | B737 | 20 | 18:33:00 | 18:33:20 | 20 |
| AS619 | B739 | 20 | 19:08:00 | 19:08:05 | 5 |
| AS517 | B737 | 20 | 18:19:00 | 18:19:12 | 12 |

| ACID | Type | T E T | RTA Assignment | Cross Fix - Time | |
|---|---|---|---|---|---|
| | | | Time | Time | Δt |
| AS233 | B738 | 20 | 03:03:00 | 3:07:45 | NA |
| AS501 | B737 | 20 | 20:30:20 | 20:30:51 | NA |
| AS511 | B737 | 20 | 04:03:00 | 4:03:13 | 13 |
| AS603 | B738 | 20 | 17:04:00 | 17:04:02 | 2 |
| AS495 | B738 | 20 | 18:25:00 | 18:25:13 | 13 |
| AS357 | B738 | 20 | 18:29:00 | 18:29:24 | 24 |
| AS685 | B737 | 20 | 17:16:00 | 17:16:08 | 8 |
| AS527 | B737 | 20 | 17:55:00 | 17:55:15 | 15 |
| AS555 | B734 | 20 | 00:33:00 | 0:33:28 | 28 |
| AS755 | B738 | 20 | 04:02:00 | 4:02:19 | 19 |
| AS533 | B737 | 20 | 20:07:00 | 20:07:33 | 33 |
| AS529 | B738 | 20 | 21:20:00 | 21:20:22 | 22 |
| AS39 | B738 | 20 | 03:50:00 | 3:49:58 | -2 |
| AS743 | B738 | 20 | 03:38:34 | 3:38:43 | 9 |
| AS11 | B738 | 20 | 18:16:00 | 18:16:12 | 12 |
| AS679 | B739 | 20 | 21:12:00 | 21:11:57 | -3 |
| AS661 | B739 | 20 | 23:55:00 | 23:55:13 | 13 |
| AS307 | B734 | 20 | 18:55:00 | 18:55:17 | 17 |
| AS3 | B738 | 20 | 03:43:49 | 3:43:56 | 7 |
| AS373 | B738 | 20 | 22:36:00 | 22:37:18 | NA |
| AS313 | B738 | 20 | 02:23:00 | 2:23:31 | 31 |
| AS321 | B738 | 20 | 18:45:00 | 18:45:09 | 9 |
| AS453 | B738 | 20 | 20:02:00 | 20:02:11 | 11 |
| AS455 | B734 | 20 | 01:40:00 | 1:42:15 | NA |
| AS21 | B739 | 20 | 17:49:00 | 17:49:17 | 17 |
| AS605 | B738 | 20 | 00:04:00 | 0:05:20 | NA |
| AS673 | B738 | 20 | 02:44:00 | 2:43:33 | NA |
| AS611 | B738 | 20 | 02:26:00 | 2:26:21 | NA |
| AS457 | B737 | 20 | 03:27:00 | 3:30:48 | NA |
| AS507 | B737 | 20 | 02:00:00 | 2:00:08 | 8 |
| AS487 | B737 | 20 | 00:52:00 | 0:54:00 | NA |
| AS515 | B737 | 20 | 17:27:00 | 17:29:10 | NA |
| AS373 | B738 | 20 | 22:56:00 | 22:56:19 | NA |
| AS495 | B738 | 20 | 18:49:00 | 18:51:09 | NA |
| AS507 | B737 | 20 | 01:54:38 | 1:54:45 | 7 |
| AS673 | B738 | 20 | 02:33:00 | 2:32:25 | NA |
| AS483 | B738 | 20 | 22:43:00 | 22:43:06 | 6 |
| AS233 | B738 | 20 | 03:16:16 | 3:16:32 | 16 |
| AS327 | B738 | 20 | 00:41:00 | 0:41:03 | 3 |
| AS357 | B738 | 20 | 18:26:00 | 18:26:07 | 7 |

| ACID | Type | TET | RTA Assignment | Cross Fix - Time | |
|---|---|---|---|---|---|
| | | | Time | Time | Δt |
| AS671 | B739 | 20 | 04:06:00 | 4:06:10 | NA |
| AS17 | B738 | 20 | 19:25:00 | 19:24:55 | -5 |
| AS365 | B738 | 20 | 19:45:00 | 19:45:19 | 19 |
| AS685 | B739 | 20 | 17:13:00 | 17:13:07 | 7 |
| AS503 | B737 | 20 | 21:50:20 | 21:50:48 | NA |
| AS601 | B739 | 20 | 22:14:00 | 22:14:16 | 16 |
| AS509 | B737 | 20 | 23:43:17 | 23:45:24 | NA |
| AS345 | B737 | 20 | 03:12:00 | 3:12:29 | NA |
| AS23 | B739 | 20 | 02:11:33 | 2:11:24 | -9 |
| AS457 | B739 | 20 | 03:34:00 | 3:34:30 | NA |
| AS305 | B737 | 20 | 23:02:00 | 23:02:10 | 10 |
| AS453 | B738 | 20 | 20:34:00 | 20:34:15 | 15 |
| AS3 | B738 | 20 | 03:53:00 | 3:53:09 | 9 |
| AS501 | B737 | 20 | 20:36:00 | 20:36:06 | 6 |
| AS1 | B738 | 20 | 18:04:00 | 18:03:58 | -2 |
| AS619 | B739 | 20 | 22:06:00 | 22:06:18 | 18 |
| AS631 | B738 | 20 | 02:30:00 | 2:30:23 | 23 |
| AS633 | B738 | 20 | 00:44:00 | 0:44:29 | 29 |
| AS603 | B738 | 20 | 17:09:00 | 17:09:06 | 6 |
| AS307 | B734 | 20 | 19:01:00 | 19:01:03 | NA |
| AS635 | B734 | 20 | 02:37:00 | 2:41:06 | NA |
| AS455 | B734 | 20 | 01:38:00 | 1:37:35 | NA |
| AS303 | B734 | 20 | 19:56:00 | 19:56:02 | 2 |
| AS555 | B734 | 20 | 00:49:00 | 0:49:12 | 12 |
| AS39 | B738 | 20 | 03:49:00 | 3:49:00 | NA |
| AS533 | B734 | 20 | 21:55:00 | 21:57:42 | NA |
| AS529 | B737 | 20 | 21:40:00 | 21:40:36 | NA |
| AS671 | B739 | 20 | 04:02:00 | 4:02:14 | 14 |
| AS365 | B738 | 20 | 19:45:00 | 19:45:16 | 16 |
| AS11 | B738 | 20 | 18:12:00 | 18:12:23 | 23 |
| AS303 | B734 | 20 | 19:47:00 | 19:47:10 | NA |
| AS605 | B738 | 20 | 23:34:42 | 23:34:54 | 12 |
| AS511 | B737 | 20 | 04:05:00 | 4:05:06 | 6 |
| AS603 | B738 | 20 | 17:04:23 | 17:04:31 | 8 |
| AS481 | B734 | 20 | 20:55:46 | 21:01:57 | NA |
| AS313 | B737 | 20 | 02:24:00 | 2:24:12 | 12 |
| AS743 | B738 | 20 | 04:08:00 | 4:08:15 | 15 |
| AS529 | B737 | 20 | 21:19:01 | 21:19:09 | 8 |
| AS555 | B734 | 20 | 00:47:00 | 0:47:12 | 12 |
| AS453 | B738 | 20 | 20:41:00 | 20:41:11 | 11 |

| ACID | Type | TET | RTA Assignment | Cross Fix - Time | |
|---|---|---|---|---|---|
| | | | Time | Time | Δt |
| AS661 | B739 | 20 | 00:01:00 | 0:01:12 | 12 |
| AS611 | B738 | 20 | 02:22:00 | 2:22:11 | 11 |
| AS461 | B738 | 20 | 23:21:00 | 23:21:22 | 22 |
| AS483 | B738 | 20 | 22:37:00 | 22:37:16 | 16 |
| AS517 | B737 | 20 | 18:17:00 | 18:16:51 | -9 |
| AS305 | B737 | 20 | 22:34:00 | 22:34:11 | 11 |
| AS17 | B738 | 20 | 19:25:00 | 19:25:22 | 22 |
| AS501 | B737 | 20 | 20:51:00 | 20:51:09 | 9 |
| AS515 | B737 | 20 | 17:33:00 | 17:33:06 | 6 |
| AS373 | B738 | 20 | 22:40:00 | 22:40:11 | 11 |
| AS619 | B739 | 20 | 19:13:00 | 19:16:30 | NA |
| AS39 | B738 | 20 | 03:47:50 | 3:48:06 | 16 |
| AS23 | B739 | 20 | 01:33:00 | 1:33:10 | 10 |
| AS553 | B734 | 20 | 03:22:00 | 3:22:14 | 14 |
| AS493 | B738 | 20 | 17:00:00 | 17:00:11 | 11 |
| AS495 | B738 | 20 | 18:40:00 | 18:40:30 | NA |
| AS685 | B739 | 20 | 17:18:51 | 17:19:03 | 12 |
| AS503 | B737 | 20 | 22:00:00 | 22:00:04 | 4 |
| AS355 | B738 | 20 | 03:13:00 | 3:13:20 | 20 |
| AS307 | B734 | 20 | 18:56:00 | 18:56:03 | 3 |
| AS673 | B738 | 20 | 02:37:00 | 2:37:10 | NA |
| AS601 | B738 | 20 | 21:27:08 | 21:27:41 | 33 |
| AS679 | B738 | 20 | 21:05:00 | 21:05:29 | 29 |
| AS469 | B734 | 20 | 18:42:00 | 18:42:04 | NA |
| AS755 | B738 | 20 | 03:56:00 | 3:56:16 | 16 |
| AS455 | B734 | 20 | 01:30:00 | 1:30:12 | 12 |
| AS527 | B737 | 20 | 18:08:00 | 18:07:58 | -2 |
| AS357 | B738 | 20 | 18:24:00 | 18:23:56 | -4 |
| AS611 | B738 | 20 | 02:28:00 | 2:27:56 | -4 |
| AS23 | B739 | 20 | 02:27:00 | 2:27:16 | NA |
| AS515 | B737 | 20 | 17:30:00 | 17:29:56 | -4 |
| AS305 | B734 | 20 | 22:31:00 | 22:31:04 | 4 |
| AS679 | B739 | 20 | 21:32:00 | 21:32:10 | 10 |
| AS345 | B734 | 20 | 03:31:00 | 3:31:00 | 0 |
| AS15 | B738 | 20 | 05:12:00 | 5:12:07 | 7 |
| AS495 | B738 | 20 | 18:35:00 | 18:35:03 | 3 |
| AS17 | B738 | 20 | 19:43:00 | 19:43:16 | 16 |
| AS529 | B737 | 20 | 21:27:00 | 21:26:31 | NA |
| AS453 | B738 | 20 | 20:21:00 | 20:21:09 | 9 |
| AS685 | B739 | 20 | 17:36:07 | 17:36:07 | 0 |

| ACID | Type | T E T | RTA Assignment | Cross Fix - Time | |
|---|---|---|---|---|---|
| | | | Time | Time | Δt |
| AS673 | B738 | 20 | 02:51:00 | 2:51:20 | NA |
| AS3 | B738 | 20 | 03:57:00 | 3:56:55 | -5 |
| AS507 | B734 | 20 | 02:09:00 | 2:08:57 | NA |
| AS555 | B734 | 20 | 00:47:00 | 0:47:03 | 3 |
| AS481 | B737 | 20 | 20:19:00 | 20:18:59 | -1 |
| AS527 | B737 | 20 | 18:11:00 | 18:11:01 | 1 |
| AS517 | B737 | 20 | 18:18:00 | 18:18:07 | 7 |
| AS661 | B739 | 20 | 00:03:00 | 0:03:07 | 7 |
| AS755 | B738 | 20 | 03:59:00 | 3:59:04 | 4 |
| AS483 | B738 | 20 | 22:53:00 | 22:53:14 | 14 |
| AS509 | B737 | 20 | 00:04:24 | 0:03:45 | -39 |
| AS461 | B738 | 20 | 23:20:00 | 23:19:48 | -12 |
| AS327 | B738 | 20 | 00:37:00 | 0:35:16 | NA |
| AS39 | B738 | 20 | 04:08:00 | 4:07:51 | -9 |
| AS307 | B734 | 20 | 18:57:00 | 18:54:43 | NA |
| AS357 | B738 | 20 | 18:25:00 | 18:25:08 | 8 |
| AS531 | B734 | 20 | 03:33:00 | 3:33:11 | 11 |
| AS457 | B738 | 20 | 03:35:17 | 3:36:13 | NA |
| AS373 | B738 | 20 | 22:50:00 | 22:50:13 | 13 |
| AS605 | B738 | 20 | 23:47:00 | 23:46:52 | -8 |
| AS487 | B737 | 20 | 01:15:00 | 1:14:24 | -36 |
| AS511 | B737 | 20 | 04:10:00 | 4:09:56 | -4 |
| AS233 | B738 | 20 | 03:24:00 | 3:24:07 | 7 |
| AS11 | B738 | 20 | 18:10:00 | 18:10:35 | 35 |
| AS601 | B739 | 20 | 21:18:00 | 21:17:53 | -7 |
| AS493 | B734 | 20 | 17:12:00 | 17:12:04 | 4 |
| AS671 | B739 | 20 | 04:02:00 | 4:02:09 | 9 |
| AS553 | B734 | 20 | NaN | 3:08:53 | NA |
| AS469 | B739 | 20 | 18:45:00 | 18:45:11 | 11 |
| AS229 | B738 | 20 | 19:53:00 | 19:55:29 | NA |
| AS1 | B738 | 20 | 18:21:00 | 18:21:13 | 13 |
| AS227 | B738 | 20 | 19:22:00 | 19:22:03 | 3 |
| AS307 | B734 | 20 | 19:46:00 | 19:45:53 | -7 |
| AS673 | B738 | 20 | 02:57:00 | 2:57:07 | 7 |
| AS685 | B739 | 20 | 17:19:00 | 17:19:49 | NA |
| AS539 | B734 | 20 | 17:09:00 | 17:01:12 | NA |
| AS327 | B738 | 20 | 00:44:00 | 0:45:02 | NA |
| AS469 | B734 | 20 | NaN | 18:57:16 | NA |
| AS23 | B739 | 20 | 01:42:54 | 1:42:54 | 0 |
| AS483 | B738 | 20 | 22:52:00 | 22:52:08 | 8 |

| ACID | Type | T E T | RTA Assignment | Cross Fix - Time | |
|---|---|---|---|---|---|
| | | | Time | Time | Δt |
| AS611 | B738 | 20 | 02:31:00 | 2:30:44 | -16 |
| AS619 | B738 | 20 | 19:11:37 | 19:14:49 | NA |
| AS345 | B737 | 20 | 03:18:00 | 3:18:05 | 5 |
| AS529 | B737 | 20 | 21:28:00 | 21:28:06 | 6 |
| AS503 | B737 | 20 | 21:42:00 | 21:41:52 | -8 |
| AS11 | B738 | 20 | 17:55:00 | 17:55:32 | NA |
| AS9001 | B737 | 20 | 17:29:00 | 17:31:43 | NA |
| AS17 | B738 | 20 | 19:25:23 | 19:25:59 | NA |
| AS511 | B737 | 20 | 04:24:00 | 4:23:04 | NA |
| AS509 | B737 | 20 | 00:08:00 | 0:08:13 | 13 |
| AS19 | B738 | 20 | 04:44:00 | 4:44:08 | 8 |
| AS467 | B737 | 20 | 00:31:04 | 0:31:29 | 25 |
| AS743 | B738 | 20 | 04:03:00 | 4:03:01 | 1 |
| AS555 | B734 | 20 | 01:05:00 | 1:05:04 | 4 |
| AS671 | B739 | 20 | 03:58:00 | 3:58:10 | 10 |
| AS551 | B738 | 20 | 20:36:14 | 20:35:37 | NA |
| AS373 | B738 | 20 | 22:50:00 | 22:49:54 | -6 |
| AS501 | B737 | 20 | 20:33:00 | 20:34:11 | NA |
| AS3 | B738 | 20 | 04:21:00 | 4:21:03 | 3 |
| AS305 | B737 | 20 | 00:21:00 | 0:21:08 | 8 |
| AS515 | B737 | 20 | 17:42:14 | 17:45:09 | NA |
| AS493 | B739 | 20 | 17:35:00 | 17:35:17 | 17 |
| AS517 | B737 | 20 | 18:14:17 | 18:18:07 | NA |
| AS755 | B738 | 20 | 04:01:00 | 4:01:12 | 12 |
| AS731 | B738 | 20 | 04:46:00 | 4:46:03 | 3 |
| AS365 | B738 | 20 | 20:06:00 | 20:05:49 | NA |
| AS457 | B737 | 20 | 03:43:00 | 3:42:19 | NA |
| AS527 | B737 | 20 | 18:10:00 | 18:10:15 | 15 |
| AS679 | B739 | 20 | 21:24:00 | 21:23:59 | -1 |
| AS1 | B738 | 20 | 18:09:00 | 18:09:20 | NA |
| AS755 | B738 | 20 | 04:30:48 | 4:30:56 | 8 |
| AS619 | B739 | 20 | 19:25:00 | 19:25:08 | 8 |
| AS355 | B739 | 20 | 03:25:00 | 3:24:56 | -4 |
| AS325 | B738 | 20 | 21:57:00 | 21:57:07 | 7 |
| AS303 | B738 | 20 | 19:44:54 | 19:44:56 | 2 |
| AS665 | B739 | 20 | 16:46:00 | 16:46:11 | 11 |
| AS307 | B738 | 20 | 19:07:00 | 19:07:31 | NA |
| AS555 | B734 | 20 | 00:44:00 | 0:43:50 | -10 |
| AS487 | B737 | 20 | 01:11:00 | 1:11:08 | 8 |
| AS3 | B738 | 20 | 03:54:00 | 3:53:49 | -11 |

| ACID | Type | T E T | RTA Assignment | Cross Fix - Time | |
|---|---|---|---|---|---|
| | | | Time | Time | Δt |
| AS551 | B738 | 20 | 20:30:00 | 20:30:10 | 10 |
| AS477 | B737 | 20 | 16:43:00 | 16:43:21 | 21 |
| AS17 | B738 | 20 | 19:42:00 | 19:41:49 | NA |
| AS467 | B739 | 20 | 00:14:00 | 0:14:03 | 3 |
| AS511 | B737 | 20 | 04:18:00 | 4:17:58 | -2 |
| AS685 | B739 | 20 | 17:39:00 | 17:39:22 | 22 |
| AS329 | B738 | 20 | 04:28:00 | 4:28:05 | 5 |
| AS671 | B739 | 20 | 04:17:00 | 4:16:51 | -9 |
| AS509 | B737 | 20 | 00:12:00 | 0:12:11 | 11 |
| AS1 | B738 | 20 | 18:46:00 | 18:46:07 | 7 |
| AS461 | B734 | 20 | 23:07:00 | 23:07:13 | 13 |
| AS533 | B734 | 20 | 20:08:00 | 20:07:23 | -37 |
| AS743 | B738 | 20 | 04:04:39 | 4:04:40 | 1 |
| AS503 | B737 | 20 | 21:52:00 | 21:52:00 | 0 |
| AS39 | B738 | 20 | 03:47:00 | 3:46:58 | -2 |
| AS345 | B737 | 20 | 03:14:00 | 3:13:54 | -6 |
| AS469 | B734 | 20 | 18:54:54 | 18:55:09 | NA |
| AS661 | B739 | 20 | 23:41:00 | 23:40:59 | -1 |
| AS229 | B738 | 20 | 19:32:00 | 19:32:04 | 4 |
| AS515 | B738 | 20 | 17:52:00 | 17:52:22 | 22 |
| AS23 | B739 | 20 | 01:49:00 | 1:49:01 | 1 |
| AS601 | B739 | 20 | 21:25:00 | 21:25:14 | 14 |
| AS305 | B737 | 20 | 22:43:49 | 22:44:02 | 13 |
| AS493 | B734 | 20 | 17:08:00 | 17:08:23 | 23 |
| AS603 | B738 | 20 | 17:14:00 | 17:14:14 | NA |
| AS233 | B738 | 20 | 03:29:00 | 3:30:04 | NA |
| AS25 | B738 | 20 | 19:10:00 | 19:10:25 | 25 |
| AS455 | B734 | 20 | 01:31:00 | 1:31:02 | 2 |
| AS37 | B739 | 20 | 22:28:00 | 22:28:19 | 19 |
| AS373 | B738 | 20 | 23:09:54 | 23:10:07 | 13 |
| AS321 | B738 | 20 | 19:00:00 | 19:00:09 | 9 |
| AS605 | B738 | 20 | 23:33:13 | 23:33:07 | -6 |
| AS315 | B738 | 20 | 16:51:00 | 16:51:04 | 4 |
| AS501 | B737 | 20 | 20:47:00 | 20:47:09 | 9 |
| AS483 | B738 | 20 | 22:49:00 | 22:49:48 | NA |
| AS755 | B738 | 20 | 04:15:04 | 4:15:48 | 44 |
| AS327 | B738 | 20 | 00:37:00 | 0:37:11 | 11 |
| AS313 | B738 | 20 | 02:42:00 | 2:42:06 | 6 |
| AS601 | B739 | 20 | 21:18:43 | 21:19:09 | 26 |
| AS665 | B739 | 20 | 16:40:00 | 16:40:05 | 5 |

| ACID | Type | T E T | RTA Assignment | Cross Fix - Time | |
|---|---|---|---|---|---|
| | | | Time | Time | Δt |
| AS325 | B738 | 20 | 22:02:00 | 22:02:05 | 5 |
| AS23 | B739 | 20 | 01:46:00 | 1:46:32 | NA |
| AS373 | B738 | 20 | 22:47:00 | 22:47:16 | 16 |
| AS685 | B739 | 20 | 17:36:00 | 17:37:03 | NA |
| AS553 | B734 | 20 | 03:04:00 | 3:04:07 | 7 |
| AS457 | B738 | 20 | 04:30:00 | 4:30:11 | 11 |
| AS603 | B738 | 20 | 17:03:00 | 17:03:16 | 16 |
| AS743 | B738 | 20 | 04:04:00 | 4:04:06 | 6 |
| AS671 | B739 | 20 | 03:48:00 | 3:48:17 | 17 |
| AS467 | B739 | 20 | 00:01:00 | 0:01:03 | NA |
| AS1 | B738 | 20 | 18:22:00 | 18:22:08 | 8 |
| AS3 | B738 | 20 | 04:02:19 | 4:02:19 | 0 |
| AS307 | B737 | 20 | 19:03:00 | 19:03:17 | 17 |
| AS37 | B737 | 20 | 22:33:00 | 22:33:16 | 16 |
| AS453 | B738 | 20 | 21:24:49 | 21:25:49 | NA |
| AS529 | B737 | 20 | 21:23:00 | 21:23:03 | 3 |
| AS39 | B738 | 20 | 04:05:00 | 4:05:00 | 0 |
| AS233 | B738 | 20 | 04:28:00 | 4:28:09 | 9 |
| AS539 | B734 | 20 | 16:41:00 | 16:41:17 | 17 |
| AS611 | B738 | 20 | 02:22:13 | 2:22:33 | 20 |
| AS345 | B737 | 20 | 03:11:00 | 3:11:16 | 16 |
| AS315 | B738 | 20 | 16:37:00 | 16:37:13 | 13 |
| AS11 | B738 | 20 | 17:51:00 | 17:52:13 | 73 |
| AS461 | B738 | 20 | 23:10:00 | 23:09:58 | -2 |
| AS227 | B738 | 20 | 18:59:00 | 18:58:46 | -14 |
| AS493 | B734 | 20 | 16:59:00 | 16:58:59 | -1 |
| AS483 | B738 | 20 | 22:43:00 | 22:43:08 | 8 |
| AS605 | B738 | 20 | 23:24:00 | 23:24:14 | 14 |
| AS329 | B738 | 20 | 04:18:06 | 4:18:19 | 13 |
| AS503 | B737 | 20 | 21:39:00 | 21:39:02 | 2 |
| AS551 | B734 | 20 | 20:32:00 | 20:32:10 | 10 |
| AS365 | B738 | 20 | 19:37:00 | 19:36:55 | -5 |
| AS305 | B738 | 20 | 22:36:00 | 22:36:14 | 14 |
| AS673 | B738 | 20 | 02:47:00 | 2:48:41 | NA |
| AS533 | B734 | 20 | 20:10:00 | 20:10:29 | NA |
| AS679 | B738 | 20 | 21:29:00 | 21:30:43 | NA |
| AS619 | B739 | 20 | 19:29:00 | 19:28:54 | -6 |
| AS555 | B739 | 20 | 00:23:17 | 0:23:31 | 14 |
| AS553 | B734 | 20 | 03:00:00 | 3:00:17 | NA |
| AS685 | B739 | 20 | 17:07:00 | 17:07:06 | 6 |

| ACID | Type | T E T | RTA Assignment | Cross Fix - Time | |
|---|---|---|---|---|---|
| | | | Time | Time | Δt |
| AS305 | B734 | 20 | 22:46:00 | 22:46:36 | NA |
| AS487 | B737 | 20 | 01:05:00 | 1:05:43 | NA |
| AS673 | B738 | 20 | 02:37:00 | 2:37:10 | 10 |
| AS21 | B739 | 20 | 18:24:00 | 18:23:50 | -10 |
| AS503 | B737 | 20 | 21:35:00 | 21:35:18 | 18 |
| AS313 | B738 | 20 | 02:29:00 | 2:29:49 | 49 |
| AS551 | B737 | 20 | 20:22:00 | 20:22:22 | 22 |
| AS1 | B738 | 20 | 18:26:30 | 18:26:34 | 4 |
| AS327 | B734 | 20 | 00:38:40 | 0:38:51 | 11 |
| AS531 | B734 | 20 | 03:41:00 | 3:40:44 | -16 |
| AS527 | B737 | 20 | 18:01:00 | 18:01:10 | 10 |
| AS325 | B738 | 20 | 21:55:00 | 21:55:30 | 30 |
| AS455 | B734 | 20 | 01:44:00 | 1:44:16 | 16 |
| AS601 | B738 | 20 | 21:32:02 | 21:32:35 | 33 |
| AS671 | B739 | 20 | 03:53:00 | 3:53:15 | 15 |
| AS743 | B738 | 20 | 03:57:00 | 3:56:57 | -3 |
| AS355 | B737 | 20 | 03:20:00 | 3:20:13 | 13 |
| AS37 | B738 | 20 | 22:33:00 | 22:32:47 | -13 |
| AS453 | B738 | 20 | 20:11:00 | 20:11:24 | 24 |
| AS303 | B738 | 20 | 19:37:35 | 19:37:36 | 1 |
| AS39 | B738 | 20 | 03:53:00 | 3:53:39 | NA |
| AS501 | B737 | 20 | 20:34:00 | 20:34:31 | 31 |
| AS25 | B738 | 20 | 19:04:00 | 19:03:20 | NA |
| AS307 | B734 | 20 | NaN | 18:50:05 | NA |
| AS469 | B734 | 20 | 18:46:00 | 18:46:09 | 9 |
| AS555 | B737 | 20 | 00:41:00 | 0:40:59 | -1 |
| AS345 | B737 | 20 | 03:16:16 | 3:16:28 | 12 |
| AS495 | B738 | 20 | 18:30:00 | 18:31:53 | NA |
| AS467 | B739 | 20 | 00:14:00 | 0:14:15 | 15 |
| AS11 | B738 | 20 | 18:02:00 | 18:01:58 | -2 |
| AS661 | B739 | 20 | 23:37:00 | 23:36:57 | -3 |
| AS619 | B739 | 20 | 19:13:00 | 19:13:14 | 14 |
| AS373 | B738 | 20 | 22:40:48 | 22:40:38 | NA |
| AS321 | B738 | 20 | 18:55:00 | 18:55:12 | 12 |
| AS23 | B738 | 20 | 01:41:00 | 1:41:14 | 14 |
| AS3 | B738 | 20 | 04:07:00 | 4:07:14 | 14 |
| AS229 | B738 | 20 | 19:42:25 | 19:44:01 | NA |
| AS9005 | B734 | 20 | 17:08:00 | 17:08:21 | 21 |
| AS453 | B734 | 20 | 20:10:00 | 20:09:58 | -2 |
| AS483 | B738 | 20 | 22:53:00 | 22:53:00 | 0 |

| ACID | Type | T E T | RTA Assignment | Cross Fix - Time | |
|---|---|---|---|---|---|
| | | | Time | Time | Δt |
| AS481 | B737 | 20 | 20:25:00 | 20:24:58 | -2 |
| AS303 | B737 | 20 | 19:50:00 | 19:51:20 | NA |
| AS37 | B739 | 20 | 22:29:00 | 22:30:30 | NA |
| AS679 | B739 | 20 | 21:40:00 | 21:40:01 | 1 |
| AS529 | B737 | 20 | 21:21:00 | 21:21:01 | 1 |
| AS315 | B738 | 20 | 16:52:00 | 16:52:58 | NA |
| AS493 | B737 | 20 | 17:11:00 | 17:11:12 | 12 |
| AS469 | B734 | 20 | 18:47:00 | 18:47:15 | 15 |
| AS551 | B734 | 20 | 20:47:00 | 20:47:15 | 15 |
| AS495 | B738 | 20 | 18:36:00 | 18:36:23 | 23 |
| AS503 | B737 | 20 | 21:49:00 | 21:49:19 | 19 |
| AS11 | B738 | 20 | 18:04:00 | 18:04:10 | 10 |
| AS357 | B738 | 20 | 18:49:00 | 18:49:17 | 17 |
| AS533 | B734 | 20 | 20:30:00 | 20:30:15 | 15 |
| AS21 | B739 | 20 | 18:06:00 | 18:05:57 | NA |
| AS325 | B738 | 20 | 22:11:00 | 22:11:17 | 17 |
| AS305 | B737 | 20 | 22:43:00 | 22:43:15 | 15 |
| AS1 | B738 | 20 | 18:27:40 | 18:29:49 | NA |
| AS373 | B738 | 20 | 22:45:00 | 22:45:20 | 20 |
| AS619 | B738 | 20 | 19:20:00 | 19:20:10 | 10 |
| AS685 | B739 | 20 | 17:23:00 | 17:22:58 | -2 |
| AS17 | B738 | 20 | 19:27:00 | 19:27:00 | 0 |
| AS25 | B738 | 20 | 19:11:00 | 19:11:22 | 22 |
| AS483 | B738 | 20 | 22:42:00 | 22:42:15 | 15 |
| AS661 | B739 | 20 | 23:45:00 | 23:45:32 | 32 |
| AS493 | B738 | 20 | 17:07:00 | 17:07:24 | 24 |
| AS533 | B734 | 20 | 20:36:00 | 20:36:23 | 23 |
| AS487 | B737 | 20 | 01:01:31 | 1:01:48 | 17 |
| AS527 | B737 | 20 | 18:01:00 | 18:01:06 | 6 |
| AS509 | B737 | 20 | 23:51:00 | 23:51:22 | 22 |
| AS481 | B734 | 20 | 20:24:00 | 20:24:26 | 26 |
| AS501 | B737 | 20 | 20:34:00 | 20:34:11 | 11 |
| AS685 | B739 | 20 | 17:24:00 | 17:24:16 | 16 |
| AS495 | B738 | 20 | 18:40:00 | 18:40:15 | 15 |
| AS373 | B738 | 20 | 22:52:00 | 22:52:20 | 20 |
| AS469 | B737 | 20 | 18:58:00 | 18:58:28 | 28 |
| AS601 | B739 | 20 | 21:23:00 | 21:23:14 | 14 |
| AS555 | B734 | 20 | 00:44:00 | 0:44:25 | 25 |
| AS551 | B734 | 20 | 20:43:00 | 20:43:13 | 13 |
| AS461 | B734 | 20 | 22:46:00 | 22:46:19 | 19 |

| ACID | Type | T E T | RTA Assignment | Cross Fix - Time | |
|---|---|---|---|---|---|
| | | | Time | Time | Δt |
| AS619 | B739 | 20 | 19:17:39 | 19:17:57 | 18 |
| AS37 | B739 | 20 | 22:42:16 | 22:42:04 | NA |
| AS679 | B739 | 20 | NaN | 21:18:18 | NA |
| AS307 | B734 | 20 | 19:07:00 | 19:07:09 | NA |
| AS453 | B738 | 20 | 20:45:00 | 20:45:28 | 28 |
| AS517 | B738 | 20 | 18:16:00 | 18:16:21 | 21 |
| AS11 | B738 | 20 | 18:26:00 | 18:26:38 | NA |
| AS515 | B737 | 20 | 17:32:00 | 17:32:21 | 21 |
| AS21 | B739 | 20 | 18:03:00 | 18:03:14 | 14 |
| AS305 | B737 | 20 | 22:34:00 | 22:34:16 | 16 |
| AS325 | B738 | 20 | 22:30:00 | 22:30:20 | 20 |
| AS605 | B738 | 20 | 23:41:00 | 23:41:21 | 21 |
| AS529 | B737 | 20 | 21:29:00 | 21:29:17 | 17 |
| AS467 | B739 | 20 | 00:15:34 | 0:16:02 | 28 |
| AS603 | B738 | 20 | 17:17:00 | 17:17:21 | 21 |
| AS661 | B739 | 20 | 23:43:00 | 23:43:10 | 10 |
| AS515 | B737 | 20 | 17:33:00 | 17:33:16 | 16 |
| AS493 | B738 | 20 | 17:09:00 | 17:11:52 | NA |
| AS303 | B737 | 20 | 19:40:00 | 19:41:47 | NA |
| AS327 | B738 | 20 | 00:52:00 | 0:53:30 | NA |
| AS501 | B737 | 20 | 20:40:46 | 20:43:43 | NA |
| AS685 | B739 | 20 | 17:22:11 | 17:22:22 | 11 |
| AS25 | B738 | 20 | 19:09:00 | 19:09:04 | 4 |
| AS503 | B737 | 20 | 21:44:00 | 21:44:09 | 9 |
| AS495 | B738 | 20 | 18:37:00 | 18:36:59 | NA |
| AS315 | B737 | 20 | 16:41:00 | 16:42:07 | NA |
| AS619 | B738 | 20 | 19:31:00 | 19:31:18 | 18 |
| AS529 | B737 | 20 | 21:24:53 | 21:25:53 | NA |
| AS23 | B739 | 20 | 01:25:00 | 1:24:59 | -1 |
| AS357 | B738 | 20 | 18:35:00 | 18:35:03 | 3 |
| AS307 | B734 | 20 | 19:12:00 | 19:12:17 | 17 |
| AS517 | B738 | 20 | 18:20:00 | 18:20:05 | 5 |
| AS509 | B737 | 20 | 23:49:00 | 23:49:24 | 24 |
| AS371 | B738 | 20 | 16:37:00 | 16:37:56 | NA |
| AS373 | B738 | 20 | 23:08:00 | 23:08:40 | NA |
| AS533 | B734 | 20 | 20:35:00 | 20:40:08 | NA |
| AS1 | B738 | 20 | 18:11:00 | 18:11:07 | 7 |
| AS539 | B734 | 20 | 16:58:00 | 16:58:12 | 12 |
| AS453 | B738 | 20 | 20:29:00 | 20:29:04 | 4 |
| AS469 | B734 | 20 | 18:51:00 | 18:51:34 | NA |

| ACID | Type | T E T | RTA Assignment | Cross Fix - Time | |
|---|---|---|---|---|---|
| | | | Time | Time | Δt |
| AS487 | B737 | 20 | 01:21:00 | 1:21:16 | 16 |
| AS603 | B738 | 20 | 17:39:00 | 17:40:23 | NA |
| AS467 | B737 | 20 | 00:15:00 | 0:15:08 | 8 |
| AS679 | B739 | 20 | 21:48:00 | 21:48:11 | 11 |
| AS17 | B738 | 20 | 19:24:00 | 19:24:36 | 36 |
| AS601 | B738 | 20 | 21:53:00 | 21:53:19 | 19 |
| AS619 | B738 | 20 | 19:35:00 | 19:35:14 | 14 |
| AS495 | B738 | 20 | 18:47:00 | 18:45:07 | NA |
| AS469 | B734 | 20 | 18:56:00 | 18:56:07 | 7 |
| AS357 | B738 | 20 | 18:43:00 | 18:43:49 | NA |
| AS601 | B739 | 20 | 21:40:41 | 21:40:55 | 14 |
| AS365 | B738 | 20 | 19:37:00 | 19:37:13 | 13 |
| AS517 | B738 | 20 | 18:33:00 | 18:33:16 | 16 |
| AS481 | B734 | 20 | 20:32:00 | 20:32:07 | 7 |
| AS453 | B738 | 20 | 20:38:00 | 20:38:05 | NA |
| AS501 | B737 | 20 | 20:55:00 | 20:58:25 | NA |
| AS303 | B738 | 20 | 19:50:58 | 19:51:57 | NA |
| AS25 | B738 | 20 | 19:57:00 | 19:58:00 | NA |
| AS551 | B734 | 20 | 21:14:00 | 21:13:59 | -1 |
| AS307 | B734 | 20 | 19:02:00 | 19:02:17 | 17 |
| AS17 | B738 | 20 | 19:11:00 | 19:10:57 | -3 |
| AS503 | B737 | 20 | 21:59:00 | 21:59:08 | 8 |

# APPENDIX E: 2012 FAA Simulation Results

| Run | Flt | ACID | Type | CI | Meter | TMA Analysis | | | TMA | Δt | FMS | FMS Analysis | | | | RTA Assignment | | | | Corr | RTA | ΔM | EDA | Cross Fix - | | Cross Fix - | | Cross Fix - | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | ETA | Δt | STA | ETA | | ETA | First | ETA | Last | Window | Time | Assn | Spd | Path | Amd | Spd | | Spd | Time | Δt | Alt | ΔAlt | Speed | ΔSpd | |
| D1R1 [A / HW] | F1 | +SW491 | B737 | 30 | NO | 14:34:17 | 00:43 | 14:35:00 | 14:34:17 | 00:02 | 14:34:15 | 14:32:30 | 14:34:15 | 14:37:30 | | 14:35:00 | 14:00 | | | | | | | 14:35:02 | 2 | 19,020 | 20 | 249 | 1 | |
| | F2 | +SW1396 | B737 | 30 | NO | 14:36:57 | 00:03 | 14:37:00 | 14:36:57 | 01:52 | 14:35:05 | 14:35:00 | 14:35:05 | 14:40:00 | | 14:37:00 | 14:02 | | | | | | | 14:37:02 | 2 | 19,024 | 24 | 250 | 0 | |
| | F6 | +DL227 | B757 | 50 | NO | 14:39:05 | 00:05 | 14:39:00 | 14:39:05 | 01:05 | 14:38:00 | NA | 14:38:00 | NA | | 14:39:00 | 14:05 | | | | | | | 14:38:59 | -1 | 19,013 | 13 | 247 | 3 | |
| | F3 | +SW2809 | B737 | 30 | NO | 14:40:33 | 00:33 | 14:40:00 | 14:40:33 | 00:40 | 14:39:53 | 14:38:00 | 14:39:53 | 14:41:00 | | 14:40:00 | 14:07 | | | | | | | 14:40:20 | 20 | 19,020 | 20 | 250 | 0 | |
| | F5 | +UA675 | B757 | 50 | NO | 14:42:31 | 00:31 | 14:42:00 | 14:42:31 | 00:31 | 14:42:00 | NA | 14:42:00 | NA | | 14:42:00 | 14:08 | | | | | | | 14:42:00 | 0 | 19,006 | 6 | 249 | 1 | |
| | F4 | +UA311 | A320 | 25 | NO | 14:46:25 | 02:25 | 14:44:00 | 14:46:25 | 08:25 | 14:38:00 | NA | 14:38:00 | NA | | 14:44:00 | 14:21 | | | | | | | 14:44:28 | 28 | 18,983 | 17 | 251 | 1 | AAU Amd 14:44 @ 1 |
| D1R2 [A / TW] | F1 | +SW491 | B737 | 30 | NO | 16:22:16 | 00:44 | 16:23:00 | 16:22:16 | 00:19 | 16:21:57 | 16:20:05 | 16:21:57 | 16:23:15 | | 16:23:00 | 15:55 | | | | | | | 16:23:10 | 10 | 19,019 | 19 | 251 | 1 | Network comm with FMSs unstable resulting in clock errors. Data per FMSs |
| | F2 | +SW1396 | B737 | 30 | NO | 16:24:59 | 00:01 | 16:25:00 | 16:24:59 | 00:02 | 16:25:01 | 16:22:43 | 16:25:01 | 16:25:56 | | 16:25:00 | 15:56 | | | | | | | 16:25:18 | 18 | 19,020 | 20 | 253 | 3 | |
| | F3 | +SW2809 | B737 | 30 | NO | 16:26:08 | 00:08 | 16:26:00 | 16:26:08 | 00:08 | 16:26:00 | 16:24:38 | 16:26:00 | 16:26:31 | | 16:26:00 | 15:59 | | | | | | | 16:26:10 | 10 | 19,022 | 22 | 260 | 10 | |
| | F4 | +UA311 | A320 | 25 | NO | 16:28:52 | 00:08 | 16:29:00 | 16:28:52 | 00:35 | 16:28:17 | NA | 16:28:17 | NA | | 16:29:00 | 16:01 | | | | | | | 16:29:57 | 57 | 19,095 | 95 | 259 | 9 | |
| | F5 | +UA675 | B757 | 50 | NO | 16:29:33 | 00:27 | 16:30:00 | 16:29:33 | 00:33 | 16:29:00 | NA | 16:29:00 | NA | | 16:30:00 | 16:02 | | | | | | | 16:30:03 | 3 | 18,996 | 4 | 260 | 10 | |
| | F6 | +DL227 | B757 | 50 | NO | 16:31:49 | 00:11 | 16:32:00 | 16:31:49 | 00:11 | 16:32:00 | NA | 16:32:00 | NA | | 16:32:00 | 16:04 | | | | | | | 16:32:08 | 8 | 19,020 | 20 | 244 | 6 | |
| D1R3 [A / HW] | F1 | +SW491 | B737 | 30 | NO | 18:31:30 | 02:00 | 18:33:30 | 18:31:30 | 00:09 | 18:31:21 | 18:29:30 | 18:31:21 | 18:34:44 | | 18:33:30 | 18:00 | | | | | | | 18:33:12 | -18 | 19,049 | 49 | 251 | 1 | |
| | F2 | +SW1396 | B737 | 30 | NO | 18:34:11 | 00:49 | 18:35:00 | 18:34:11 | 00:02 | 18:34:09 | 18:32:09 | 18:34:09 | 18:38:00 | | 18:35:00 | 18:02 | | | | | | | 18:34:54 | -6 | 19,020 | 20 | 250 | 0 | |
| | F6 | +DL227 | B757 | 50 | NO | 18:36:23 | 00:07 | 18:36:30 | 18:36:23 | 00:35 | 18:35:48 | NA | 18:35:48 | NA | | 18:36:30 | 18:03 | | | | | | | 18:36:31 | 1 | 19,041 | 41 | 247 | 3 | |
| | F3 | +SW2809 | B737 | 30 | NO | 18:37:46 | 00:14 | 18:38:00 | 18:37:46 | 00:40 | 18:37:06 | 14:38:00 | 18:37:06 | 14:41:00 | | 18:38:00 | 18:04 | | | | | | | 18:38:00 | 0 | 19,019 | 19 | 250 | 0 | |
| | F5 | +UA311 | A320 | 25 | NO | 18:38:25 | 01:05 | 18:39:30 | 18:38:25 | 01:25 | 18:37:00 | NA | 18:37:00 | NA | | 18:39:30 | 18:06 | | | | | | | 18:38:55 | -35 | 20,214 | 1214 | 255 | 5 | |
| | F4 | +UA675 | B757 | 50 | NO | 18:39:40 | 01:20 | 18:41:00 | 18:39:40 | 00:04 | 18:39:36 | NA | 18:39:36 | NA | | 18:41:00 | 18:07 | | | | | | | 18:40:57 | -3 | 19,300 | 300 | 247 | 3 | |

| Run | Flt | ACID | Type | CI | Meter | TMA Analysis | | | TMA | Δt | FMS | FMS Analysis | | | | RTA Assignment | | | | Corr | RTA | ΔM | EDA | Cross Fix - | | Cross Fix - | | Cross Fix - | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | ETA | Δt | STA | ETA | | ETA | First | ETA | Last | Window | Time | Assn | Spd | Path | Amd | Spd | | Spd | Time | Δt | Alt | ΔAlt | Speed | ΔSpd | |
| D1R4 [A / TW] | F1 | +SW491 | B737 | 30 | NO | 19:59:58 | 00:04 | 19:59:54 | 19:59:58 | 00:25 | 19:59:33 | 19:57:29 | 19:59:33 | 20:00:59 | | 19:59:54 | 19:35 | | | | | | | 20:00:04 | 10 | 19,019 | 19 | 254 | 4 | |
| | F2 | +SW1396 | B737 | 30 | NO | 20:02:34 | 01:10 | 20:01:24 | 20:02:34 | 00:21 | 20:02:13 | 20:00:08 | 20:02:13 | 20:03:39 | | 20:01:24 | 19:37 | | | | | | | 20:01:27 | 3 | 19,020 | 20 | 286 | 36 | |
| | F3 | +SW2809 | B737 | 30 | NO | | | | | | | | | | | | | | | | | | | | | | | | | FMS Software Failed |
| | F4 | +UA311 | A320 | 25 | NO | 20:06:17 | 00:01 | 20:06:18 | 20:06:17 | 00:17 | 20:06:00 | NA | 20:06:00 | NA | | 20:06:18 | 19:40 | | | | | | | 20:06:37 | 19 | 18,984 | 16 | 254 | 4 | |
| | F5 | +UA675 | B757 | 50 | NO | 20:06:58 | 00:50 | 20:07:48 | 20:06:58 | 00:02 | 20:07:00 | NA | 20:07:00 | NA | | 20:07:48 | 19:41 | | | | | | | 20:07:49 | 1 | 19,038 | 38 | 250 | 0 | |
| | F6 | +DL227 | B757 | 50 | NO | 20:09:17 | 00:01 | 20:09:18 | 20:09:17 | 00:31 | 20:09:48 | NA | 20:09:48 | NA | | 20:09:18 | 19:44 | | | | | | | 20:09:22 | 4 | 18,991 | 9 | 253 | 3 | |
| D2R1 [A / HW] | F1 | +SW491 | B737 | 15 | NO | 14:32:18 | 00:48 | 14:33:06 | 14:32:18 | 00:22 | 14:32:40 | 14:29:15 | 14:32:40 | 14:34:27 | | 14:33:06 | 14:01 | | | | | | | 14:32:52 | -14 | 19,054 | 54 | 250 | 0 | |
| | F2 | +SW1396 | B737 | 30 | NO | 14:33:39 | 00:21 | 14:33:18 | 14:33:39 | 00:04 | 14:33:35 | 14:31:41 | 14:33:35 | 14:37:05 | | 14:34:18 | 14:01 | | | | | | | 14:34:09 | -9 | 19,020 | 20 | 250 | 0 | |
| | F6 | +DL227 | B757 | 25 | NO | 14:35:30 | 00:00 | 14:35:30 | 14:35:30 | 00:18 | 14:35:12 | NA | 14:35:12 | NA | | 14:35:30 | 14:03 | | | | | | | 14:35:28 | -2 | 19,003 | 3 | 249 | 1 | |
| | F3 | +SW2809 | B737 | 30 | NO | 14:37:28 | 00:46 | 14:36:42 | 14:37:28 | 00:57 | 14:36:31 | 14:34:48 | 14:36:31 | 14:36:42 | | 14:36:42 | 14:05 | | | | | | | 14:37:13 | 31 | 19,023 | 23 | 250 | 0 | |
| | F4 | +UA311 | A320 | 25 | NO | 14:37:55 | 00:01 | 14:37:54 | 14:37:55 | 05:55 | 14:32:00 | NA | 14:32:00 | NA | | 14:37:54 | 14:07 | | | | | | | 14:39:24 | 90 | 18,983 | 17 | 250 | 0 | |
| | F5 | +UA675 | B757 | 50 | NO | 14:39:40 | 00:34 | 14:39:06 | 14:39:40 | 00:40 | 14:39:00 | NA | 14:39:00 | NA | | 14:39:06 | 14:07 | | | | | | | 14:39:07 | 1 | 19,020 | 20 | 248 | 2 | |
| D2R2 [A / TW] | F1 | +SW491 | B737 | 30 | NO | 15:58:19 | 00:41 | 15:59:00 | 15:58:19 | 00:21 | 15:57:58 | 15:55:52 | 15:57:58 | 15:59:28 | | 15:59:06 | 15:34 | | | | | | | 15:59:18 | 12 | 19,020 | 20 | 251 | 1 | |
| | F2 | +SW1396 | B737 | 30 | NO | 16:00:55 | 00:53 | 16:01:48 | 16:00:55 | 01:13 | 15:59:42 | 16:55:52 | 15:59:42 | 16:02:06 | | 16:01:48 | 15:39 | | | | | | | 16:01:57 | 9 | 19,055 | 55 | 251 | 1 | |
| | F3 | +SW2809 | B737 | 15 | NO | 16:02:09 | 00:51 | 16:03:00 | 16:02:09 | 00:26 | 16:02:35 | 16:00:39 | 16:02:35 | 16:03:00 | | 16:03:00 | 15:40 | | | | | | | 16:03:13 | 13 | 19,019 | 19 | 252 | 2 | |
| | F4 | +UA311 | A320 | 25 | NO | 16:04:31 | 00:07 | 16:04:24 | 16:04:31 | 00:29 | 16:05:00 | NA | 16:05:00 | NA | | 16:04:24 | 15:42 | | | | | | | 16:04:32 | 8 | 18,983 | 17 | 232 | 18 | |
| | F5 | +UA675 | B757 | 50 | NO | 16:05:40 | 00:08 | 16:05:48 | 16:05:40 | 00:34 | 16:05:06 | NA | 16:05:06 | NA | | 16:05:48 | 15:43 | | | | | | | 16:06:00 | 12 | 19,027 | 27 | 256 | 6 | |
| | F6 | +DL227 | B757 | 100 | NO | 16:07:52 | 00:46 | 16:07:06 | 16:07:52 | 00:26 | 16:08:18 | NA | 16:08:18 | NA | | 16:07:06 | 15:44 | | | | | | | 16:07:11 | 5 | 19,003 | 3 | 250 | 0 | |

| Run | Flt | ACID | Type | CI | Meter | TMA Analysis |  |  | TMA | Δt | FMS | FMS Analysis |  |  |  | RTA Assignment |  |  |  | Corr | RTA | ΔM | EDA | Cross Fix - |  | Cross Fix - |  | Cross Fix - |  | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  | ETA | Δt | STA | ETA |  | ETA | First | ETA | Last | Window | Time | Assn | Spd | Path | Amd | Spd |  | Spd | Time | Δt | Alt | ΔAlt | Speed | ΔSpd |  |
| D2R4 [B / HW] | F1 | +SW325 | B737 | 15 | NO | 17:22:54 | 00:36 | 17:23:30 | 17:22:54 | 00:39 | 17:22:15 | 17:20:25 | 17:22:15 | 17:23:34 |  | 17:23:30 | 16:47 |  |  |  |  |  |  | 17:23:29 | -1 | 19,012 | 12 | 250 | 0 |  |
|  | F4 | +UA320 | A320 | 25 | NO | 17:24:20 | 00:46 | 17:25:06 | 17:24:20 | 02:20 | 17:22:00 | NA | 17:22:00 | NA |  | 17:25:06 | 16:47 |  |  |  |  |  |  | 17:24:44 | -22 | 19,812 | 812 | 245 | 5 |  |
|  | F2 | +SW362 | B737 | 30 | NO | 17:25:48 | 01:00 | 17:26:48 | 17:25:48 | 00:59 | 17:24:49 | 17:23:30 | 17:24:49 | 17:29:54 |  | 17:26:48 | 16:48 |  |  |  |  |  |  | 17:26:42 | -6 | 19,022 | 22 | 250 | 0 |  |
|  | F5 | +UA456 | B757 | 50 | NO | 17:27:05 | 01:25 | 17:28:30 | 17:27:05 | 00:05 | 17:27:00 | NA | 17:27:00 | NA |  | 17:28:30 | 16:49 |  |  |  |  |  |  | 17:28:20 | -10 | 19,027 | 27 | 254 | 4 |  |
|  | F3 | +SW114 | B737 | 15 | NO | 17:27:19 | 02:47 | 17:30:06 | 17:27:19 | 00:41 | 17:28:00 | 17:23:42 | 17:28:00 | 17:32:27 |  | 17:30:06 | 16:50 |  |  |  |  |  |  | 17:29:57 | -9 | 19,066 | 66 | 250 | 0 |  |
|  | F6 | +UA517 | B757 | 100 | NO | 17:30:55 | 00:53 | 17:31:48 | 17:30:55 | 00:01 | 17:30:54 | NA | 17:30:54 | NA |  | 17:31:48 | 16:54 |  |  |  |  |  |  | 17:31:44 | -4 | 19,071 | 71 | 249 | 1 |  |
| D2R5 [B / TW] | F1 | +SW325 | B737 | 30 | NO | 19:42:32 | 00:40 | 19:43:12 | 19:42:32 | 00:09 | 19:42:41 | 19:41:33 | 19:42:41 | 19:43:05 |  | 19:43:12 | 19:21 |  |  |  |  |  |  | 19:43:21 | 9 | 19,070 | 70 | 250 | 0 |  |
|  | F2 | +SW362 | B737 | 30 | NO | 19:44:34 | 00:44 | 19:45:18 | 19:44:34 | 00:31 | 19:44:03 | 19:41:54 | 19:44:03 | 19:45:32 |  | 19:45:18 | 19:22 |  |  |  |  |  |  | 19:45:27 | 9 | 19,049 | 49 | 250 | 0 |  |
|  | F3 | +SW114 | B737 | 30 | NO | 19:46:02 | 00:16 | 19:46:18 | 19:46:02 | 01:17 | 19:44:45 | 19:42:13 | 19:44:45 | 19:47:23 |  | 19:46:18 | 19:22 |  |  |  |  |  |  | 19:46:29 | 11 | 19,022 | 22 | 250 | 0 |  |
|  | F5 | +UA456 | B757 | 50 | NO | 19:45:56 | 01:28 | 19:47:24 | 19:45:56 | 00:02 | 19:45:54 | NA | 19:45:54 | NA |  | 19:47:24 | 19:24 |  |  |  |  |  |  | 19:47:26 | 2 | 19,106 | 106 | 250 | 0 |  |
|  | F4 | +UA320 | A320 | 25 | NO | 19:47:42 | 01:12 | 19:48:54 | 19:47:42 | 02:42 | 19:45:00 | NA | 19:45:00 | NA |  | 19:48:54 | 19:23 |  |  |  |  |  |  | 19:49:13 | 19 | 18,983 | 17 | 259 | 9 |  |
|  | F6 | +UA517 | B757 | 100 | NO | 19:48:11 | 02:25 | 19:50:36 | 19:48:11 | 00:01 | 19:48:12 | NA | 19:48:12 | NA |  | 19:50:36 | 19:24 |  |  |  |  |  |  | 19:50:39 | 3 | 19,001 | 1 | 250 | 0 |  |
| D3R3 [C / HW] | F2 | +DL1214 | B737 | 30 | 1-3 | 21:26:59 | 00:35 | 21:26:24 | 21:26:59 | 00:22 | 21:26:37 | 21:23:57 | 21:26:37 | 21:35:02 |  | 21:26:24 | 20:51 |  |  |  |  |  |  | 21:26:00 | -24 | 19,012 | 12 | 251 | 1 |  |
|  | F3 | +SW449 | B737 | 30 | 1-3 | 21:27:25 | 00:11 | 21:27:36 | 21:27:25 | 00:39 | 21:26:46 | 21:25:04 | 21:26:46 | 21:28:01 |  | 21:27:36 | 20:55 |  |  |  |  |  |  | 21:27:37 | 1 | 19,020 | 20 | 250 | 0 |  |
|  | F1 | +SW2241 | B737 | 30 | 1-3 | 21:27:00 | 01:48 | 21:28:48 | 21:27:00 | 00:25 | 21:27:25 | 21:25:26 | 21:27:25 | 21:31:12 |  | 21:28:48 | 20:55 |  |  |  |  |  |  | 21:28:46 | -2 | 19,012 | 12 | 250 | 0 |  |
|  | F6 | +UA745 | B757 | 50 | 1-3 | 21:28:04 | 02:02 | 21:30:06 | 21:28:04 | 00:34 | 21:27:30 | NA | 21:27:30 | NA |  | 21:30:06 | 20:56 |  |  |  |  |  |  | 21:30:00 | -6 | 19,096 | 96 | 250 | 0 |  |
|  | F4 | +UA962 | A320 | 25 | 1-3 | 21:31:18 | 01:00 | 21:32:18 | 21:31:18 | 01:18 | 21:30:00 | NA | 21:30:00 | NA |  | 21:32:18 | 20:58 |  |  |  |  |  |  | 21:32:04 | -14 | 20,870 | 1870 | 240 | 10 |  |
|  | F5 | +UA923 | B757 | 50 | 1-3 | 21:34:02 | 00:02 | 21:34:00 | 21:34:02 | 00:14 | 21:33:48 | NA | 21:33:48 | NA |  | 21:34:00 | 20:59 |  |  |  |  |  |  | 21:34:06 | 6 | 19,043 | 43 | 249 | 1 |  |

| Run | Flt | ACID | Type | CI | Meter | TMA Analysis |  |  | TMA | Δt | FMS | FMS Analysis |  |  |  | RTA Assignment |  |  |  | Corr | RTA | ΔM | EDA | Cross Fix - |  | Cross Fix - |  | Cross Fix - |  | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  | ETA | Δt | STA | ETA |  | ETA | First | ETA | Last | Window | Time | Assn | Spd | Path | Amd | Spd |  | Spd | Time | Δt | Alt | ΔAlt | Speed | ΔSpd |  |
| D3R1 [B / HW] | F4 | +UA320 | A320 | 25 | 1-3 | 14:44:17 | 00:37 | 14:44:54 | 14:44:17 | 04:17 | 14:40:00 | NA | 14:40:00 | NA |  | 14:44:54 | 14:06 |  |  |  |  |  |  | 14:45:38 | 44 | 18,983 | 17 | 248 | 2 | Clock error (FMS ≈20s late) |
|  | F1 | +SW325 | B737 | 45 | 1-3 | 14:45:14 | 00:58 | 14:46:12 | 14:45:14 | 00:59 | 14:44:15 | 14:43:22 | 14:44:15 | 14:46:24 |  | 14:46:12 | 14:08 |  |  |  |  |  |  | 14:46:10 | -2 | 19,021 | 21 | 250 | 0 |  |
|  | F3 | +SW114 | B737 | 30 | 1-3 | 14:46:17 | 01:13 | 14:47:30 | 14:46:17 | 00:28 | 14:46:45 | 14:44:47 | 14:46:45 | 14:53:19 |  | 14:47:30 | 14:10 |  |  |  |  |  |  | 14:47:24 | -6 | 19,072 | 72 | 250 | 0 |  |
|  | F2 | +SW362 | B737 | 30 | 1-3 | 14:46:45 | 02:03 | 14:48:48 | 14:46:45 | 00:20 | 14:46:25 | 14:44:23 | 14:46:25 | 14:50:23 |  | 14:48:48 | 14:12 |  |  |  |  |  |  | 14:48:33 | -15 | 19,046 | 46 | 250 | 0 |  |
|  | F5 | +UA456 | B757 | 50 | 1-3 | 14:47:53 | 02:13 | 14:50:06 | 14:47:53 | 00:01 | 14:47:54 | NA | 14:47:54 | NA |  | 14:50:36 | 14:13 |  |  |  |  |  |  | 14:49:56 | -40 | 19,089 | 89 | 249 | 1 |  |
|  | F6 | +UA517 | B757 | 100 | 1-3 | 14:51:23 | 00:13 | 14:51:36 | 14:51:23 | 00:41 | 14:50:42 | NA | 14:50:42 | NA |  | 14:51:36 | 16:54 |  |  |  |  |  |  | 14:51:44 | 8 | 19,030 | 30 | 241 | 9 |  |
| D3R2 [B / TW] | F1 | +SW325 | B737 | 45 | 1-3 | 15:59:46 | 01:14 | 16:01:00 | 15:59:46 | 00:11 | 15:59:35 | 15:58:33 | 15:59:35 | 16:00:27 |  | 16:00:30 | 15:34 |  |  |  |  |  |  | 16:01:02 | 32 | 19,022 | 22 | 252 | 2 | AUI Amd 16:00:30 @ |
|  | F2 | +SW362 | B737 | 30 | 1-3 | 16:01:40 | 00:38 | 16:02:18 | 16:01:40 | 00:42 | 16:00:58 | 15:58:48 | 16:00:58 | 16:02:15 |  | 16:02:18 | 15:34 |  |  |  |  |  |  | 16:02:18 | 0 | 19,022 | 22 | 256 | 6 |  |
|  | F3 | +SW114 | B737 | 30 | 1-3 | 16:02:12 | 01:06 | 16:03:18 | 16:02:12 | 00:35 | 16:01:37 | 15:59:03 | 16:01:37 | 16:04:17 |  | 16:03:18 | 15:35 |  |  |  |  |  |  | 16:03:24 | 6 | 19,019 | 19 | 250 | 0 |  |
|  | F5 | +UA456 | B757 | 50 | 1-3 | 16:02:48 | 01:36 | 16:04:24 | 16:02:48 | 00:06 | 16:02:42 | NA | 16:02:42 | NA |  | 16:04:24 | 15:36 |  |  |  |  |  |  | 16:04:28 | 4 | 19,127 | 127 | 249 | 1 |  |
|  | F4 | +UA320 | A320 | 45 | 1-3 | 16:04:54 | 00:36 | 16:05:30 | 16:04:54 | 00:54 | 16:04:00 | NA | 16:04:00 | NA |  | 16:05:30 | 15:37 |  |  |  |  |  |  | 16:05:46 | 16 | 18,983 | 17 | 250 | 0 |  |
|  | F6 | +UA517 | B757 | 100 | 1-3 | 16:05:01 | 01:59 | 16:07:00 | 16:05:01 | 00:31 | 16:04:30 | NA | 16:04:30 | NA |  | 16:06:24 | 15:40 |  |  |  |  |  |  | 16:06:30 | 6 | 19,103 | 103 | 235 | 15 | AUI Amd 16:06:24 @ 15:45 |
| D3R4 [C / TW] | F3 | +SW449 | B737 | 30 | 1-3 | 17:11:50 | 00:50 | 17:11:00 | 17:11:50 | 00:01 | 17:11:51 | 17:10:24 | 17:11:51 | 17:12:13 |  | 17:11:00 | 16:41 |  |  |  |  |  |  | 17:11:05 | 5 | 19,012 | 12 | 250 | 0 |  |
|  | F2 | +DL1214 | B737 | 30 | 1-3 | 17:12:11 | 00:13 | 17:12:24 | 17:12:11 | 00:05 | 17:12:16 | 17:09:35 | 17:12:16 | 17:15:23 |  | 17:12:24 | 16:49 |  |  |  |  |  |  | 17:12:24 | 0 | 19,021 | 21 | 267 | 17 |  |
|  | F1 | +SW2241 | B737 | 30 | 1-3 | 17:11:34 | 02:14 | 17:13:48 | 17:11:34 | 00:28 | 17:12:02 | 17:10:07 | 17:12:02 | 17:13:21 |  | 17:13:48 | 16:52 |  |  |  |  |  |  | 17:13:51 | 3 | 19,020 | 20 | 252 | 2 |  |
|  | F4 | +UA962 | A320 | 25 | 1-3 | 17:15:46 | 00:28 | 17:15:18 | 17:15:46 | 00:14 | 17:16:00 | NA | 17:16:00 | NA |  | 17:15:16 | 16:54 |  |  |  |  |  |  | 17:15:48 | 32 | 18,983 | 17 | 245 | 5 |  |
|  | F5 | +UA923 | B757 | 50 | 1-3 | 17:16:29 | 00:01 | 17:16:30 | 17:16:29 | 00:01 | 17:16:30 | NA | 17:16:30 | NA |  | 17:16:30 | 16:55 |  |  |  |  |  |  | 17:17:01 | 31 | 19,020 | 20 | 267 | 17 |  |
|  | F6 | +UA745 | B757 | 50 | 1-3 | 17:17:40 | 00:14 | 17:17:54 | 17:17:40 | 00:32 | 17:18:12 | NA | 17:18:12 | NA |  | 17:17:54 | 16:56 |  |  |  |  |  |  | 17:18:06 | 12 | 19,013 | 13 | 242 | 8 |  |

| Run | Flt | ACID | Type | CI | Meter | TMA Analysis | | | TMA | Δt | FMS | FMS Analysis | | | | RTA Assignment | | | | Corr | RTA | ΔM | EDA | Cross Fix - | | Cross Fix - | | Cross Fix - | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | ETA | Δt | STA | ETA | | ETA | First | ETA | Last | Window | Time | Assn | Spd | Path | Amd | Spd | | Spd | Time | Δt | Alt | ΔAlt | Speed | ΔSpd | |
| D3R5 [C / HW] | F2 | +DL1214 | B737 | 30 | 1-3 | 18:57:20 | 00:14 | 18:57:06 | 18:57:20 | 00:37 | 18:56:43 | 18:54:11 | 18:56:43 | 19:05:16 | | 18:57:06 | 18:24 | | | | | | | 18:56:59 | -7 | 19,037 | 37 | 250 | 0 | |
| | F3 | +SW449 | B737 | 30 | 1-3 | 18:57:24 | 02:18 | 18:59:42 | 18:57:24 | 01:37 | 18:55:47 | 18:55:07 | 18:55:47 | 18:58:06 | | 18:58:24 | 18:25 | | | | | | | 18:58:11 | -13 | 19,070 | 70 | 250 | 0 | Swap Amd 18:58:24@18:28 |
| | F1 | +SW2241 | B737 | 30 | 1-3 | 18:57:24 | 01:00 | 18:58:24 | 18:57:24 | 00:08 | 18:57:32 | 18:55:34 | 18:57:32 | 19:01:12 | | 18:59:42 | 18:25 | | | | | | | 18:59:36 | -6 | 19,057 | 57 | 250 | 0 | Swap Amd 18:59:42@18:29 |
| | F6 | +UA745 | B757 | 50 | 1-3 | 18:58:48 | 02:12 | 19:01:00 | 18:58:48 | 01:12 | 18:57:36 | NA | 18:57:36 | NA | | 19:01:00 | 18:27 | | | | | | | 19:00:59 | -1 | 19,000 | 0 | 250 | 0 | |
| | F4 | +UA962 | A320 | 25 | 1-3 | 19:01:43 | 00:35 | 19:02:18 | 19:01:43 | 01:43 | 19:00:00 | NA | 19:00:00 | NA | | 19:02:18 | 18:30 | | | | | | | 19:02:33 | 15 | 18,983 | 17 | 240 | 10 | |
| | F5 | +UA923 | B757 | 50 | 1-3 | 19:04:01 | 00:25 | 19:03:36 | 19:04:01 | 00:07 | 19:03:54 | NA | 19:03:54 | NA | | 19:03:36 | 18:31 | | | | | | | 19:03:32 | -4 | 19,002 | 2 | 250 | 0 | |
| 12-2 D1R1 [B / TW] | F1 | SW325 | B737 | 30 | 1-3 | 13:25:08 | 00:08 | 13:25:00 | 13:25:08 | 00:05 | 13:25:13 | 13:23:47 | 13:25:13 | 13:25:34 | | 13:25:00 | Y | Y | N | N | | | | 13:25:11 | 11 | 19,018 | 18 | 250 | 0 | RTA entered as 13:25:09 |
| | F2 | SW362 | B737 | 30 | 1-3 | 13:27:03 | 00:21 | 13:26:42 | 13:27:03 | 00:40 | 13:26:23 | 13:24:38 | 13:26:23 | 13:27:40 | | | | | | | | | | | | | | | | Network Comm; A/C dropped |
| | F5 | AA456 | B757 | 50 | 1-3 | 13:26:55 | 00:59 | 13:27:54 | 13:26:55 | 00:01 | 13:26:54 | NA | 13:26:54 | NA | | 13:27:54 | NA | Y | N | N | | | | 13:27:55 | 1 | 19,118 | 118 | 248 | 2 | |
| | F3 | SW114 | B737 | 15 | 1-3 | 13:27:50 | 01:16 | 13:29:06 | 13:27:50 | 01:04 | 13:26:46 | 13:24:30 | 13:26:46 | 13:29:12 | | 13:29:06 | Y | Y | N | N | | | | 13:29:08 | 2 | 19,017 | 17 | 259 | 9 | |
| | F4 | UA320 | A320 | 25 | 1-3 | 13:28:13 | 02:05 | 13:30:18 | 13:28:13 | 00:13 | 13:28:00 | NA | 13:28:00 | NA | | 13:30:18 | NA | Y | N | N | | | | 13:30:28 | 10 | 18,983 | 17 | 243 | 7 | |
| | F6 | AA517 | B757 | 100 | 1-3 | 13:29:41 | 03:07 | 13:32:48 | 13:29:41 | 00:05 | 13:29:36 | NA | 13:29:36 | NA | | 13:31:42 | NA | Y | N | N | | | | 13:31:44 | 2 | 18,994 | 6 | 248 | 2 | |
| 12-2 D1R2 [C / TW] | F1 | SW 241 | B737 | 30 | 1-3 | 15:43:59 | 00:17 | 15:43:42 | 15:43:59 | 00:37 | 15:43:22 | 15:41:26 | 15:43:22 | 15:44:59 | | 15:43:42 | Y | Y | N | N | | | | 15:43:57 | 15 | 19,013 | 13 | 250 | 0 | |
| | F3 | SW449 | B737 | 30 | 1-3 | 15:44:04 | 00:52 | 15:44:56 | 15:44:04 | 00:06 | 15:44:10 | 15:43:02 | 15:44:10 | 15:44:49 | | 15:45:00 | N | Y | N | N | | | | 15:45:14 | 14 | 19,012 | 12 | 250 | 0 | |
| | F2 | DL121 | B737 | 30 | 1-3 | 15:45:20 | 00:42 | 15:46:02 | 15:45:20 | 01:26 | 15:43:54 | 15:41:09 | 15:43:54 | 15:47:47 | | 15:46:00 | Y | Y | N | N | | | | 15:45:47 | -13 | 19,015 | 15 | 296 | 46 | |
| | F5 | AA923 | B757 | 50 | 1-3 | 15:44:55 | 02:22 | 15:47:17 | 15:44:55 | 00:07 | 15:44:48 | NA | 15:44:48 | NA | | | NA | N | Y | N | | | | | | 18,972 | 28 | 250 | 0 | AUI: Amd RTA not issued |
| | F4 | UA962 | A320 | 25 | 1-3 | 15:45:55 | 02:36 | 15:48:31 | 15:45:55 | 00:05 | 15:46:00 | NA | 15:46:00 | NA | | 15:48:30 | NA | Y | N | N | | | | 15:47:35 | -55 | 19,024 | 24 | 250 | 0 | |
| | F6 | AA745 | B757 | 50 | 1-3 | 15:49:30 | 00:15 | 15:49:45 | 15:49:30 | 00:18 | 15:49:48 | NA | 15:49:48 | NA | | 15:49:48 | NA | Y | N | N | | | | 15:49:51 | 3 | 18,999 | 1 | 249 | 1 | |

| Run | Flt | ACID | Type | CI | Meter | TMA Analysis | | | TMA | Δt | FMS | FMS Analysis | | | | RTA Assignment | | | | Corr | RTA | ΔM | EDA | Cross Fix - | | Cross Fix - | | Cross Fix - | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | ETA | Δt | STA | ETA | | ETA | First | ETA | Last | Window | Time | Assn | Spd | Path | Amd | Spd | | Spd | Time | Δt | Alt | ΔAlt | Speed | ΔSpd | |
| 12-2 D1R3 [B / HW] | F1 | SW325 | B737 | 30 | 4-8 | 17:32:24 | 03:06 | 17:35:30 | 17:32:24 | 00:44 | 17:31:40 | 17:30:05 | 17:31:40 | 17:33:05 | | 17:35:30 | N | N | Y | N | | | | 17:35:36 | 6 | 19,012 | 12 | 250 | 0 | |
| | F4 | UA320 | A320 | 25 | 4-8 | 17:33:56 | 03:14 | 17:37:10 | 17:33:56 | 01:56 | 17:32:00 | NA | 17:32:00 | NA | | 17:37:12 | N | N | Y | N | | | | 17:37:52 | 40 | 18,983 | 17 | 236 | 14 | |
| | F3 | SW114 | B737 | 15 | 4-8 | 17:34:51 | 03:39 | 17:38:30 | 17:34:51 | 00:26 | 17:35:17 | 17:32:58 | 17:35:17 | 17:41:13 | | 17:38:48 | Y | N | Y | N | | | | 17:42:26 | | 25,001 | 6001 | 251 | 1 | LNAV/VNAV Disconnect |
| | F2 | SW362 | B737 | 30 | 4-8 | 17:35:34 | 04:56 | 17:40:30 | 17:35:34 | 00:30 | 17:35:04 | 17:33:03 | 17:35:04 | 17:39:00 | | | | | | | | | | | | | | | | Network Comm, A/C dropped |
| | F5 | AA456 | B757 | 50 | 4-8 | 17:36:50 | 05:20 | 17:42:10 | 17:36:50 | 00:26 | 17:36:24 | NA | 17:36:24 | NA | | 17:42:12 | NA | N | Y | N | | | | 17:41:58 | -14 | 19,006 | 6 | 247 | 3 | |
| | F6 | AA517 | B757 | 100 | 4-8 | 17:40:53 | 07:57 | 17:48:50 | 17:40:53 | 00:35 | 17:40:18 | NA | 17:40:18 | NA | | 17:48:48 | NA | N | Y | N | | | | 17:48:48 | 0 | 19,001 | 1 | 251 | 1 | |
| 12-2 D1R4 [C /HW] | F2 | DL121 | B737 | 30 | 4-8 | 19:58:10 | 02:14 | 20:00:24 | 19:58:10 | 58:10 | 0:00:00 | 19:54:50 | | 20:06:10 | | 20:00:24 | | | | | | | | 20:00:07 | -17 | 19,065 | 65 | 251 | 1 | |
| | F1 | SW 241 | B737 | 30 | 4-8 | 19:58:10 | 04:02 | 20:02:12 | 19:58:10 | 58:10 | 0:00:00 | 19:56:13 | | 20:01:51 | | 20:02:12 | N | N | Y | N | | | | 20:02:16 | 4 | 19,029 | 29 | 250 | 0 | |
| | F3 | SW449 | B737 | 30 | 4-8 | 19:58:08 | 05:58 | 20:04:06 | 19:58:08 | 00:38 | 19:57:30 | | 19:57:30 | | | 20:04:06 | N | N | Y | Y | | | | 20:04:17 | 11 | 18,983 | 17 | 245 | 5 | |
| | F6 | AA745 | B757 | 50 | 4-8 | 19:58:50 | 07:10 | 20:06:00 | 19:58:50 | 58:50 | 0:00:00 | NA | | NA | | 20:06:00 | N | N | Y | N | | | | 20:05:58 | -2 | 19,007 | 7 | 251 | 1 | |
| | F4 | UA962 | A320 | 25 | 4-8 | 20:00:44 | 07:10 | 20:07:54 | 20:00:44 | 06:34 | 19:54:10 | NA | 19:54:10 | NA | | | N | N | Y | N | | | | | | 19,000 | 0 | 227 | 23 | AUI: Amd RTA not issued |
| | F5 | AA923 | B757 | 50 | 4-8 | 20:01:24 | 08:18 | 20:09:42 | 20:01:24 | 01:24 | 0:00:00 | NA | | NA | | 20:09:42 | N | N | Y | N | | | | 20:09:42 | 0 | 19,016 | 16 | 250 | 0 | |
| 12-2 D2R1 [B / HW] | F1 | SW325 | B737 | 30 | 4-8 | 13:40:20 | 00:11 | 13:40:09 | 13:40:20 | 40:20 | 0:00:00 | | | | | EDA Validation | NA | N | Y | N | | | | 13:40:34 | | 19,011 | 11 | 250 | 0 | |
| | F4 | UA320 | A320 | 25 | 4-8 | 13:40:18 | 01:42 | 13:42:00 | 13:40:18 | 40:18 | 0:00:00 | | | | | | NA | N | Y | Y | | | | 13:44:18 | | 18,986 | 14 | 249 | 1 | Unable 1st path; Reqd Corr |
| | F3 | SW114 | B737 | 15 | 4-8 | 13:41:16 | 02:35 | 13:43:51 | 13:41:16 | 41:16 | 0:00:00 | | | | | | NA | Y | N | N | | | | 13:43:24 | | 19,086 | 86 | 250 | 0 | |
| | F2 | SW362 | B737 | 30 | 4-8 | 13:41:22 | 04:20 | 13:45:42 | 13:41:22 | 41:22 | 0:00:00 | | | | | | NA | N | Y | N | | | | 13:45:55 | | 19,037 | 37 | 250 | 0 | |
| | F5 | AA456 | B757 | 50 | 4-8 | 13:43:14 | 04:19 | 13:47:33 | 13:43:14 | 43:14 | 0:00:00 | | | | | | NA | N | Y | N | | | | 13:47:37 | | 18,999 | 1 | 230 | 20 | |
| | F6 | AA517 | B757 | 100 | 4-8 | 13:47:08 | 07:49 | 13:54:57 | 13:47:08 | 47:08 | 0:00:00 | | | | | | NA | N | Y | N | | | | 13:54:23 | | 19,001 | 1 | 250 | 0 | |

| Run | Flt | ACID | Type | CI | Meter | TMA Analysis | | | TMA | Δt | FMS | FMS Analysis | | | | RTA Assignment | | | | Corr | RTA | ΔM | EDA | Cross Fix - | | Cross Fix - | | Cross Fix - | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | ETA | Δt | STA | ETA | | ETA | First | ETA | Last | Window | Time | Assn | Spd | Path | Amd | Spd | | Spd | Time | Δt | Alt | ΔAlt | Speed | ΔSpd | |
| 12-2D2R2 [C / HW] | F2 | DL121 | B737 | 30 | 4-8 | 15:17:04 | 01:13 | 15:18:17 | 15:17:04 | 17:04 | 0:00:00 | | | | | EDA Validation | NA | N | Y | N | | | | 15:16:51 | | 20,511 | 1511 | 251 | 1 | |
| | F3 | SW449 | B737 | 30 | 4-8 | 15:17:45 | 02:27 | 15:20:12 | 15:17:45 | 17:45 | 0:00:00 | | | | | | NA | N | Y | N | | | | 15:20:44 | | 19,084 | 84 | 250 | 0 | |
| | F1 | SW 241 | B737 | 30 | 4-8 | 15:17:52 | 04:14 | 15:22:06 | 15:17:52 | 17:52 | 0:00:00 | | | | | | NA | N | Y | Y | | | | 15:22:34 | | 19,071 | 71 | 250 | 0 | |
| | F6 | AA745 | B757 | 50 | 4-8 | 15:18:25 | 05:36 | 15:24:01 | 15:18:25 | 18:25 | 0:00:00 | | | | | | NA | N | Y | N | | | | 15:23:16 | | 19,002 | 2 | 250 | 0 | |
| | F4 | UA962 | A320 | 25 | 4-8 | 15:20:14 | 05:42 | 15:25:56 | 15:20:14 | 20:14 | 0:00:00 | | | | | | NA | N | Y | N | | | | 15:25:44 | | 18,983 | 17 | 250 | 0 | Vect past SAYGE for Spacing |
| | F5 | AA923 | B757 | 50 | 4-8 | 15:21:08 | 06:44 | 15:27:52 | 15:21:08 | 21:08 | 0:00:00 | | | | | | NA | N | Y | N | | | | 15:28:06 | | 19,007 | 7 | 248 | 2 | |
| 12-2 D2R3 [B / HW] | F1 | SW325 | B737 | 30 | 4-8 | 17:10:38 | 01:10 | 17:11:48 | 17:10:38 | 00:41 | 17:09:57 | 17:08:27 | 17:09:57 | 17:11:04 | | 17:11:48 | N | N | Y | N | | | | 17:11:52 | 4 | 19,014 | 14 | 250 | 0 | |
| | F4 | UA320 | A320 | 25 | 4-8 | 17:12:02 | 01:16 | 17:13:18 | 17:12:02 | 02:02 | 17:10:00 | NA | 17:10:00 | NA | | 17:13:18 | NA | Y | N | N | | | | 17:13:05 | -13 | 18,983 | 17 | 240 | 10 | |
| | F3 | SW114 | B737 | 15 | 4-8 | 17:12:58 | 02:14 | 17:15:12 | 17:12:58 | 00:16 | 17:13:14 | 17:11:05 | 17:13:14 | 17:18:41 | | 17:15:12 | Y | Y | N | N | | | | 17:14:55 | -17 | 20,013 | 0 | 250 | 0 | ATC assigned FL200 |
| | F2 | SW362 | B737 | 30 | 4-8 | 17:13:02 | 03:46 | 17:16:48 | 17:13:02 | 00:46 | 17:12:16 | 17:11:16 | 17:12:16 | 17:16:34 | | 17:16:48 | N | N | Y | Y | | | | 17:16:51 | 3 | 19,002 | 2 | 250 | 0 | Pilot Error Entry of RTA |
| | F5 | AA456 | B757 | 50 | 4-8 | 17:18:14 | 00:04 | 17:18:18 | 17:18:14 | 03:38 | 17:14:36 | NA | 17:14:36 | NA | | 17:18:18 | NA | N | Y | N | | | | 17:18:21 | 3 | 19,004 | 4 | 251 | 1 | |
| | F6 | AA517 | B757 | 100 | 4-8 | 17:18:53 | 06:31 | 17:25:24 | 17:18:53 | 00:29 | 17:18:24 | NA | 17:18:24 | NA | | 17:25:24 | NA | N | Y | N | | | | 17:25:33 | 9 | 18,997 | 3 | 248 | 2 | |
| 12-2 D2R4 [C / HW] | F2 | DL121 | B737 | 30 | 4-8 | 18:42:08 | 06:04 | 18:48:12 | 18:42:08 | 01:48 | 18:43:56 | 18:41:19 | 18:43:56 | 18:52:58 | | 18:48:12 | Y | N | Y | N | | | | 18:48:13 | 1 | 19,043 | 43 | 239 | 11 | |
| | F3 | SW449 | B737 | 30 | 4-8 | 18:45:38 | 02:34 | 18:48:12 | 18:45:38 | 01:33 | 18:44:05 | 18:42:23 | 18:44:05 | 18:45:17 | | | | | | | | | | | | 19,000 | 0 | 250 | 0 | AUI; Ext Vectors; No Amd |
| | F1 | SW 241 | B737 | 30 | 4-8 | 18:45:13 | 07:34 | 18:52:47 | 18:45:13 | 00:22 | 18:44:51 | 18:42:48 | 18:44:51 | 18:48:46 | | 18:52:42 | N | N | Y | N | | | | 18:53:20 | 38 | 19,012 | 12 | 220 | 30 | ATC Spd Rstr ≤250K/ ≤220K |
| | F6 | AA745 | B757 | 50 | 4-8 | 18:53:16 | 00:56 | 18:54:12 | 18:53:16 | 08:28 | 18:44:48 | NA | 18:44:48 | NA | | | | | | | | | | 18:51:50 | | 19,000 | 0 | 250 | 0 | AUI; No Amd |
| | F4 | UA962 | A320 | 25 | 4-8 | 18:55:43 | 00:07 | 18:55:36 | 18:55:43 | 09:43 | 18:46:00 | NA | 18:46:00 | NA | | 18:55:42 | NA | N | Y | N | | | | 18:56:18 | 36 | 18,986 | 14 | 240 | 10 | |
| | F5 | AA923 | B757 | 50 | 4-8 | 18:44:24 | 09:48 | 18:54:12 | 18:44:24 | 03:06 | 18:47:30 | NA | 18:47:30 | NA | | | | | | | | | | 19:00:14 | | 19,000 | 0 | 250 | 0 | No RTA Issued |

| Run | Flt | ACID | Type | CI | Meter | TMA Analysis | | | TMA | Δt | FMS | FMS Analysis | | | | RTA Assignment | | | | Corr | RTA | ΔM | EDA | Cross Fix - | | Cross Fix - | | Cross Fix - | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | ETA | Δt | STA | ETA | | ETA | First | ETA | Last | Window | Time | Assn | Spd | Path | Amd | Spd | | Spd | Time | Δt | Alt | ΔAlt | Speed | ΔSpd | |
| 12-2D2R5 [C / TW] | F2 | DL121 | B737 | 30 | 4-8 | 20:06:02 | 02:40 | 20:08:42 | 20:06:02 | 05:06 | 20:00:56 | 19:58:38 | 20:00:56 | 20:04:04 | | 20:04:51 | N | N | Y | N | | | | 20:04:57 | 6 | 19,018 | 18 | 262 | 12 | |
| | F1 | SW 241 | B737 | 30 | 4-8 | 20:10:43 | 00:43 | 20:10:00 | 20:10:43 | 09:47 | 20:00:56 | 19:58:52 | 20:00:56 | 20:02:02 | | | | | | | | | | 20:04:30 | | 19,069 | 69 | 250 | 0 | AUI w/ Path Stretch; No Amd |
| | F3 | SW449 | B737 | 30 | 4-8 | 20:06:22 | 04:56 | 20:11:18 | 20:06:22 | 05:49 | 20:00:33 | | 20:00:33 | | | 20:03:36 | Y | Y | Y | N | | | | 20:03:47 | 11 | 19,002 | 2 | 250 | 0 | |
| | F5 | AA923 | B757 | 50 | 4-8 | | 00:00 | | 0:00:00 | 01:54 | 20:01:54 | NA | 20:01:54 | NA | | 20:05:54 | NA | N | Y | N | | | | 20:05:56 | 2 | 19,001 | 1 | 250 | 0 | |
| | F4 | UA962 | A320 | 25 | 4-8 | | 00:00 | | 0:00:00 | 03:00 | 20:03:00 | NA | 20:03:00 | NA | | | | | Y | | | | | 20:13:06 | | 18,983 | 17 | 220 | 0 | No RTA; ATC Assn 220K |
| | F6 | AA745 | B757 | 50 | 4-8 | | 00:00 | | 0:00:00 | 06:54 | 20:06:54 | NA | 20:06:54 | NA | | 20:09:54 | NA | N | Y | N | | | | 20:09:54 | 0 | 19,001 | 1 | 250 | 0 | |
| 12-2 D3R1 [B / HW] | F1 | SW325 | B737 | 30 | 4-8 | 13:26:24 | 03:24 | 13:29:48 | 13:26:24 | 00:41 | 13:25:43 | 13:23:58 | 13:25:43 | 13:27:03 | | 13:29:48 | N | N | Y | Y | | | | 13:32:13 | | 17,001 | 0 | 250 | 0 | ATC Spd/Alt Restr; x17000 |
| | F2 | SW362 | B737 | 30 | 4-8 | 13:26:00 | 03:26 | 13:29:26 | 13:26:00 | 03:03 | 13:29:03 | 13:26:57 | 13:29:03 | 13:33:11 | | 13:29:36 | Y | Y | N | N | | | | 13:29:34 | -2 | 19,002 | 2 | 250 | 0 | |
| | F4 | UA320 | A320 | 25 | 4-8 | 13:27:57 | 03:54 | 13:31:51 | 13:27:57 | 02:57 | 13:25:00 | NA | 13:25:00 | NA | | 13:32:30 | N | N | N | N | | | | 13:31:19 | | 19,209 | 209 | 244 | 6 | AUI; Amd AUI |
| | F3 | SW114 | B737 | 30 | 4-8 | 13:28:50 | 04:31 | 13:33:21 | 13:28:50 | 00:26 | 13:29:16 | 13:26:58 | 13:29:16 | 13:35:19 | | 13:33:24 | Y | N | Y | N | | | | 13:33:42 | | 19,015 | 15 | 220 | 0 | ATC Assn 220K |
| | F5 | AA456 | B757 | 50 | 4-8 | 13:30:47 | 05:31 | 13:36:18 | 13:30:47 | 00:23 | 13:30:24 | NA | 13:30:24 | NA | | 13:35:42 | N | N | Y | Y | | | | 13:37:58 | | 19,004 | 4 | 250 | 0 | AUI: Amd AUI |
| | F6 | AA517 | B757 | 50 | 4-8 | 13:34:46 | 01:56 | 13:36:42 | 13:34:46 | 00:28 | 13:34:18 | NA | 13:34:18 | NA | | 13:36:42 | N | N | Y | N | | | | 13:36:21 | | 23,001 | 0 | 285 | 0 | ATC Assn Spd/Alt Restr |
| 12-2 D3R2 [C / HW] | F2 | DL121 | B737 | 30 | 4-8 | 15:03:56 | 00:52 | 15:04:48 | 15:03:56 | 00:44 | 15:03:12 | 15:00:34 | 15:03:12 | 15:12:11 | | 15:04:48 | Y | Y | N | N | | | | 15:04:45 | -3 | 19,031 | 31 | 250 | 0 | |
| | F3 | SW449 | B737 | 30 | 4-8 | 15:04:03 | 00:45 | 15:04:48 | 15:04:03 | 04:43 | 14:59:20 | 14:58:18 | 14:59:20 | 15:01:29 | | 15:06:24 | N | N | Y | N | | | | 15:06:36 | 12 | 19,034 | 34 | 250 | 0 | |
| | F1 | SW 241 | B737 | 30 | 4-8 | 15:04:08 | 03:57 | 15:08:05 | 15:04:08 | 00:05 | 15:04:03 | 15:01:58 | 15:04:03 | 15:08:10 | | 15:08:06 | N | N | Y | N | | | | 15:08:09 | 3 | 19,012 | 12 | 250 | 0 | |
| | F6 | AA745 | B757 | 50 | 4-8 | 15:04:44 | 05:01 | 15:09:45 | 15:04:44 | 00:38 | 15:04:06 | NA | 15:04:06 | NA | | 15:09:48 | NA | N | Y | Y | | | | 15:09:12 | -36 | 19,003 | 3 | 248 | 2 | AUI w/ 1st Path; OK w/ 2nd |
| | F4 | UA962 | A320 | 25 | 4-8 | 15:06:24 | 05:01 | 15:11:25 | 15:06:24 | 09:24 | 14:57:00 | NA | 14:57:00 | NA | | 15:11:24 | NA | N | Y | N | | | | 15:11:20 | -4 | 18,983 | 17 | 216 | 34 | |
| | F5 | AA923 | B757 | 50 | 4-8 | 15:07:21 | 02:24 | 15:09:45 | 15:07:21 | 00:33 | 15:06:48 | NA | 15:06:48 | NA | | 15:12:42 | NA | N | Y | N | | | | 15:12:43 | 1 | 19,009 | 9 | 250 | 0 | |

| Run | Flt | ACID | Type | CI | Meter | TMA Analysis |  |  | TMA | Δt | FMS | FMS Analysis |  |  |  | RTA Assignment |  |  |  | Corr | RTA | ΔM | EDA | Cross Fix - |  | Cross Fix - |  | Cross Fix - |  | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  | ETA | Δt | STA | ETA |  | ETA | First | ETA | Last | Window | Time | Assn | Spd | Path | Amd | Spd |  | Spd | Time | Δt | Alt | ΔAlt | Speed | ΔSpd |  |
| 12-2D3R3 [B / TW] | F1 | SW325 | B737 | 30 | 4-8 | 16:12:05 | 03:18 | 16:15:23 | 16:12:05 | 00:03 | 16:12:08 | 16:10:37 | 16:12:08 | 16:12:33 |  | 16:15:24 | N | N | Y | N |  |  |  | 16:15:34 | 10 | 19,012 | 12 | 250 | 0 |  |
|  | F2 | SW362 | B737 | 30 | 4-8 | 16:15:12 | 03:21 | 16:18:33 | 16:15:12 | 00:11 | 16:15:01 | 16:12:51 | 16:15:01 | 16:16:28 |  | 16:18:32 | N | N | Y | N |  |  |  | 16:18:25 | -7 | 19,011 | 11 | 250 | 0 |  |
|  | F3 | SW114 | B737 | 30 | 4-8 | 16:16:15 | 03:53 | 16:20:08 | 16:16:15 | 00:31 | 16:15:44 | 16:13:11 | 16:15:44 | 16:24:05 |  | 16:20:06 | Y | N | Y | N |  |  |  | 16:20:08 | 2 | 19,016 | 16 | 250 | 0 |  |
|  | F5 | AA456 | B757 | 50 | 4-8 | 16:16:53 | 05:07 | 16:22:00 | 16:16:53 | 00:05 | 16:16:48 | NA | 16:16:48 | NA |  | 16:22:00 | NA | N | Y | N |  |  |  | 16:23:15 |  | 19,003 | 3 | 251 | 1 | AAU; Flt FREEZE Error |
|  | F4 | UA320 | A320 | 25 | 4-8 | 16:19:03 | 04:52 | 16:23:55 | 16:19:03 | 04:03 | 16:15:00 | NA | 16:15:00 | NA |  | 16:23:36 | NA | N | Y | N |  |  |  | 16:23:30 | -6 | 20,866 | 866 | 255 | 5 | ATC Assn FL200 |
|  | F6 | AA517 | B757 | 50 | 4-8 | 16:19:18 | 05:58 | 16:25:16 | 16:19:18 | 00:06 | 16:19:12 | NA | 16:19:12 | NA |  | 16:25:18 | NA | N | Y | N |  |  |  | 16:25:16 | -2 | 23,654 | 0 | 251 | 1 | ATC Restr Alt; Unable FL190 |
| 12-2 D3R4 [C / TW] | F3 | SW449 | B737 | 30 | 4-8 | 18:03:48 | 02:18 | 18:06:06 | 18:03:48 | 00:00 | 18:03:48 | 18:02:26 | 18:03:48 | 18:04:14 |  | 18:06:06 | N | N | Y | N |  |  |  | 18:06:13 | 7 | 19,018 | 18 | 250 | 0 |  |
|  | F2 | DL121 | B737 | 30 | 4-8 | 18:04:11 | 03:35 | 18:07:46 | 18:04:11 | 00:00 | 18:04:11 | 18:01:17 | 18:04:11 | 18:08:02 |  | 18:07:48 | N | N | Y | N |  |  |  | 18:07:47 | -1 | 19,017 | 17 | 263 | 13 |  |
|  | F1 | SW 241 | B737 | 30 | 4-8 | 18:04:16 | 05:05 | 18:09:21 | 18:04:16 | 00:18 | 18:03:58 | 18:01:50 | 18:03:58 | 18:05:27 |  | 18:09:24 | N | N | Y | N |  |  |  | 18:09:37 | 13 | 19,012 | 12 | 250 | 0 |  |
|  | F5 | AA923 | B757 | 50 | 4-8 | 18:05:16 | 05:40 | 18:10:56 | 18:05:16 | 00:04 | 18:05:12 | NA | 18:05:12 | NA |  | 18:11:00 | NA | N | Y | N |  |  |  | 18:10:29 |  | 19,007 | 7 | 250 | 0 | AUI; No Amd |
|  | F4 | UA962 | A320 | 25 | 4-8 | 18:06:25 | 06:06 | 18:12:31 | 18:06:25 | 00:25 | 18:06:00 | NA | 18:06:00 | NA |  | 18:12:30 | NA | N | Y | N |  |  |  | 18:12:13 | -17 | 18,986 | 14 | 250 | 0 |  |
|  | F6 | AA745 | B757 | 50 | 4-8 | 18:10:00 | 04:06 | 18:14:06 | 18:10:00 | 00:12 | 18:10:12 | NA | 18:10:12 | NA |  | 18:14:06 | NA | N | Y | Y |  |  |  | 18:13:27 |  | 19,007 | 7 | 249 | 1 | AUI; Revised Path AUI |

| Run | Flt | ACID | Type | CI | Meter | TMA Analysis | | | TMA ETA | Δt | FMS ETA | FMS Analysis | | | | RTA Assignment | | | | Corr Amd | RTA Spd | ΔM | EDA Spd | Cross Fix - | | Cross Fix - | | Cross Fix - | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | ETA | Δt | STA | | | | First | ETA | Last | Window | Time | Assn | Spd | Path | | | | | Time | Δt | Alt | ΔAlt | Speed | ΔSpd | |
| 12-3 D1R1 [C / HW] | F1 | SWA241 | B737 | 30 | 3-4 | 15:44:43 | 02:47 | 15:47:30 | 15:44:43 | 01:36 | 15:43:07 | 15:42:26 | 15:43:07 | 15:48:52 | | 15:47:30 | | | LBF AMW043/62 AMW | 1 | 0.763 | 0.023 | 0.74 | 15:47:12 | -18 | 19,000 | 0 | 280 | 30 | 1 Amdt / NC |
| | F2 | DAL121 | B737 | 30 | 3-4 | 15:34:10 | 03:02 | 15:37:12 | 15:34:10 | 00:40 | 15:33:30 | 15:32:45 | 15:33:30 | 15:39:30 | | 15:37:12 | | | | 0 | 0.707 | 0.007 | 0.70 | 15:37:20 | | 19,100 | 100 | 250 | 0 | |
| | F3 | SWA449 | B737 | 30 | 3-4 | 15:30:16 | 03:02 | 15:33:18 | 15:30:16 | 01:21 | 15:31:37 | 15:31:03 | 15:31:37 | 15:33:12 | | 15:33:18 | | | Vector / D AMWAY | 0 | 0.776 | 0.006 | 0.77 | 15:33:13 | -5 | 19,000 | 0 | 250 | 0 | No PATH; Vector for RTA |
| | F4 | UAL962 | B737 | 30 | 3-4 | 15:40:23 | 03:13 | 15:43:36 | 15:40:23 | 00:36 | 15:40:59 | 15:38:27 | 15:40:59 | 15:48:07 | | | | | | | | | | 15:42:02 | | 19,000 | 0 | 250 | 0 | No RTA; EDA NVT |
| | F5 | AAL923 | B757 | 50 | 3-4 | 15:38:36 | 02:30 | 15:41:06 | 15:38:36 | 00:12 | 15:38:24 | NA | 15:38:24 | NA | | 15:41:06 | | | LBF AMW052/59 AMW | 0 | 0.765 | 0.025 | 0.79 | 15:41:06 | 0 | 19,100 | 100 | 249 | 1 | |
| | F6 | AAL745 | B757 | 30 | 3-4 | 15:29:17 | 01:43 | 15:31:00 | 15:29:17 | 00:19 | 15:29:36 | NA | 15:29:36 | NA | | | | | | | | | | | | | | | | FMST FAILED; End Run |
| 12-3 D1R2 [B / HW] | F1 | SWA325 | B737 | 30 | 3-4 | 17:27:58 | 02:56 | 17:30:54 | 17:27:58 | 00:10 | 17:27:48 | 17:26:45 | 17:27:48 | 17:28:22 | | 17:30:54 | | | LBF AMW038/65 AMW | 1 | 0.778 | 0.008 | 0.77 | 17:30:50 | -4 | 19,000 | 0 | 258 | 8 | 1 Amdt / NC |
| | F2 | SWA362 | B737 | 30 | 3-4 | 17:34:33 | 02:39 | 17:37:12 | 17:34:33 | 00:23 | 17:34:56 | 17:32:06 | 17:34:56 | 17:43:19 | | 17:37:12 | | | | 0 | 0.726 | 0.006 | 0.72 | 17:37:07 | | 20,200 | 0 | 262 | 12 | AAC: EDA [FFT165]; Alt |
| | F3 | SWA114 | B737 | 30 | 3-4 | 17:35:52 | 04:28 | 17:40:20 | 17:35:52 | 00:09 | 17:36:01 | 17:33:27 | 17:36:01 | 17:41:37 | | 17:40:18 | | | LBF SA026/59 SA | 0 | 0.733 | 0.023 | 0.71 | 17:40:18 | 0 | 19,000 | 0 | 251 | 1 | |
| | F4 | UAL320 | B737 | 30 | 3-4 | 17:24:01 | 02:11 | 17:26:12 | 17:24:01 | 00:05 | 17:23:56 | 17:22:59 | 17:23:56 | 17:27:31 | | 17:26:12 | | | YANKI SNY079/54 SNY | 0 | 0.762 | 0.022 | 0.74 | 17:26:11 | -1 | 19,000 | 0 | 254 | 4 | |
| | F5 | AAL456 | B757 | 50 | 3-4 | 17:26:53 | 02:29 | 17:29:22 | 17:26:53 | 00:07 | 17:27:00 | NA | 17:27:00 | NA | | 17:29:24 | | | LBF AMW048/46 AMW | 0 | 0.787 | 0.037 | 0.75 | 17:29:21 | -3 | 19,100 | 100 | 257 | 7 | |
| | F6 | AAL517 | B757 | 50 | 3-4 | 17:31:56 | 02:08 | 17:34:04 | 17:31:56 | 00:02 | 17:31:54 | NA | 17:31:54 | NA | | 17:34:06 | | | | 2 | 0.753 | 0.013 | 0.74 | 17:34:05 | -1 | 19,000 | 0 | 246 | 4 | 2 Amdt / NC |
| 12-3 D1R3 [C / TW] | F1 | SWA241 | B737 | 30 | 3-4 | 19:05:05 | 03:31 | 19:08:36 | 19:05:05 | 00:29 | 19:05:34 | 19:07:22 | 19:05:34 | 19:10:09 | | 19:08:36 | | | LBF AMW051/103 AMW | 0 | 0.769 | 0.049 | 0.72 | 19:08:45 | 9 | 19,000 | 0 | 250 | 0 | |
| | F2 | DAL121 | B737 | 30 | 3-4 | 18:58:21 | 03:21 | 19:01:42 | 18:58:21 | 00:15 | 18:58:06 | 18:58:36 | 18:58:06 | 19:03:44 | | 19:01:36 | | | LBF AMW035/66 AMW | 0 | 0.710 | 0.030 | 0.68 | 19:01:45 | 9 | 19,100 | 100 | 251 | 1 | |
| | F3 | SWA449 | B737 | 30 | 3-4 | 18:55:48 | 01:54 | 18:57:42 | 18:55:48 | 00:51 | 18:56:39 | 18:56:18 | 18:56:39 | 18:57:53 | | 18:57:42 | | | | 0 | 0.776 | 0.026 | 0.75 | 18:57:23 | -19 | 19,000 | 0 | 250 | 0 | EDA NVT; RTA LATE: PFSC |
| | F4 | UAL962 | B737 | 30 | 3-4 | 19:04:16 | 01:44 | 19:06:00 | 19:04:16 | 00:27 | 19:04:43 | 19:03:14 | 19:04:43 | 19:06:21 | | 19:06:00 | | | | 1 | 0.703 | 0.037 | 0.74 | 19:06:19 | | 19,100 | 100 | 250 | 0 | AAC; ATC > 250K in DES |
| | F5 | AAL923 | B757 | 50 | 3-4 | 19:00:38 | 02:28 | 19:03:06 | 19:00:38 | 00:04 | 19:00:42 | NA | 19:00:42 | NA | | 19:03:06 | | | LBF AMW051/59 AMW | 0 | 0.758 | 0.018 | 0.74 | 19:03:13 | 7 | 19,100 | 100 | 253 | 3 | |
| | F6 | AAL745 | B757 | 30 | 3-4 | 18:52:56 | 02:40 | 18:55:36 | 18:52:56 | 00:08 | 18:52:48 | NA | 18:52:48 | NA | | 18:55:36 | | | YANKI SA067/126 SA | 0 | 0.770 | 0.030 | 0.74 | 18:55:40 | 4 | 19,200 | 200 | 265 | 15 | |
| 12-3 D1R4 [B /TW] | F1 | SWA325 | B737 | 30 | 3-4 | 20:27:49 | 03:05 | 20:30:54 | 20:27:49 | 00:11 | 20:28:00 | 20:29:23 | 20:28:00 | 20:31:00 | | 20:30:48 | | | PP AMW057/115 AMW | 0 | 0.776 | 0.006 | 0.77 | 20:30:45 | -3 | 19,000 | 0 | 251 | 1 | |
| | F2 | SWA362 | B737 | 30 | 3-4 | 20:34:51 | 02:27 | 20:37:18 | 20:34:51 | 00:14 | 20:34:37 | 20:34:31 | 20:34:37 | 20:38:28 | | 20:37:12 | | | HCT SA358/27 SA | 0 | 0.697 | 0.017 | 0.68 | 20:37:16 | 4 | 19,000 | 0 | 251 | 1 | Early Descent |
| | F3 | SWA114 | B737 | 30 | 3-4 | 20:33:09 | 02:33 | 20:35:42 | 20:33:09 | 00:04 | 20:33:13 | 20:33:54 | 20:33:13 | 20:36:47 | | 20:35:36 | | | PP AMW041/64 AMW | 0 | 0.740 | 0.030 | 0.71 | 20:35:40 | 4 | 19,000 | 0 | 250 | 0 | Laddered Descent |
| | F4 | UAL320 | B737 | 30 | 3-4 | 20:23:50 | 02:16 | 20:26:06 | 20:23:50 | 00:12 | 20:23:38 | 20:24:17 | 20:23:38 | 20:26:43 | | 20:26:00 | | | YANKI SNY092/60 SNY | 0 | 0.751 | 0.011 | 0.74 | 20:25:52 | -8 | 19,000 | 0 | 252 | 2 | |
| | F5 | AAL456 | B757 | 50 | 3-4 | 20:26:46 | 00:56 | 20:27:42 | 20:26:46 | 00:52 | 20:25:54 | NA | 20:25:54 | NA | | 20:27:36 | | | **NONE, BUT NEEDED** | | | | | 20:26:30 | | 19,100 | 100 | 250 | 0 | AUI; Adj Spd to > Corr; None |
| | F6 | AAL517 | B757 | 50 | 3-4 | 20:29:39 | 04:27 | 20:34:06 | 20:29:39 | 00:09 | 20:29:48 | NA | 20:29:48 | NA | | 20:34:00 | | | LBF AMW034/67 AMW | 0 | 0.761 | 0.021 | 0.74 | 20:34:02 | 2 | 19,100 | 100 | 254 | 4 | |
| 12-3 D2R1 [C / HW] | F1 | SWA241 | B737 | 15 | 3-4 | 13:38:07 | 01:35 | 13:39:42 | 13:38:07 | 00:13 | 13:37:54 | 13:37:02 | 13:37:54 | 13:41:02 | | 13:39:42 | | | LBF AMW044/61 AMW | 0 | 0.765 | 0.025 | 0.74 | 13:39:27 | -15 | 19,000 | 0 | 261 | 11 | |
| | F2 | DAL121 | B737 | 45 | 3-4 | 13:25:11 | 03:55 | 13:29:06 | 13:25:11 | 00:11 | 13:25:22 | 13:24:06 | 13:25:22 | 13:35:00 | | 13:29:06 | | | | 0 | 0.701 | 0.001 | 0.70 | 13:29:07 | 1 | 19,100 | 100 | 250 | 0 | |
| | F3 | SWA449 | B737 | 15 | 3-4 | 13:22:30 | 03:24 | 13:25:54 | 13:22:30 | 01:56 | 13:24:26 | 13:22:22 | 13:24:26 | 13:24:47 | | 13:25:54 | | | Vectors > DHCT / DSA | | | | | 13:26:55 | | 19,100 | 100 | 252 | 2 | EDA NVT then AUI |
| | F4 | UAL962 | B737 | 45 | 3-4 | 13:31:35 | 03:31 | 13:35:06 | 13:31:35 | 00:06 | 13:31:41 | 13:32:37 | 13:31:41 | 13:38:05 | | 13:35:00 | | | | 1 | 0.772 | 0.042 | 0.73 | 13:35:04 | 4 | 19,000 | 0 | 251 | 1 | EDA NVT: PFSC; 1 Amdt / NC |
| | F5 | AAL923 | B757 | 100 | 3-4 | 13:27:48 | 02:54 | 13:30:42 | 13:27:48 | 01:18 | 13:29:06 | NA | 13:29:06 | NA | | 13:30:36 | | | | 0 | 0.773 | 0.007 | 0.78 | 13:30:37 | 1 | 19,000 | 0 | 230 | 20 | CRZ DES to FL360 |
| | F6 | AAL745 | B757 | 30 | 3-4 | 13:21:48 | 01:48 | 13:23:36 | 13:21:48 | 00:54 | 13:22:42 | NA | 13:22:42 | NA | | 13:23:30 | | | | 0 | 0.766 | 0.016 | 0.75 | 13:23:33 | 3 | 19,000 | 0 | 255 | 5 | |
| 12-3 D2R2 [B / TW] | F1 | SWA325 | B737 | 45 | 3-4 | 14:57:37 | 03:53 | 15:01:30 | 14:57:37 | 01:23 | 14:59:00 | 14:59:58 | 14:59:00 | 15:01:39 | | 15:01:30 | | | LBF AMW014/45 AMW | 0 | 0.776 | 0.006 | 0.77 | 15:01:31 | 1 | 19,000 | 0 | 250 | 0 | |
| | F2 | SWA362 | B737 | 15 | 3-4 | 15:06:54 | 03:42 | 15:10:36 | 15:06:54 | 03:26 | 15:10:20 | 15:10:03 | 15:10:20 | 15:12:18 | | 15:10:36 | | | PP AMW042/64 AMW | 0 | 0.759 | 0.029 | 0.73 | 15:10:39 | 3 | 19,000 | 0 | 254 | 4 | Vector to generate |
| | F3 | SWA114 | B737 | 45 | 3-4 | 15:02:37 | 03:41 | 15:06:18 | 15:02:37 | 00:18 | 15:02:19 | 15:03:51 | 15:02:19 | 15:07:24 | | 15:06:18 | | | LBF AM036/67 AMW | 0 | 0.724 | 0.014 | 0.71 | 15:06:26 | 8 | 19,000 | 0 | 250 | 0 | |
| | F4 | UAL320 | B737 | 15 | 3-4 | 14:54:19 | 03:59 | 14:58:18 | 14:54:19 | 00:41 | 14:55:00 | 14:56:20 | 14:55:00 | 14:59:16 | | 14:58:18 | | | YANKI SNY102/69 SNY | 0 | 0.751 | 0.011 | 0.74 | 14:58:14 | -4 | 19,000 | 0 | 250 | 0 | |
| | F5 | AAL456 | B757 | 25 | 3-4 | 14:55:45 | 00:45 | 14:56:30 | 14:55:45 | 00:39 | 14:56:24 | NA | 14:56:24 | NA | | 14:56:30 | | | PP AMW060/61 AMW | 0 | 0.767 | 0.027 | 0.74 | 14:56:36 | 6 | 19,100 | 100 | 256 | 6 | |
| | F6 | AAL517 | B757 | 100 | 3-4 | 14:58:18 | 04:48 | 15:03:06 | 14:58:18 | 00:24 | 14:57:54 | NA | 14:57:54 | NA | | 15:03:06 | | | LBF AMW015/45 AMW | 0 | 0.749 | 0.009 | 0.74 | 15:03:09 | 3 | 19,200 | 200 | 255 | 5 | |

| Run | Flt | ACID | Type | CI | Meter | TMA Analysis | | | TMA | Δt | FMS | FMS Analysis | | | | RTA Assignment | | | | Corr | RTA | ΔM | EDA | Cross Fix - | | Cross Fix - | | Cross Fix - | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | ETA | Δt | STA | ETA | | ETA | First | ETA | Last | Window | Time | Assn | Spd | Path | Amd | Spd | | Spd | Time | Δt | Alt | ΔAlt | Speed | ΔSpd | |
| 12-3 D2R3 [C / HW] | F1 | SWA241 | B737 | 45 | 4-5 | 17:11:42 | 04:06 | 17:15:48 | 17:11:42 | 06:42 | 17:05:00 | 17:08:26 | 17:05:00 | 17:13:19 | | 17:11:54 | | | LBF AMW004/38 AMW | | 0.762 | 0.022 | 0.74 | 17:12:35 | | 19,000 | 0 | 260 | 10 | AAC/FMS Snapshot ERROR |
| | F2 | DAL121 | B737 | 15 | 4-5 | 16:59:05 | 03:31 | 17:02:36 | 16:59:05 | 00:31 | 16:58:34 | 16:56:11 | 16:58:34 | 17:04:26 | | 17:02:36 | | | LBF AMW057/58 AMW | 0 | 0.687 | 0.007 | 0.68 | 17:02:41 | 5 | 19,100 | 100 | 250 | 0 | |
| | F3 | SWA449 | B737 | 45 | 4-5 | 16:53:35 | 04:37 | 16:58:12 | 16:53:35 | 00:19 | 16:53:16 | 16:56:19 | 16:53:16 | 16:58:24 | | 16:58:30 | | | | 0 | 0.776 | 0.026 | 0.75 | 16:58:26 | -4 | 19,300 | 300 | 251 | 1 | EDA NVT |
| | F4 | UAL962 | B737 | 15 | 4-5 | 17:05:12 | 05:12 | 17:10:24 | 17:05:12 | 00:24 | 17:05:36 | 17:07:30 | 17:05:36 | 17:13:00 | | 17:08:12 | | | Vector then DSA | 0 | 0.795 | 0.015 | 0.78 | 17:08:18 | 6 | 19,000 | 0 | 262 | 12 | EDA NVT |
| | F5 | AAL923 | B757 | 25 | 4-5 | 16:59:46 | 04:50 | 17:04:36 | 16:59:46 | 00:38 | 17:00:24 | NA | 17:00:24 | NA | | 17:04:36 | | | LBF AMW034/67 AMW | 0 | 0.763 | 0.023 | 0.74 | 17:04:34 | -2 | 19,000 | 0 | 257 | 7 | |
| | F6 | AAL745 | B757 | 100 | 4-5 | 16:50:15 | 04:00 | 16:54:15 | 16:50:15 | 00:27 | 16:49:48 | NA | 16:49:48 | NA | | 16:54:18 | | | YANKI SA064/146 SA | 0 | 0.750 | 0.010 | 0.74 | 16:54:20 | 2 | 19,000 | 0 | 253 | 3 | |
| 12-3 D2R4 [C / TW] | F1 | SWA241 | B737 | 15 | 4-5 | 18:36:11 | 05:13 | 18:41:24 | 18:36:11 | 02:26 | 18:38:37 | 18:41:34 | 18:38:37 | 18:43:22 | | 18:41:24 | | | LBF AMW031/70 AMW | 0 | 0.781 | 0.041 | 0.74 | 18:41:33 | 9 | 19,000 | 0 | 250 | 0 | |
| | F2 | DAL121 | B737 | 45 | 4-5 | 18:29:25 | 03:29 | 18:32:54 | 18:29:25 | 00:24 | 18:29:01 | 18:31:31 | 18:29:01 | 18:34:06 | | 18:32:54 | | | LBF AMW039/64 AMW | 0 | 0.709 | 0.029 | 0.68 | 18:33:04 | 10 | 19,000 | 0 | 250 | 0 | |
| | F3 | SWA449 | B737 | 15 | 4-5 | 18:28:59 | 02:25 | 18:31:24 | 18:28:59 | 00:40 | 18:29:39 | 18:29:45 | 18:29:39 | 18:31:33 | | 18:31:24 | | | HCT AMW058/58 AMW | 0 | 0.776 | 0.006 | 0.77 | 18:31:32 | 8 | 19,100 | 100 | 250 | 0 | |
| | F4 | UAL962 | B737 | 45 | 4-5 | 18:35:45 | 04:03 | 18:39:48 | 18:35:45 | 00:13 | 18:35:32 | 18:36:40 | 18:35:32 | 18:41:12 | | 18:39:48 | | | LBF AMW036/66 AMW | 0 | 0.724 | 0.014 | 0.71 | 18:39:58 | 10 | 19,000 | 0 | 250 | 0 | |
| | F5 | AAL923 | B757 | 100 | 4-5 | 18:32:04 | 04:32 | 18:36:36 | 18:32:04 | 00:22 | 18:31:42 | NA | 18:31:42 | NA | | 18:36:36 | | | LBF AMW038/64 AMW | 1 | 0.744 | 0.004 | 0.74 | 18:36:40 | 4 | 19,100 | 100 | 249 | 1 | 1 Amdt / NC |
| | F6 | AAL745 | B757 | 25 | 4-5 | 18:25:31 | 04:17 | 18:29:48 | 18:25:31 | 00:29 | 18:26:00 | NA | 18:26:00 | NA | | 18:29:48 | | | YANKI SA069/147 SA | 0 | 0.768 | 0.028 | 0.74 | 18:29:52 | 4 | 19,100 | 100 | 253 | 3 | |
| 12-3 D2R5 [B / TW] | F1 | SWA325 | B737 | 15 | 5-6 | 19:53:04 | 04:26 | 19:57:30 | 19:53:04 | 00:45 | 19:53:49 | 19:59:44 | 19:53:49 | 20:00:58 | | 20:00:48 | | | PP SA020/59 SA | 0 | 0.776 | 0.006 | 0.77 | 20:00:52 | 4 | 19,000 | 0 | 250 | 0 | No EDA Initially; Vectored |
| | F2 | SWA362 | B737 | 45 | 5-6 | 19:59:13 | 04:11 | 20:03:24 | 19:59:13 | 00:24 | 19:58:49 | 20:00:16 | 19:58:49 | 20:04:56 | | 20:03:24 | | | HCT SA010/43 SA | 0 | 0.699 | 0.019 | 0.68 | 20:03:23 | -1 | 19,000 | 0 | 252 | 2 | |
| | F3 | SWA114 | B737 | 15 | 5-6 | 20:00:08 | 04:40 | 20:04:48 | 20:00:08 | 00:39 | 20:00:47 | 20:01:49 | 20:00:47 | 20:06:22 | | 20:04:48 | | | LBF AMW026/74 AMW | 0 | 0.726 | 0.016 | 0.71 | 20:04:52 | 4 | 19,000 | 0 | 250 | 0 | |
| | F4 | UAL320 | B737 | 45 | 5-6 | 19:48:09 | 04:27 | 19:52:36 | 19:48:09 | 00:09 | 19:48:00 | 19:50:27 | 19:48:00 | 19:53:18 | | 19:52:36 | | | YANKI SNY100/66 SNY | 0 | 0.743 | 0.003 | 0.74 | 19:52:45 | 9 | 19,000 | 0 | 250 | 0 | |
| | F5 | AAL456 | B757 | 100 | 5-6 | 19:49:42 | 04:54 | 19:54:36 | 19:49:42 | 00:00 | 19:49:42 | NA | 19:49:42 | NA | | 19:53:54 | | | LBF AMW030/37 AMW | 0 | 0.738 | 0.002 | 0.74 | 19:53:54 | 0 | 19,000 | 0 | 255 | 5 | ATC > Spd/Vec; RTA AAC?? |
| | F6 | AAL517 | B757 | 25 | 5-6 | 19:54:57 | 04:03 | 19:59:00 | 19:54:57 | 00:51 | 19:55:48 | NA | 19:55:48 | NA | | 19:59:06 | | | LBF AMW035/68 AMW | 0 | 0.754 | 0.014 | 0.74 | 19:59:06 | 0 | 19,100 | 100 | 251 | 1 | |
| 12-3 D3R1 [B / HW] | F1 | SWA325 | B737 | 45 | 5-6 | 13:30:22 | 04:26 | 13:34:48 | 13:30:22 | 00:21 | 13:30:43 | 13:33:04 | 13:30:43 | 13:34:49 | | 13:34:48 | | | LBF AMW032/70 AMW | 0 | 0.787 | 0.017 | 0.77 | 13:34:40 | -8 | 19,017 | 17 | 254 | 4 | |
| | F2 | SWA362 | B737 | 15 | 5-6 | 13:39:58 | 05:02 | 13:45:00 | 13:39:58 | 01:43 | 13:41:41 | 13:38:49 | 13:41:41 | 13:47:33 | | 13:45:00 | | | HCT SA014/38 SA | 1 | 0.697 | 0.017 | 0.68 | 13:44:39 | -21 | 19,075 | 75 | 250 | 0 | |
| | F3 | SWA114 | B737 | 45 | 5-6 | 13:38:12 | 04:48 | 13:43:00 | 13:38:12 | 00:29 | 13:38:41 | 13:38:49 | 13:38:41 | 13:46:10 | | 13:43:00 | | | LBF AMW044/62 AMW | 0 | 0.750 | 0.040 | 0.71 | 13:42:46 | -14 | 19,064 | 64 | 250 | 0 | |
| | F4 | UAL320 | B737 | 15 | 5-6 | 13:28:28 | 04:32 | 13:33:00 | 13:28:28 | 01:05 | 13:29:33 | 13:33:14 | 13:29:33 | 13:38:02 | | 13:33:00 | | | PP SNY057/102 SNY | 0 | 0.806 | 0.006 | 0.80 | 13:32:54 | -6 | 19,017 | 17 | 252 | 2 | |
| | F5 | AAL456 | B757 | 25 | 5-6 | 13:31:12 | 05:24 | 13:36:36 | 13:31:12 | 01:06 | 13:32:18 | NA | 13:32:18 | NA | | 13:36:36 | | | LBF AMW004/39 AMW | 0 | 0.762 | 0.022 | 0.74 | 13:36:29 | -7 | 19,039 | 39 | 248 | 2 | |
| | F6 | AAL517 | B757 | 100 | 5-6 | 13:34:52 | 04:38 | 13:39:30 | 13:34:52 | 00:22 | 13:34:30 | NA | 13:34:30 | NA | | 13:39:24 | | | LBF AMW039/63 AMW | 0 | 0.762 | 0.022 | 0.74 | 13:39:23 | -1 | 19,100 | 100 | 242 | 8 | |
| 12-3 D3R2 [B / TW] | F1 | SWA325 | B737 | 15 | 5-6 | 15:00:34 | 04:02 | 15:04:36 | 15:00:34 | 00:15 | 15:00:49 | 15:02:50 | 15:00:49 | 15:04:33 | | 15:04:36 | | | LBF AMW003/39 AMW | 0 | 0.776 | 0.006 | 0.77 | 15:04:49 | 13 | 19,000 | 0 | 250 | 0 | |
| | F2 | SWA362 | B737 | 45 | 5-6 | 15:06:47 | 04:19 | 15:11:06 | 15:06:47 | 00:56 | 15:05:51 | 15:10:06 | 15:05:51 | 15:14:26 | | 15:11:06 | | | PP AMW059/45 AMW | 0 | 0.792 | 0.012 | 0.78 | 15:10:44 | -22 | 19,000 | 0 | 258 | 8 | |
| | F3 | SWA114 | B737 | 15 | 5-6 | 15:07:41 | 03:49 | 15:11:30 | 15:07:41 | 00:07 | 15:07:48 | 15:12:45 | 15:07:48 | 15:16:21 | | 15:13:06 | | | PP AMW066/70 AMW | 1 | 0.806 | 0.004 | 0.81 | 15:13:40 | 34 | 19,000 | 0 | 252 | 2 | 1 Amdt/AAC; Pilot Error; LNAV |
| | F4 | UAL320 | B737 | 45 | 5-6 | 14:55:39 | 04:03 | 14:59:42 | 14:55:39 | 00:28 | 14:55:11 | 14:57:28 | 14:55:11 | 15:00:05 | | 14:59:42 | | | YANKI SNY098/65 SNY | 0 | 0.740 | 0.000 | 0.74 | 14:59:52 | 10 | 19,000 | 0 | 250 | 0 | |
| | F5 | AAL456 | B757 | 100 | 5-6 | 14:58:33 | 04:27 | 15:03:00 | 14:58:33 | 00:39 | 14:57:54 | NA | 14:57:54 | NA | | 15:03:00 | | | LBF AMW035/66 AMW | 0 | 0.757 | 0.017 | 0.74 | 15:03:08 | 8 | 19,100 | 100 | 250 | 0 | |
| | F6 | AAL517 | B757 | 25 | 5-6 | 15:03:27 | 04:51 | 15:08:18 | 15:03:27 | 00:21 | 15:03:48 | NA | 15:03:48 | NA | | 15:08:18 | | | LBF AMW002/39 AMW | 0 | 0.791 | 0.051 | 0.74 | 15:08:22 | 4 | 19,000 | 0 | 247 | 3 | |

| Run | Flt | ACID | Type | CI | Meter | TMA Analysis | | | TMA | Δt | FMS | FMS Analysis | | | | RTA Assignment | | | | Corr | RTA | ΔM | EDA | Cross Fix - | | Cross Fix - | | Cross Fix - | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | ETA | Δt | STA | ETA | | ETA | First | ETA | Last | Window | Time | Assn | Spd | Path | Amd | Spd | | Spd | Time | Δt | Alt | ΔAlt | Speed | ΔSpd | |
| 12-3 D3R3 [C / HW] | F1 | SWA241 | B737 | 45 | 2-3 | N/A | 02:00 | 17:51:00 | N/A | N/A | 17:49:00 | 17:47:48 | 17:49:00 | 17:53:32 | | 17:51:00 | | | | | 0.765 | | | 17:51:06 | 6 | | | | | 1 Amdt / NC |
| | | | | | 4-5 | 18:15:43 | 02:17 | 18:18:00 | 18:15:43 | 15:00 | 18:19:14 | 18:15:33 | 18:15:00 | 18:19:14 | | 18:18:00 | | | PP AMW044/60 AMW | 1 | 0.769 | 0.029 | 0.74 | 18:17:54 | -6 | 19,000 | 0 | 259 | 9 | |
| | F2 | DAL121 | B737 | 30 | 2-3 | N/A | 01:13 | 17:41:36 | N/A | N/A | 17:40:23 | 17:38:05 | 17:40:23 | 17:50:17 | | 17:41:36 | | | | | 0.753 | | | 17:41:38 | 2 | | | | | |
| | | | | | 4-5 | 18:06:23 | 02:19 | 18:08:42 | 18:06:23 | 01:22 | 18:05:01 | 18:04:15 | 18:05:01 | 18:10:38 | | 18:08:42 | | | | 0 | 0.702 | 0.002 | 0.70 | 18:08:48 | 6 | 19,000 | 0 | 252 | 2 | |
| | F3 | SWA449 | B737 | 45 | 2-3 | N/A | 01:02 | 17:37:36 | N/A | N/A | 17:36:34 | 17:36:16 | 17:36:34 | 17:38:01 | | 17:37:36 | | | | | 0.784 | | | 17:37:36 | 0 | | | | | |
| | | | | | 4-5 | 17:59:54 | 00:48 | 18:00:42 | 17:59:54 | 01:38 | 17:58:16 | 17:58:52 | 17:58:16 | 18:00:48 | | 18:00:42 | | | | 0 | 0.776 | 0.006 | 0.77 | 18:00:38 | -4 | 19,000 | 0 | 252 | 2 | |
| | F4 | UAL962 | B737 | 30 | 2-3 | N/A | 02:51 | 17:46:48 | N/A | N/A | 17:45:45 | 17:43:51 | 17:45:45 | 17:53:01 | | 17:46:48 | | | | | 0.765 | | | 17:46:48 | 0 | | | | | |
| | | | | | 4-5 | 18:14:12 | 02:00 | 18:16:12 | 18:14:12 | 03:50 | 18:10:22 | 18:12:43 | 18:10:22 | 18:17:26 | | 18:16:12 | | | PP AMW048/61 AMW | 0 | 0.733 | 0.023 | 0.71 | 18:16:05 | -7 | 19,000 | 0 | 250 | 0 | |
| | F5 | AAL923 | B757 | 50 | 2-3 | N/A | 02:30 | 17:48:36 | N/A | N/A | 17:46:06 | NA | 17:46:06 | NA | | 17:48:36 | | | | | 0.791 | | | 17:48:41 | 5 | | | | | |
| | | | | | 4-5 | 18:13:06 | 01:24 | 18:14:30 | 18:13:06 | 03:24 | 18:09:42 | NA | 18:09:42 | NA | | 18:14:30 | | | PP AMW057/53 AMW | 0 | 0.754 | 0.014 | 0.74 | 18:14:31 | 1 | 19,000 | 0 | 257 | 7 | |
| | F6 | AAL745 | B757 | 100 | 2-3 | N/A | 01:00 | 17:34:00 | N/A | N/A | 17:33:00 | NA | 17:33:00 | NA | | 17:34:00 | | | | | 0.795 | | | 17:33:57 | -3 | | | | | |
| | | | | | 4-5 | 18:00:50 | 01:40 | 18:02:30 | 18:00:50 | 02:20 | 17:58:30 | NA | 17:58:30 | NA | | 18:02:30 | | | | 0 | 0.744 | 0.004 | 0.74 | 18:02:31 | 1 | 19,100 | 100 | 238 | 12 | |
| 12-2 D3R4 [C / TW] | F1 | SWA241 | B737 | 30 | 2-3 | N/A | 01:00 | 19:37:00 | N/A | N/A | 19:36:47 | 19:33:55 | 19:36:47 | 19:36:55 | | 19:37:00 | | | | | 0.732 | | | 19:37:04 | 4 | | | | | |
| | | | | | 4-5 | 19:55:45 | 04:09 | 19:59:54 | 19:55:45 | 04:09 | 19:59:54 | 19:59:11 | 19:59:54 | 20:01:55 | | 19:59:54 | | | PP AMW023/52 | 0 | 0.780 | 0.010 | 0.77 | 19:59:59 | 5 | 19,000 | 0 | 250 | 0 | |
| | F2 | DAL121 | B737 | 30 | 2-3 | N/A | 03:00 | 19:32:00 | N/A | N/A | 19:32:00 | 19:26:08 | 19:32:00 | 19:32:10 | | 19:32:00 | | | | | 0.660 | | | 19:32:13 | 13 | | | | | En Route RTA Crossing Time from Track Data |
| | | | | | 4-5 | 19:51:28 | 01:50 | 19:53:18 | 19:51:28 | 03:26 | 19:54:54 | 19:49:52 | 19:54:54 | 19:53:34 | | 19:53:18 | | | PP AMW047/63 AMW | 0 | 0.685 | 0.005 | 0.68 | 19:53:27 | 9 | 19,000 | 0 | 251 | 1 | |
| | F3 | SWA449 | B737 | 30 | 2-3 | N/A | 00:54 | 19:27:54 | N/A | N/A | 19:27:00 | 19:27:03 | 19:27:00 | 19:27:57 | | 19:27:54 | | | | | 0.776 | | | 19:27:54 | 0 | | | | | |
| | | | | | 4-5 | 19:45:41 | 03:31 | 19:49:12 | 19:45:41 | 00:19 | 19:46:00 | 19:47:53 | 19:46:00 | 19:49:22 | | 19:49:12 | | | PP AMW023/33 AMW | 0 | 0.776 | 0.006 | 0.77 | 19:49:19 | 7 | 19,000 | 0 | 250 | 0 | |
| | F4 | UAL962 | B737 | 45 | 2-3 | N/A | 03:00 | 19:39:00 | N/A | N/A | 19:36:00 | 19:34:25 | 19:36:00 | 19:39:07 | | 19:39:00 | | | | | 0.700 | | | 19:39:00 | 0 | | | | | 1 Amdt / NC |
| | | | | | 4-5 | 19:58:34 | 04:14 | 20:02:48 | 19:58:34 | 04:34 | 19:54:00 | 20:02:30 | 19:54:00 | 20:05:29 | | 20:02:48 | | | PP AMW012/38 AMW | 1 | 0.704 | 0.006 | 0.71 | 20:02:58 | 10 | 19,000 | 0 | 250 | 0 | |
| | F5 | AAL923 | B757 | 100 | 2-3 | N/A | 02:00 | 19:34:00 | N/A | N/A | 19:32:30 | NA | 19:32:30 | NA | | 19:34:00 | | | | | 0.762 | | | 19:34:05 | 5 | | | | | |
| | | | | | 4-5 | 19:52:37 | 03:29 | 19:56:06 | 19:52:37 | 04:05 | 19:56:42 | NA | 19:56:42 | NA | | 19:56:06 | | | PP AMW036/63 AMW | 0 | 0.765 | 0.025 | 0.74 | 19:56:10 | 4 | 19,300 | 300 | 250 | 0 | |
| | F6 | AAL745 | B757 | 100 | 2-3 | N/A | 01:00 | 19:24:00 | N/A | N/A | 19:23:00 | NA | 19:23:00 | NA | | 19:24:00 | | | | | 0.741 | | | 19:24:00 | 0 | | | | | 1 Amdt / NC |
| | | | | | 4-5 | 19:45:08 | 02:34 | 19:47:42 | 19:45:08 | 01:08 | 19:44:00 | NA | 19:44:00 | NA | | 19:47:42 | | | PP SNY080/81 SNY | 1 | 0.764 | 0.024 | 0.74 | 19:47:41 | -1 | 19,100 | 100 | 254 | 4 | |
| 12-4 D1R1 [B / HW] | F1 | SWA325 | B737 | 45 | 2-3 | 13:20:55 | 01:11 | 13:22:06 | 13:20:55 | 00:39 | 13:20:16 | 13:20:09 | 13:20:16 | 13:21:11 | 01:02 | 13:21:00 | | | | | 0.783 | | | 13:21:08 | 8 | | | | | |
| | | | | | 4-5 | 14:01:29 | 04:43 | 14:06:12 | 14:01:29 | 01:03 | 14:00:26 | 14:03:50 | 14:00:26 | 14:06:32 | 02:42 | 14:06:18 | | | LBF AMW006/40 AMW | 0 | 0.779 | 0.009 | 0.77 | 14:06:20 | 2 | 19,100 | 100 | 238 | 12 | |
| | F2 | SWA362 | B737 | 45 | 2-3 | 13:28:24 | 00:36 | 13:29:00 | 13:28:24 | 02:42 | 13:25:42 | 13:25:14 | 13:25:42 | 13:33:21 | 08:07 | 13:29:00 | | | | | 0.729 | | | 13:29:00 | 0 | | | | | |
| | | | | | 4-5 | 14:12:28 | 06:20 | 14:18:48 | 14:12:28 | 06:42 | 14:05:46 | 14:16:12 | 14:05:46 | 14:20:20 | 04:08 | 14:18:48 | | | None | 0 | 0.690 | 0.000 | 0.69 | 14:18:55 | 7 | 19,000 | 0 | 245 | 5 | |
| | F3 | SWA114 | B737 | 45 | 2-3 | 13:27:31 | 01:17 | 13:28:48 | 13:27:31 | 00:29 | 13:28:00 | 13:26:54 | 13:28:00 | 13:32:30 | 05:36 | 13:28:48 | | | | | 0.768 | | | 13:28:55 | 7 | | | | | |
| | | | | | 4-5 | 14:11:23 | 05:49 | 14:17:12 | 14:11:23 | 42:23 | 13:29:00 | 13:28:46 | 13:29:00 | 13:29:11 | 00:25 | 14:17:12 | | | LBF AMW014/45 AMW | 0 | 0.734 | 0.024 | 0.71 | 14:17:17 | 5 | 19,100 | 100 | 241 | 9 | |
| | F4 | UAL320 | B737 | 45 | 2-3 | 12:56:55 | 26:05 | 13:23:00 | 12:56:55 | 07:48 | 13:04:43 | 13:01:56 | 13:04:43 | 13:09:58 | 08:02 | 13:23:00 | | | | | 0.741 | | | 13:23:00 | 0 | | | | | |
| | | | | | 4-5 | 14:05:30 | 05:30 | 14:11:00 | 14:05:30 | 05:30 | 14:11:00 | 14:04:29 | 14:11:00 | 14:15:15 | 10:46 | 14:11:00 | | | None | 0 | 0.689 | 0.001 | 0.69 | 14:11:06 | 6 | 19,100 | 100 | 242 | 8 | |
| | F5 | AAL456 | B757 | 100 | 2-3 | 13:19:19 | 00:59 | 13:20:18 | 13:19:19 | 00:19 | 13:19:00 | NA | 13:19:00 | NA | NA | 13:20:18 | | | | | 0.791 | | | 13:20:14 | -4 | | | | | |
| | | | | | 4-5 | 14:00:18 | 02:42 | 14:03:00 | 14:00:18 | 02:06 | 13:58:12 | NA | 13:58:12 | NA | NA | 14:03:00 | | | LBF AMW050/46 AMW | 0 | 0.743 | 0.013 | 0.73 | 14:02:54 | -6 | 19,000 | 0 | 245 | 5 | |
| | F6 | UAL946 | B757 | 100 | 2-3 | 12:56:22 | 24:38 | 13:21:00 | 12:56:22 | 04:20 | 13:00:42 | NA | 13:00:42 | NA | NA | 13:21:00 | | | | | 0.800 | | | 13:21:09 | 9 | | | | | |
| | | | | | 4-5 | 14:00:28 | 04:20 | 14:04:48 | 14:00:28 | 04:20 | 14:04:48 | NA | 14:04:48 | NA | NA | 14:04:48 | | | None | 0 | 0.732 | 0.018 | 0.75 | 14:04:49 | 1 | 19,000 | 0 | 247 | 3 | |
| 12-4 D1R2 [C / TW] | F1 | SWA255 | B737 | 45 | 2-3 | 15:14:29 | 01:07 | 15:15:36 | 15:14:29 | 00:43 | 15:13:46 | 15:13:12 | 15:13:46 | 15:16:20 | 03:08 | 15:15:42 | | | | | 0.708 | | | 15:15:50 | 8 | | | | | |
| | | | | | 4-5 | 15:49:25 | 04:57 | 15:54:22 | 15:49:25 | 15:00 | 15:45:19 | 15:46:22 | 15:45:19 | 15:50:43 | 04:21 | 15:53:00 | | | LBF AMW003/39 AMW | 0 | 0.735 | 0.025 | 0.71 | 15:53:06 | 6 | 19,000 | 0 | 250 | 0 | |
| | F2 | DAL121 | B737 | 45 | 2-3 | 15:19:48 | 00:00 | 15:19:48 | 15:19:48 | 03:38 | 15:16:10 | 15:17:12 | 15:16:10 | 15:22:02 | 04:50 | 15:19:18 | | | | | 0.686 | | | 15:19:24 | 6 | | | | | |
| | | | | | 4-5 | 15:53:29 | 05:13 | 15:58:42 | 15:53:29 | 04:18 | 15:49:11 | 15:54:29 | 15:49:11 | 16:00:57 | 06:28 | 15:57:18 | | | LBF AMW030/70 AMW | 0 | 0.736 | 0.056 | 0.68 | 15:57:40 | 22 | 19,000 | 0 | 250 | 0 | |
| | F3 | SWA449 | B737 | 45 | 2-3 | 15:17:08 | 01:46 | 15:18:54 | 15:17:08 | 00:20 | 15:16:48 | 15:16:29 | 15:16:48 | 15:16:45 | 00:16 | 15:16:54 | | | | | 0.776 | | | 15:16:54 | 0 | | | | | |
| | | | | | 4-5 | 15:48:37 | 04:23 | 15:53:00 | 15:48:37 | 03:26 | 15:52:03 | 15:52:03 | 15:52:03 | 15:53:46 | 01:43 | | | | | | | | | | | 19,000 | 0 | 250 | 0 | AUI; Error in Path Stretch |
| | F4 | UAL350 | B737 | 45 | 2-3 | 14:57:52 | 08:08 | 15:06:00 | 14:57:52 | 07:55 | 14:49:57 | 14:47:50 | 14:49:57 | 14:50:58 | 03:08 | 15:06:00 | | | | | 0.696 | | | 15:06:00 | 0 | | | | | |
| | | | | | 4-5 | 15:42:38 | 04:16 | 15:46:54 | 15:42:38 | 04:16 | 15:46:54 | 15:42:30 | 15:46:54 | 15:49:31 | 07:01 | 15:46:54 | | | YANKI SNY099/66 SNY | 1 | 0.690 | 0.040 | 0.65 | 15:46:33 | -21 | 29,700 | 10700 | 259 | 9 | Altitude Restriction |
| | F5 | AAL923 | B757 | 100 | 2-3 | 15:12:31 | 01:50 | 15:14:21 | 15:12:31 | 00:19 | 15:12:12 | NA | 15:12:12 | NA | NA | 15:14:24 | | | | | 0.710 | | | 15:14:21 | -3 | | | | | |
| | | | | | 4-5 | 15:46:04 | 04:02 | 15:50:06 | 15:46:04 | 03:16 | 15:42:48 | NA | 15:42:48 | NA | NA | 15:50:06 | | | LBF AMW034/68 AMW | 0 | 0.732 | 0.008 | 0.74 | 15:50:05 | -1 | 19,080 | 80 | 251 | 1 | |
| | F6 | AAL431 | B757 | 100 | 2-3 | 14:57:39 | 12:33 | 15:10:12 | 14:57:39 | 03:09 | 14:54:30 | NA | 14:54:30 | NA | NA | 15:10:12 | | | | | 0.834 | | | 15:10:44 | 32 | | | | | |
| | | | | | 4-5 | 15:41:38 | 03:52 | 15:45:30 | 15:41:38 | 03:52 | 15:45:30 | NA | 15:45:30 | NA | NA | 15:45:30 | | | LBF AMW 045/61 AMW | 0 | 0.670 | 0.010 | 0.68 | 15:45:35 | 5 | 19,200 | 200 | 261 | 11 | |

| Run | Flt | ACID | Type | CI | Meter | TMA Analysis |  |  | TMA | Δt | FMS | FMS Analysis |  |  |  | RTA Assignment |  |  |  | Corr | RTA | ΔM | EDA | Cross Fix - |  | Cross Fix - |  | Cross Fix - |  | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  | ETA | Δt | STA | ETA |  | ETA | First | ETA | Last | Window | Time | Assn | Spd | Path | Amd | Spd |  | Spd | Time | Δt | Alt | ΔAlt | Speed | ΔSpd |  |
| 12-4 D1R3 [C / HW] | F1 | SWA255 | B737 | 45 | 2-3 | 17:30:11 | 01:04 | 17:31:15 | 17:30:11 | 01:07 | 17:31:18 | 17:29:43 | 17:31:18 | 17:35:36 | 05:53 | 17:30:24 |  |  |  |  | 0.792 |  |  | 17:30:30 | 6 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 18:11:25 | 04:41 | 18:16:06 | 18:11:25 | 00:01 | 18:11:26 | 18:10:22 | 18:11:26 | 18:17:17 | 06:55 | 18:16:06 |  |  | LBF AMW045/61 AMW | 0 | 0.737 | 0.027 | 0.71 | 18:15:46 | -20 | 36,000 | 17000 | 227 | 23 | No Descent; Pilot Error |
|  | F2 | DAL121 | B737 | 45 | 2-3 | 17:32:44 | 00:00 | 17:32:44 | 17:32:44 | 00:57 | 17:31:47 | 17:30:57 | 17:31:47 | 17:39:33 | 08:36 | 17:33:18 |  |  |  |  | 0.761 |  |  | 17:33:15 | -3 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 18:15:40 | 03:53 | 18:19:33 | 18:15:40 | 02:58 | 18:12:42 | 18:12:47 | 18:12:42 | 18:23:22 | 10:35 | 18:19:36 |  |  | LBF AMW053/60 AMW | 0 | 0.689 | 0.009 | 0.68 | 18:19:19 | -17 | 23,700 | 4700 | 229 | 21 | Late DES; Pilot Distracted |
|  | F3 | SWA449 | B737 | 45 | 2-3 | 17:34:45 | 00:40 | 17:35:25 | 17:34:45 | 00:10 | 17:34:35 | 17:33:20 | 17:34:35 | 17:34:35 | 01:15 | 17:34:30 |  |  |  |  | 0.776 |  |  | 17:34:34 | 4 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 18:14:04 | 03:20 | 18:17:24 | 18:14:04 | 03:19 | 18:17:23 | 18:15:40 | 18:17:23 | 18:17:40 | 02:00 | 18:17:24 |  |  | HCT SA014/39 SA | 1 | 0.776 | 0.006 | 0.77 | 18:18:05 | 41 | 19,000 | 0 | 260 | 10 |  |
|  | F4 | UAL350 | B737 | 45 | 2-3 | 17:06:37 | 16:23 | 17:23:00 | 17:06:37 | 01:34 | 17:05:03 | 17:01:54 | 17:05:03 | 17:05:56 | 04:02 | 17:23:00 |  |  |  |  | 0.749 |  |  | 17:23:07 | 7 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 18:07:06 | 04:18 | 18:11:24 | 18:07:06 | 04:18 | 18:11:24 | 18:04:11 | 18:11:24 | 18:16:12 | 12:01 | 18:11:24 |  |  |  | 0 | 0.689 | 0.001 | 0.69 | 18:11:21 | -3 | 19,000 | 0 | 246 | 4 |  |
|  | F5 | AAL923 | B757 | 100 | 2-3 | 17:28:24 | 01:30 | 17:29:54 | 17:28:24 | 00:24 | 17:28:00 | NA | 17:28:00 | NA | NA | 17:29:54 |  |  |  |  | 0.773 |  |  | 17:30:04 | 10 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 18:10:30 | 04:00 | 18:14:30 | 18:10:30 | 03:12 | 18:07:18 | NA | 18:07:18 | NA | NA | 18:14:18 |  |  | LBF AMW042/63 AMW | 0 | 0.758 | 0.018 | 0.74 | 18:13:56 | -22 | 19,000 | 0 | 246 | 4 |  |
|  | F6 | AAL431 | B757 | 100 | 2-3 | 17:07:27 | 15:27 | 17:22:54 | 17:07:27 | 03:09 | 17:04:18 | NA | 17:04:18 | NA | NA |  |  |  |  |  |  |  |  |  |  |  |  |  |  | FMS Emulation FAILED |
|  |  |  |  |  | 4-5 | 18:02:08 | 03:58 | 18:06:06 | 18:02:08 | 57:50 | 17:04:18 | NA | 17:04:18 | NA | NA | 18:06:24 |  |  |  | 0 | 0.820 | 0.010 | 0.83 | 18:06:18 | -6 | 19,000 | 0 | 250 | 0 | Restored for EDA/RTA |
| 12-4 D1R4 [B / TW] | F1 | SWA325 | B737 | 45 | 2-3 | 19:17:53 | 00:01 | 19:17:54 | 19:17:53 | 00:12 | 19:17:41 | 19:17:13 | 19:17:41 | 19:17:56 | 00:43 | 19:17:54 |  |  |  |  | 0.777 |  |  | 19:17:43 | -11 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 19:49:20 | 02:10 | 19:51:30 | 19:49:20 | 00:00 | 19:49:20 | 19:48:26 | 19:49:20 | 19:50:15 | 01:49 | 19:51:30 |  |  | LBF AMW043/61 AMW | 0 | 0.776 | 0.006 | 0.77 | 19:51:35 | 5 | 19,000 | 0 | 250 | 0 |  |
|  | F2 | SWA362 | B737 | 45 | 2-3 | 19:24:51 | 02:28 | 19:27:19 | 19:24:51 | 00:49 | 19:24:02 | 19:23:02 | 19:24:02 | 19:27:45 | 04:43 | 19:27:18 |  |  |  |  | 0.666 |  |  | 19:27:24 | 6 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 20:01:52 | 04:26 | 20:06:18 | 20:01:52 | 06:08 | 19:55:44 | 20:04:58 | 19:55:44 | 20:10:10 | 05:12 | 20:06:18 |  |  | PP AM028/22 AMW | 0 | 0.754 | 0.056 | 0.81 | 20:06:26 | 8 | 19,000 | 0 | 250 | 0 |  |
|  | F3 | SWA114 | B737 | 45 | 2-3 | 19:26:03 | 00:57 | 19:27:00 | 19:26:03 | 07:03 | 19:19:00 | 19:26:18 | 19:19:00 | 19:27:01 | 00:43 | 19:27:00 |  |  |  |  | 0.693 |  |  | 19:27:06 | 6 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 20:00:45 | 04:07 | 20:04:52 | 20:00:45 | 00:45 | 0:00:00 |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 19,000 | 0 | 254 | 4 | FMS Interface Failure |
|  | F4 | UAL320 | B737 | 45 | 2-3 | 18:59:15 | 13:15 | 19:12:30 | 18:59:15 | 03:11 | 18:56:04 | 18:54:23 | 18:56:04 | 18:57:21 | 02:58 | 19:12:30 |  |  |  |  | 0.705 |  |  | 19:12:31 | 1 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 19:49:03 | 03:39 | 19:52:42 | 19:49:03 | 03:39 | 19:52:42 | 19:48:18 | 19:52:42 | 19:55:22 | 07:04 | 19:52:42 |  |  | YANKI SNY096/62 SNY | 0 | 0.685 | 0.035 | 0.65 | 19:52:51 | 9 | 19,000 | 0 | 250 | 0 |  |
|  | F5 | AAL456 | B757 | 100 | 2-3 | 19:17:31 | 02:11 | 19:19:42 | 19:17:31 | 00:37 | 19:16:54 | NA | 19:16:54 | NA | NA | 19:19:24 |  |  |  |  | 0.693 |  |  | 19:19:34 | 10 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 19:52:23 | 04:37 | 19:57:00 | 19:52:23 | 04:59 | 19:47:24 | NA | 19:47:24 | NA | NA | 19:57:00 |  |  | LBF AMW027/73 AMW | 0 | 0.727 | 0.013 | 0.74 | 19:57:07 | 7 | 19,000 | 0 | 296 | 46 |  |
|  | F6 | UAL946 | B757 | 100 | 2-3 |  |  |  |  |  | 18:56:30 | NA | 18:56:30 | NA | NA | 19:12:30 |  |  |  |  | 0.781 |  |  | 19:13:04 | 34 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 19:44:34 | 04:08 | 19:48:42 | 19:44:34 | 11:56 | 19:56:30 | NA | 19:56:30 | NA | NA |  |  |  |  |  |  |  |  |  |  |  |  |  |  | FMS Emulation FAILED |
| 12-4 D2R1 [C / HW] | F1 | SWA255 | B737 | 45 | 2-3 | 13:16:21 | 01:27 | 13:17:48 | 13:16:21 | 00:37 | 13:16:58 | 13:15:57 | 13:16:58 | 13:21:44 | 05:47 | 13:17:48 |  |  |  |  | 0.764 |  |  | 13:17:53 | 5 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 13:59:30 | 04:00 | 14:03:30 | 13:59:30 | 15:00 | 18:19:14 | 13:57:42 | 13:58:50 | 14:05:32 | 07:50 | 14:03:30 |  |  | LBF AM047/62 AMW | 0 | 0.739 | 0.029 | 0.71 | 14:03:34 | 4 | 19,200 | 200 | 251 | 1 |  |
|  | F2 | DAL121 | B737 | 30 | 2-3 | 13:18:18 | 01:05 | 13:19:23 | 13:18:18 | 00:09 | 13:18:27 | 13:17:13 | 13:18:27 | 13:25:21 | 08:08 | 13:19:24 |  |  |  |  | 0.756 |  |  | 13:19:28 | 4 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 14:01:37 | 05:23 | 14:07:00 | 14:01:37 | 01:23 | 14:00:14 | 14:00:36 | 14:00:14 | 14:08:56 | 08:20 | 14:07:06 |  |  | LBF AM047/62 AMW | 0 | 0.688 | 0.008 | 0.68 | 14:07:03 | -3 | 19,200 | 200 | 250 | 0 |  |
|  | F3 | SWA449 | B737 | 45 | 2-3 | 13:20:10 | 00:20 | 13:20:30 | 13:20:10 | 00:20 | 13:20:30 | 13:20:06 | 13:20:30 | 13:20:49 | 00:43 | 13:20:30 |  |  |  |  | 0.778 |  |  | 13:20:34 | 4 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 14:00:11 | 05:07 | 14:05:18 | 14:00:11 | 05:07 | 14:05:18 | 14:05:26 | 14:05:18 | 14:07:50 | 02:24 | 14:05:18 |  |  |  | 0 | 0.805 | 0.005 | 0.81 | 14:05:53 | 35 | 19,000 | 0 | 250 | 0 |  |
|  | F4 | UAL350 | B737 | 30 | 2-3 | 12:53:00 | 13:54 | 13:06:54 | 12:53:00 | 04:23 | 12:48:37 | 12:45:50 | 12:48:37 | 12:49:52 | 04:02 | 13:06:54 |  |  |  |  | 0.665 |  |  | 13:07:00 | 6 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 13:56:42 | 03:18 | 14:00:00 | 13:56:42 | 03:18 | 14:00:00 | 13:51:02 | 14:00:00 | 14:02:24 | 11:22 | 14:00:00 |  |  | YANKI SNY087/67 SNY | 0 | 0.658 | 0.008 | 0.65 | 14:00:13 | 13 | 19,200 | 200 | 250 | 0 |  |
|  | F5 | AAL923 | B757 | 100 | 2-3 | 13:14:33 | 01:30 | 13:16:03 | 13:14:33 | 00:27 | 13:14:06 | NA | 13:14:06 | NA | NA | 13:16:06 |  |  |  |  | 0.794 |  |  | 13:16:14 | 8 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 13:57:00 | 04:48 | 14:01:48 | 13:57:00 | 03:36 | 13:53:24 | NA | 13:53:24 | NA | NA | 14:01:48 |  |  | LBF AMW037/67 AMW | 0 | 0.741 | 0.001 | 0.74 | 14:01:49 | 1 | 19,100 | 100 | 251 | 1 |  |
|  | F6 | AAL431 | B757 | 50 | 2-3 | 12:52:50 | 14:10 | 13:07:00 | 12:52:50 | 04:50 | 12:48:00 | NA | 12:48:00 | NA | NA | 13:07:00 |  |  |  |  | 0.760 |  |  | 13:07:02 | 2 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 13:46:47 | 04:31 | 13:51:18 | 13:46:47 | 04:31 | 13:51:18 | NA | 13:51:18 | NA | NA | 13:51:18 |  |  |  | 0 | 0.732 | 0.012 | 0.72 | 13:51:17 | -1 | 19,200 | 200 | 253 | 3 |  |
| 12-4 D2R2 [B / TW] | F1 | SWA325 | B737 | 45 | 3-4 | 15:07:28 | 00:02 | 15:07:30 | 15:07:28 | 00:12 | 15:07:16 | 15:06:27 | 15:07:16 | 15:07:31 | 01:04 | 15:07:30 |  |  |  |  | 0.776 |  |  | 15:07:23 | -7 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 15:39:06 | 04:54 | 15:44:00 | 15:39:06 | 15:00 | 15:38:56 | 15:38:03 | 15:38:56 | 15:39:52 | 01:49 | 15:44:00 |  |  |  | 0 | 0.790 | 0.020 | 0.81 | 15:44:16 | 16 | 19,000 | 0 | 251 | 1 |  |
|  | F2 | SWA362 | B737 | 30 | 3-4 | 15:15:16 | 01:56 | 15:17:12 | 15:15:16 | 00:48 | 15:14:28 | 15:13:09 | 15:14:28 | 15:17:17 | 04:08 | 15:17:12 |  |  |  |  | 0.656 |  |  | 15:17:18 | 6 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 15:51:19 | 05:29 | 15:56:48 | 15:51:19 | 04:12 | 15:47:07 | 15:47:35 | 15:47:07 | 15:53:54 | 06:19 | 15:56:48 |  |  | PP AMW040/73 AMW | 0 | 0.754 | 0.024 | 0.73 | 15:57:00 | 12 | 19,000 | 0 | 250 | 0 |  |
|  | F3 | SWA114 | B737 | 30 | 3-4 | 15:15:45 | 00:45 | 15:16:30 | 15:15:45 | 07:45 | 15:08:00 | 15:14:15 | 15:08:00 | 15:16:32 | 02:17 | 15:16:30 |  |  |  |  | 0.700 |  |  | 15:16:33 | 3 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 15:50:03 | 05:09 | 15:55:12 | 15:50:03 | 05:09 | 15:55:12 | 15:54:11 | 15:55:12 | 15:58:37 | 04:26 |  |  |  |  |  |  |  |  |  |  | 19,000 | 0 | 249 | 1 | AUI |
|  | F4 | UAL320 | B737 | 45 | 3-4 | 14:50:26 | 14:22 | 15:04:48 | 14:50:26 | 12:22 | 15:02:48 |  | 15:02:48 |  | 00:00 | 15:04:48 |  |  |  |  | 0.800 |  |  | 15:04:48 | 0 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 15:37:32 | 04:52 | 15:42:24 | 15:37:32 | 04:52 | 15:42:24 | 15:38:08 | 15:42:24 | 15:44:10 | 06:02 | 15:42:24 |  |  | YANKI SNY086/57 SNY | 0 | 0.675 | 0.025 | 0.65 | 15:42:34 | 10 | 19,000 | 0 | 250 | 0 |  |
|  | F5 | AAL456 | B757 | 100 | 3-4 | 15:07:15 | 00:45 | 15:08:00 | 15:07:15 | 00:33 | 15:06:42 | NA | 15:06:42 | NA | NA | 15:08:00 |  |  |  |  | 0.730 |  |  | 15:08:00 | 0 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 15:40:34 | 06:26 | 15:47:00 | 15:40:34 | 03:22 | 15:37:12 | NA | 15:37:12 | NA | NA | 15:47:30 |  |  | PP AMW085/45 AMW | 1 | 0.796 | 0.004 | 0.80 | 15:47:50 | 20 | 19,020 | 20 | 259 | 9 |  |
|  | F6 | UAL946 | B757 | 100 | 3-4 | 14:51:02 | 10:46 | 15:01:48 | 14:51:02 | 05:42 | 14:45:20 | NA | 14:45:20 | NA | NA | 15:01:48 |  |  |  |  | 0.782 |  |  | 15:02:06 | 18 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 15:33:33 | 05:21 | 15:38:54 | 15:33:33 | 05:27 | 15:39:00 | NA | 15:39:00 | NA | NA | 15:38:54 |  |  | LBF AMW015/44 AMW | 0 | 0.716 | 0.036 | 0.68 | 15:38:57 | 3 | 19,000 | 0 | 250 | 0 |  |

| Run | Flt | ACID | Type | CI | Meter | TMA Analysis |  |  | TMA | Δt | FMS | FMS Analysis |  |  |  | RTA Assignment |  |  |  | Corr | RTA | ΔM | EDA | Cross Fix - |  | Cross Fix - |  | Cross Fix - |  | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  | ETA | Δt | STA | ETA |  | ETA | First | ETA | Last | Window | Time | Assn | Spd | Path | Amd | Spd |  | Spd | Time | Δt | Alt | ΔAlt | Speed | ΔSpd |  |
| 12-4 D2R3 [B / HW] | F1 | SWA325 | B737 | 30 | 3-4 | 17:30:20 | 02:28 | 17:32:48 | 17:30:20 | 01:13 | 17:29:07 | 17:28:45 | 17:29:07 | 17:29:55 | 01:10 | 17:29:36 |  |  |  |  | 0.785 |  |  | 17:30:00 | 24 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 18:10:32 | 04:40 | 18:15:12 | 18:10:32 | 15:00 | 18:19:14 | 18:12:02 | 18:08:58 | 18:14:49 | 02:47 | 18:14:36 |  |  | LBF AMW031/70 AMW | 1 | 0.776 | 0.006 | 0.77 | 18:14:46 | 10 | 19,000 | 0 | 255 | 5 |  |
|  | F2 | SWA362 | B737 | 45 | 3-4 | 17:34:40 | 02:27 | 17:37:07 | 17:34:40 | 00:17 | 17:34:23 | 17:33:28 | 17:34:23 | 17:41:23 | 07:55 | 17:37:06 |  |  |  |  | 0.735 |  |  | 17:37:18 | 12 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 18:19:42 | 04:54 | 18:24:36 | 18:19:42 | 06:09 | 18:13:33 | 18:15:13 | 18:13:33 | 18:25:27 | 10:14 | 18:24:36 |  |  | HCT SA026/44 SA | 0 | 0.679 | 0.001 | 0.68 | 18:24:47 | 11 | 19,000 | 0 | 250 | 0 |  |
|  | F3 | SWA114 | B737 | 45 | 3-4 | 17:36:15 | 03:03 | 17:39:18 | 17:36:15 | 04:15 | 17:32:00 | 17:35:47 | 17:32:00 | 17:40:37 | 04:50 | 17:39:18 |  |  |  |  | 0.721 |  |  | 17:39:25 | 7 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 18:23:08 | 06:10 | 18:29:18 | 18:23:08 | 05:52 | 18:29:00 | 18:23:37 | 18:29:00 | 18:30:46 | 07:09 | 18:29:18 |  |  | LBF AMW027/73 AMW | 0 | 0.728 | 0.018 | 0.71 | 18:29:34 | 16 | 19,000 | 0 | 250 | 0 |  |
|  | F4 | UAL320 | B737 | 30 | 3-4 | 17:05:24 | 09:12 | 17:14:36 | 17:05:24 | 08:52 | 16:56:32 | 16:53:53 | 16:56:32 | 16:57:00 | 03:07 | 17:14:36 |  |  |  |  | 0.696 |  |  | 17:14:44 | 8 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 18:01:03 | 05:45 | 18:06:48 | 18:01:03 | 05:57 | 18:07:00 | 17:51:47 | 18:07:00 | 18:07:58 | 16:11 | 18:06:48 |  |  | YANKI SNY084/57 SNY | 0 | 0.648 | 0.002 | 0.65 | 18:06:53 | 5 | 19,000 | 0 | 250 | 0 |  |
|  | F5 | AAL456 | B757 | 100 | 3-4 | 17:28:20 | 01:52 | 17:30:12 | 17:28:20 | 00:26 | 17:27:54 | NA | 17:27:54 | NA | NA | 17:30:12 |  |  |  |  | 0.771 |  |  | 17:30:12 | 0 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 18:11:37 | 05:11 | 18:16:48 | 18:11:37 | 05:19 | 18:06:18 | NA | 18:06:18 | NA | NA | 18:16:42 |  |  | LBF AMW015/46 AMW | 0 | 0.740 | 0.020 | 0.76 | 18:16:30 | -12 | 19,000 | 0 | 253 | 3 |  |
|  | F6 | UAL946 | B757 | 50 | 3-4 | 17:05:51 | 18:57 | 17:24:48 | 17:05:51 | 00:15 | 17:06:06 | NA | 17:06:06 | NA | NA | 17:24:48 |  |  |  |  | 0.799 |  |  | 17:24:55 | 7 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 18:03:33 | 05:57 | 18:09:30 | 18:03:33 | 06:27 | 18:10:00 | NA | 18:10:00 | NA | NA | 18:09:30 |  |  |  |  | 0.727 | 0.027 | 0.70 | 18:09:26 | -4 | 19,000 | 0 | 250 | 0 |  |
| 12-4 D2R4 [C / TW] | F1 | SWA255 | B737 | 45 | 3-4 | 19:20:29 | 01:43 | 19:22:12 | 19:20:29 | 00:35 | 19:19:54 | 19:19:20 | 19:19:54 | 19:22:12 | 02:52 | 19:22:12 |  |  |  |  | 0.693 |  |  | 19:21:54 | -18 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 19:55:17 | 04:31 | 19:59:48 | 19:55:17 | 15:00 | 19:52:00 | 19:57:07 | 19:52:00 | 20:02:11 | 05:04 | 19:59:48 |  |  | LBF AMW027/73 AMW | 0 | 0.744 | 0.034 | 0.71 | 19:59:50 | 2 | 19,000 | 0 | 250 | 0 |  |
|  | F2 | DAL121 | B737 | 30 | 3-4 | 19:23:36 | 02:30 | 19:26:06 | 19:23:36 | 00:28 | 19:23:08 | 19:21:54 | 19:23:08 | 19:26:06 | 04:12 | 19:26:06 |  |  |  |  | 0.650 |  |  | 19:26:00 | -6 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 19:59:35 | 04:43 | 20:04:18 | 19:59:35 | 02:03 | 19:57:32 | 20:01:35 | 19:57:32 | 20:09:06 | 07:31 | 20:04:18 |  |  | LBF AMW028/73 AMW | 1 | 0.746 | 0.066 | 0.68 | 20:03:44 | -34 | 24,000 | 5000 | 250 | 0 | Late DES; Pilot Distracted |
|  | F3 | SWA449 | B737 | 45 | 3-4 | 19:22:57 | 00:00 | 19:22:57 | 19:22:57 | 00:15 | 19:22:42 | 19:22:19 | 19:22:42 | 19:22:57 | 00:38 | 19:22:54 |  |  |  |  | 0.778 |  |  | 19:22:38 | -16 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 19:54:09 | 04:09 | 19:58:18 | 19:54:09 | 03:51 | 19:58:00 | 19:56:59 | 19:58:00 | 19:58:38 | 01:39 | 19:58:18 |  |  | PP SA051/94 SA | 0 | 0.776 | 0.004 | 0.78 | 19:58:11 | -7 | 19,000 | 0 | 250 | 0 |  |
|  | F4 | UAL350 | B737 | 30 | 3-4 | 19:03:33 | 05:39 | 19:09:12 | 19:03:33 | 12:03 | 18:51:30 | 18:50:50 | 18:51:30 | 18:53:52 | 03:02 | 19:09:12 |  |  |  |  | 0.615 |  |  | 19:09:11 | -1 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 19:46:55 | 05:11 | 19:52:06 | 19:46:55 | 05:05 | 19:52:00 | 19:48:15 | 19:52:00 | 19:55:53 | 07:38 | 19:52:06 |  |  | YANKI SNY103/69 SNY | 0 | 0.703 | 0.053 | 0.65 | 19:52:03 | -3 | 19,000 | 0 | 250 | 0 |  |
|  | F5 | AAL923 | B757 | 100 | 3-4 | 19:16:08 | 00:52 | 19:17:00 | 19:16:08 | 00:14 | 19:15:54 | NA | 19:15:54 | NA | NA | 19:17:00 |  |  |  |  | 0.743 |  |  | 19:17:10 | 10 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 19:49:17 | 05:19 | 19:54:36 | 19:49:17 | 02:29 | 19:46:48 | NA | 19:46:48 | NA | NA | 19:54:36 |  |  | LBF AMW027/73 AMW | 0 | 0.718 | 0.022 | 0.74 | 19:54:39 | 3 | 19,020 | 20 | 275 | 25 |  |
|  | F6 | AAL431 | B757 | 100 | 3-4 | 19:04:57 | 05:15 | 19:10:12 | 19:04:57 | 05:15 | 19:10:12 | NA | 19:10:12 | NA | NA | 19:10:12 |  |  |  |  | 0.783 |  |  | 19:10:53 | 41 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 19:42:23 | 04:55 | 19:47:18 | 19:42:23 | 04:55 | 19:47:18 | NA | 19:47:18 | NA | NA | 19:47:18 |  |  | LBF AMW034/67 AMW | 0 | 0.717 | 0.037 | 0.68 | 19:47:24 | 6 | 19,000 | 0 | 250 | 0 |  |
| 12-4 D3R1 [B / HW] | F1 | SWA325 | B737 | 45 | 3-4 | 13:12:37 | 00:00 | 13:12:37 | 13:12:37 | 00:35 | 13:12:02 | 13:11:27 | 13:12:02 | 13:13:07 | 01:40 | 13:12:30 |  |  |  |  | 0.787 |  |  | 13:12:40 | 10 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 13:53:04 | 04:44 | 13:57:48 | 13:53:04 | 00:53 | 13:52:11 | 13:55:10 | 13:52:11 | 13:58:04 | 02:54 | 13:57:48 |  |  | LBF AMW032/70 AMW | 0 | 0.780 | 0.010 | 0.77 | 13:57:46 | -2 | 19,000 | 0 | 256 | 6 |  |
|  | F2 | SWA362 | B737 | 30 | 3-4 | 13:20:21 | 01:27 | 13:18:54 | 13:20:21 | 02:17 | 13:18:04 | 13:16:41 | 13:18:04 | 13:25:44 | 09:03 | 13:18:54 |  |  |  |  | 0.761 |  |  | 13:18:54 | 0 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 13:59:37 | 05:23 | 14:05:00 | 13:59:37 | 00:39 | 13:58:58 | 13:57:24 | 13:58:58 | 14:08:04 | 10:40 | 14:05:00 |  |  |  | 0 | 0.697 | 0.017 | 0.68 | 14:04:56 | -4 | 19,000 | 0 | 250 | 0 |  |
|  | F3 | SWA114 | B737 | 45 | 3-4 | 13:23:12 | 00:12 | 13:23:00 | 13:23:12 | 00:12 | 13:23:00 | 13:18:46 | 13:23:00 | 13:24:29 | 05:43 | 13:23:00 |  |  |  |  | 0.725 |  |  | 13:23:03 | 3 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 14:07:53 | 06:31 | 14:14:24 | 14:07:53 | 06:07 | 14:14:00 | 14:08:34 | 14:14:00 | 14:17:18 | 08:44 | 14:14:24 |  |  | LBF AMW023/79 AMW | 0 | 0.741 | 0.031 | 0.71 | 14:14:23 | -1 | 19,000 | 0 | 259 | 9 |  |
|  | F4 | UAL320 | B737 | 30 | 3-4 | 12:48:25 | 07:53 | 12:56:18 | 12:48:25 | 10:23 | 12:38:02 | 12:35:16 | 12:38:02 | 12:39:16 | 04:00 | 12:56:18 |  |  |  |  | 0.687 |  |  | 12:56:25 | 7 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 13:44:38 | 06:34 | 13:51:12 | 13:44:38 | 06:22 | 13:51:00 | 13:41:07 | 13:51:00 | 13:54:16 | 13:09 | 13:51:12 |  |  | YANKI SNY099/68 SNY | 0 | 0.661 | 0.011 | 0.65 | 13:51:22 | 10 | 19,100 | 100 | 250 | 0 |  |
|  | F5 | AAL456 | B757 | 100 | 3-4 | 13:10:55 | 00:35 | 13:11:30 | 13:10:55 | 00:13 | 13:10:42 | NA | 13:10:42 | NA | NA | 13:11:30 |  |  |  |  | 0.800 |  |  | 13:11:39 | 9 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 13:51:56 | 04:28 | 13:56:24 | 13:51:56 | 01:56 | 13:50:00 | NA | 13:50:00 | NA | NA | 13:56:24 |  |  | LBF AMW045/60 AMW | 0 | 0.742 | 0.002 | 0.74 | 13:56:23 | -1 | 19,100 | 100 | 257 | 7 |  |
|  | F6 | UAL946 | B757 | 50 | 3-4 | 12:49:15 | 05:15 | 12:54:30 | 12:49:15 | 13:45 | 12:35:30 | NA | 12:35:30 | NA | NA | 12:54:30 |  |  |  |  | 0.795 |  |  | 12:54:35 | 5 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 13:34:08 | 05:52 | 13:40:00 | 13:34:08 | 05:52 | 13:40:00 | NA | 13:40:00 | NA | NA | 13:40:00 |  |  | LBF AMW048/58 AMW | 0 | 0.710 | 0.030 | 0.68 | 13:39:58 | -2 | 19,100 | 100 | 253 | 3 |  |
| 12-4 D3R2 [B / TW] | F1 | SWA325 | B737 | 45 | 3-4 | 15:09:00 | 00:42 | 15:09:42 | 15:09:00 | 00:27 | 15:09:27 | 15:08:58 | 15:09:27 | 15:09:41 | 00:43 | 15:09:42 |  |  |  |  | 0.776 |  |  | 15:09:31 | -11 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 15:40:56 | 02:28 | 15:43:24 | 15:40:56 | 02:26 | 15:43:22 | 15:41:45 | 15:43:22 | 15:43:22 | 01:37 | 15:43:24 |  |  | LBF AMW043/61 AMW | 0 | 0.776 | 0.006 | 0.77 |  |  | 19,000 | 0 | 250 | 0 | AAC; Pilot Comm Issues |
|  | F2 | SWA362 | B737 | 30 | 3-4 | 15:25:55 | 01:31 | 15:24:24 | 15:25:55 | 02:39 | 15:23:16 | 15:20:35 | 15:23:16 | 15:24:24 | 03:49 | 15:24:24 |  |  |  |  | 0.650 |  |  | 15:24:26 | 2 |  |  |  |  | Start-up in HOVER |
|  |  |  |  |  | 5-6 | 15:58:38 | 04:40 | 16:03:18 | 15:58:38 | 03:11 | 15:55:27 | 15:59:27 | 15:55:27 | 16:06:21 | 06:54 | 16:03:18 |  |  | HCT AMW044/69 AMW | 0 | 0.717 | 0.037 | 0.68 | 16:03:24 | 6 | 19,000 | 0 | 250 | 0 |  |
|  | F3 | SWA114 | B737 | 45 | 3-4 | 15:17:53 | 01:05 | 15:18:58 | 15:17:53 | 00:07 | 15:18:00 | 15:16:19 | 15:18:00 | 15:18:58 | 02:39 | 15:18:58 |  |  |  |  | 0.693 |  |  | 15:19:05 | 7 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 15:52:42 | 05:18 | 15:47:24 | 15:52:42 | 04:18 | 15:57:00 | 15:54:35 | 15:57:00 | 15:59:04 | 04:29 | 15:57:24 |  |  | LBF AMW044/69 AMW | 0 | 0.734 | 0.024 | 0.71 | 15:57:30 | 6 | 19,000 | 0 | 264 | 14 |  |
|  | F4 | UAL320 | B737 | 45 | 3-4 | 14:52:32 | 07:52 | 15:00:24 | 14:52:32 | 08:24 | 14:44:08 | 14:42:17 | 14:44:08 | 14:45:15 | 02:58 | 15:00:24 |  |  |  |  | 0.642 |  |  | 15:00:26 | 2 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 15:37:58 | 03:50 | 15:41:48 | 15:37:58 | 04:02 | 15:42:00 | 15:36:49 | 15:42:00 | 15:45:19 | 08:30 | 15:41:48 |  |  | YANKI SNY099/67 SNY | 0 | 0.691 | 0.041 | 0.65 | 15:41:53 | 5 | 19,000 | 0 | 266 | 16 |  |
|  | F5 | AAL456 | B757 | 100 | 3-4 | 15:09:23 | 00:37 | 15:10:00 | 15:09:23 | 00:35 | 15:08:48 | NA | 15:08:48 | NA | NA | 15:10:00 |  |  |  |  | 0.724 |  |  | 15:10:12 | 12 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 15:42:29 | 04:07 | 15:46:36 | 15:42:29 | 03:05 | 15:39:24 | NA | 15:39:24 | NA | NA | 15:46:36 |  |  | LBF AMW031/69 AMW | 0 | 0.739 | 0.001 | 0.74 | 15:46:54 | 18 | 19,160 | 160 | 248 | 2 |  |
|  | F6 | UAL946 | B757 | 50 | 3-4 | 14:52:56 | 07:28 | 15:00:24 | 14:52:56 | 04:04 | 14:57:00 | NA | 14:57:00 | NA | NA | 15:00:24 |  |  |  |  | 0.720 |  |  | 15:00:56 | 32 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 15:34:48 | 04:12 | 15:39:00 | 15:34:48 | 34:24 | 15:00:24 | NA | 15:00:24 | NA | NA | 15:39:00 |  |  | LBF AMW079/49 AMW | 1 | 0.743 | 0.043 | 0.70 | 15:39:08 | 8 | 19,000 | 0 | 250 | 0 |  |

# APPENDIX F: 2013 FAA Simulation Results

| Run | Flt | ACID | Type | CI | Meter | TMA Analysis |  |  | TMA | Δt | FMS | FMS Analysis |  |  |  | RTA Assignment |  | RTA | ΔM | EDA | Cross Fix - Time |  | Cross Fix - Altitude |  | Cross Fix - Speed |  | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  | ETA | Δt | STA | ETA |  | ETA | First | ETA | Last | Window | Time | Path | Spd |  | Spd | Time | Δt | Alt | ΔAlt | Speed | ΔSpd |  |
| 13-1 D1R1 [C / HW] | F1 | SWA255 | B737$^{GE}$ | 30 | 2-3 |  |  |  |  |  |  | 14:17:54 | 14:19:20 | 14:22:36 | 04:42 | 14:19:30 |  | 0.760 |  |  | 14:19:32 | 2 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 15:02:14 | 03:40 | 15:05:54 | 15:02:14 |  |  | 15:00:43 |  | 15:07:26 | 06:43 | 15:05:54 | LBF AMW044/61 AMW | 0.737 | 0.027 | 0.71 | 15:06:05 | 11 | 19,000 | 0 | 250 | 0 |  |
|  | F2 | UAL350 | B737$^{GE}$ | 30 | 2-3 |  |  |  |  |  |  | 14:03:47 | 14:05:15 | 14:07:57 | 04:10 | 14:05:00 |  | 0.755 |  |  | 14:05:05 | 5 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 14:49:58 | 07:02 | 14:57:00 | 14:49:58 |  |  | 14:46:17 |  | 14:59:12 | 12:55 | 14:57:00 | YANKI SNY077/53 SNY | 0.636 | 0.014 | 0.65 | 14:57:01 | 1 | 19,000 | 0 | 250 | 0 |  |
|  | F3 | AAL923 | B752$^{RL}$ | 50 | 2-3 |  |  |  |  |  |  | 14:17:27 | 14:19:17 | 14:25:04 | 07:37 |  |  |  |  |  |  |  |  |  |  |  | FMS Emulation FAILED |
|  |  |  |  |  | 4-5 | 15:06:00 | 05:06 | 15:11:06 | 15:06:00 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | F4 | AAL431 | B752$^{RL}$ | 50 | 2-3 |  |  |  |  |  |  | 13:59:14 | 14:03:00 | 14:03:07 | 03:53 | 14:03:00 |  | 0.768 |  |  | 14:03:13 | 13 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 15:06:48 | 02:48 | 15:04:00 | 15:06:48 | 03:41 | 15:03:07 | 14:59:05 | 15:03:07 | 15:07:18 | 08:13 |  |  |  |  |  |  |  |  |  |  |  | FMS Emulation FAILED |
|  | F5 | AAL256 | B752$^{BL}$ | 50 | 2-3 |  |  |  |  |  |  | NA | 14:23:00 | NA | NA | 14:28:00 |  | 0.726 |  |  | 14:28:11 | 11 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 15:10:48 | 03:30 | 15:14:18 | 15:10:48 | 02:12 | 15:13:00 | NA | 15:13:00 | NA | NA | 15:14:18 | LBF AMW034/66 AMW | 0.750 | 0.000 | 0.75 | 15:14:30 | 12 | 19,012 | 12 | 245 | 5 |  |
|  | F6 | AAL764 | B752$^{BL}$ | 50 | 2-3 |  |  |  |  |  |  | NA | 14:06:30 | NA | NA | 14:19:00 |  | 0.652 |  |  | 14:19:20 | 20 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 15:00:39 | 07:03 | 15:07:42 | 15:00:39 | 01:21 | 15:02:00 | NA | 15:02:00 | NA | NA | 15:07:42 | LBF AMW047/60 AMW | 0.686 | 0.006 | 0.68 | 15:07:51 | 9 | 19,028 | 28 | 243 | 7 |  |
| 13-1 D1R2 [B / TW] | F1 | SWA325 | B737$^{GE}$ | 30 | 2-3 |  |  |  |  |  |  | 16:24:30 |  | 16:27:30 | 03:00 | 16:27:30 |  |  |  |  | 16:27:28 | -2 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 16:59:30 | 04:00 | 17:03:30 | 16:59:30 |  |  | 17:00:51 |  | 17:04:47 | 03:56 | 17:03:30 | LBF AMW035/66 AMW | 0.731 | 0.021 | 0.71 | 17:03:41 | 11 | 19,000 | 0 | 250 | 0 |  |
|  | F2 | UAL320 | B737$^{GE}$ | 30 | 2-3 |  |  |  |  |  |  | 16:04:16 |  | 16:07:00 | 02:44 | 16:22:48 |  |  |  |  | 16:22:47 | -1 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 16:57:15 | 04:45 | 17:02:00 | 16:57:15 | 04:49 | 17:02:04 | 16:57:10 | 17:02:04 | 17:04:48 | 07:38 | 17:02:00 | YANKI SNY091/61 SNY | 0.684 | 0.034 | 0.65 | 17:02:14 | 14 | 19,000 | 0 | 250 | 0 |  |
|  | F3 | AA456 | B752$^{RL}$ | 50 | 2-3 |  |  |  |  |  |  | 16:27:23 | 16:30:41 | 16:30:43 | 03:20 | 16:30:30 |  | 0.705 |  |  | 16:30:38 | 8 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 17:01:32 | 04:46 | 17:06:18 | 17:01:32 | 02:58 | 17:04:30 | 17:02:58 | 17:04:30 | 17:07:29 | 04:31 | 17:06:18 | LBF AMW034/67 AMW | 0.728 | 0.012 | 0.74 | 17:06:26 | 8 | 19,000 | 0 | 250 | 0 |  |
|  | F4 | UAL946 | B752$^{RL}$ | 50 | 2-3 |  |  |  |  |  |  | 16:26:05 | 16:26:48 | 16:28:04 | 01:59 | 16:26:48 |  | 0.833 |  |  | 16:27:04 | 16 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 16:57:00 | 03:31 | 17:00:31 | 16:57:00 | 03:10 | 17:00:10 | 16:56:46 | 17:00:10 | 17:01:39 | 04:53 | 17:00:30 |  | 0.724 | 0.024 | 0.70 | 17:00:36 | 6 | 19,014 | 14 | 250 | 0 |  |
|  | F5 | AAL789 | B752$^{BL}$ | 50 | 2-3 |  |  |  |  |  |  | NA |  | NA | NA |  |  |  |  |  |  |  |  |  |  |  | No RTA; Pos Error on Start |
|  |  |  |  |  | 4-5 | 17:04:30 | 04:36 | 17:09:06 | 17:04:30 | 04:48 | 17:09:18 | NA | 17:09:18 | NA | NA | 17:09:06 | PP SA023/68 SA | 0.750 | 0.010 | 0.74 | 17:09:17 | 11 | 19,013 | 13 | 256 | 6 |  |
|  | F6 | UAL279 | B752$^{BL}$ | 50 | 2-3 |  |  |  |  |  |  | NA | 16:36:48 | NA | NA | 16:36:48 |  | 0.781 |  |  | 16:36:46 | -2 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 17:08:17 | 05:01 | 17:13:18 | 17:08:17 | 04:37 | 17:12:54 | NA | 17:12:54 | NA | NA | 17:13:18 | LBF AMW036/67 AMW | 0.682 | 0.002 | 0.68 | 17:13:41 | 23 | 19,021 | 21 | 252 | 2 |  |

| Run | Flt | ACID | Type | CI | Meter | TMA Analysis |  |  | TMA | Δt | FMS | FMS Analysis |  |  |  | RTA Assignment |  | RTA | ΔM | EDA | Cross Fix - Time |  | Cross Fix - Altitude |  | Cross Fix - Speed |  | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  | ETA | Δt | STA | ETA |  | ETA | First | ETA | Last | Window | Time | Path | Spd |  | Spd | Time | Δt | Alt | ΔAlt | Speed | ΔSpd |  |
| 13-1 D1R3 [B / HW] | F1 | SWA325 | B737$^{GE}$ | 30 | 2-3 |  |  |  |  |  |  | 19:01:19 |  | 19:07:29 | 06:10 | 19:03:12 |  | 0.767 |  |  | 19:03:15 | 3 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 19:45:20 | 03:16 | 19:48:36 | 19:45:20 |  |  | 19:43:23 |  | 19:50:44 | 07:21 | 19:48:36 | LBF AMW057/60 AMW | 0.730 | 0.020 | 0.71 | 19:48:35 | -1 | 19,000 | 0 | 250 | 0 |  |
|  | F2 | UAL320 | B737$^{GE}$ | 30 | 2-3 |  |  |  |  |  |  | 18:34:54 |  | 18:38:34 | 03:40 | 18:56:00 |  | 0.722 |  |  | 18:56:05 | 5 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 19:41:49 | 04:11 | 19:46:00 | 19:41:49 |  |  | 19:37:46 |  | 19:48:36 | 10:50 | 19:46:00 |  | 0.664 | 0.004 | 0.66 | 19:46:02 | 2 | 19,000 | 0 | 250 | 0 |  |
|  | F3 | AA456 | B752$^{RL}$ | 50 | 2-3 |  |  |  |  |  |  | 19:02:40 | 19:06:50 | 19:10:09 | 07:29 | 19:06:54 |  | 0.756 |  |  | 19:06:57 | 3 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 19:45:29 | 04:55 | 19:50:24 | 19:45:29 | 04:31 | 19:50:00 | 19:45:17 | 19:50:00 | 19:53:37 | 08:20 | 19:50:24 | LBF AMW059/59 AMW | 0.756 | 0.016 | 0.74 | 19:50:27 | 3 | 19,000 | 0 | 250 | 0 |  |
|  | F4 | UAL946 | B752$^{RL}$ | 50 | 2-3 |  |  |  |  |  |  | 18:54:47 | 18:56:00 | 18:58:40 | 03:53 | 18:56:00 |  | 0.740 |  |  | 18:56:02 | 2 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 19:37:36 | 05:00 | 19:42:36 | 19:37:36 | 04:00 | 19:41:36 | 19:33:43 | 19:41:36 | 19:41:47 | 08:04 | 19:41:36 |  | 0.700 | 0.010 | 0.69 | 19:41:32 | -4 | 19,011 | 11 | 250 | 0 |  |
|  | F5 | AAL789 | B752$^{BL}$ | 50 | 2-3 |  |  |  |  |  |  | NA | 19:07:54 | NA | NA | 19:08:00 |  | 0.786 |  |  | 19:08:09 | 9 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 19:49:03 | 04:27 | 19:53:30 | 19:49:03 | 02:09 | 19:51:12 | NA | 19:51:12 | NA | NA | 19:53:30 | LBF AMW038/65 AMW | 0.752 | 0.012 | 0.74 | 19:53:41 | 11 | 19,024 | 24 | 238 | 12 |  |
|  | F6 | UAL279 | B752$^{BL}$ | 50 | 2-3 |  |  |  |  |  |  | NA | 18:58:00 | NA | NA |  |  |  |  |  |  |  |  |  |  |  | No RTA; FMC Unstable |
|  |  |  |  |  | 4-5 | 19:38:56 | 05:16 | 19:44:12 | 19:38:56 | 01:52 | 19:40:48 | NA | 19:40:48 | NA | NA | 19:44:12 |  | 0.740 | 0.000 | 0.74 | 19:44:11 | -1 | 19,023 | 23 | 243 | 7 |  |
| 13-1 D1R4 [C / TW] | F1 | SWA255 | B737$^{GE}$ | 30 | 2-3 |  |  |  |  |  |  | 20:49:06 | 20:50:00 | 20:53:36 | 04:30 | 20:52:36 |  | 0.761 |  |  | 20:52:36 | 0 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 21:22:52 | 04:08 | 21:27:00 | 21:22:52 |  |  | 21:24:10 |  | 21:28:46 | 04:36 | 21:27:00 | LBF AMW034/69 AMW | 0.733 | 0.023 | 0.71 | 21:27:06 | 6 | 19,000 | 0 | 250 | 0 |  |
|  | F2 | UAL350 | B737$^{GE}$ | 30 | 2-3 |  |  |  |  |  |  | 20:25:31 | 20:27:12 | 20:28:14 | 02:43 | 20:44:00 |  | 0.684 |  |  | 20:44:00 | 0 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 21:18:34 | 05:14 | 21:23:48 | 21:18:34 |  |  | 21:19:39 |  | 21:26:30 | 06:51 | 21:23:48 | YANKI SNY095/63 SNY | 0.686 | 0.036 | 0.65 | 21:23:56 | 8 | 19,000 | 0 | 250 | 0 |  |
|  | F3 | AAL923 | B752$^{RL}$ | 50 | 2-3 |  |  |  |  |  |  | 20:52:27 |  | 20:55:12 | 02:45 |  |  |  |  |  |  |  |  |  |  |  | FMS Emulation FAILED |
|  |  |  |  |  | 4-5 | 21:26:30 | 03:36 | 21:30:06 | 21:26:30 |  |  | 21:26:24 |  | 21:30:55 | 04:31 | 21:30:06 | LBF AMW050-58 AMW | 0.718 | 0.008 | 0.71 | 21:30:14 | 8 | 19,000 | 0 | 250 | 0 |  |
|  | F4 | AAL431 | B752$^{RL}$ | 50 | 2-3 |  |  |  |  |  |  | 20:43:19 | 20:44:00 | 20:45:17 | 01:58 | 20:44:00 |  | 0.840 |  |  | 20:43:58 | -2 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 21:19:00 | 03:06 | 21:22:06 | 21:19:00 | 03:13 | 21:22:13 | 21:17:26 | 21:22:13 | 21:22:54 | 05:28 | 21:22:12 | LBF AMW028/73 AMW | 0.711 | 0.031 | 0.68 | 21:22:20 | 8 | 19,014 | 14 | 249 | 1 |  |
|  | F5 | AAL256 | B752$^{BL}$ | 50 | 2-3 |  |  |  |  |  |  | NA | 20:52:48 | NA | NA | 20:55:12 |  | 0.680 |  |  | 20:55:23 | 11 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 21:27:54 | 03:48 | 21:31:42 | 21:27:54 | 02:12 | 21:30:06 | NA | 21:30:06 | NA | NA | 21:31:42 | LBF AMW032/70 AMW | 0.734 | 0.006 | 0.74 | 21:32:04 | 22 | 19,011 | 11 | 256 | 6 |  |
|  | F6 | AAL764 | B752$^{BL}$ | 50 | 2-3 |  |  |  |  |  |  | NA | 20:48:36 | NA | NA |  |  |  |  |  |  |  |  |  |  |  | FMS Emulation FAILED |
|  |  |  |  |  | 4-5 | 21:21:52 | 03:32 | 21:25:24 | 21:21:52 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 13-1 D2R1 [B / HW] | F1 | SWA325 | B737$^{GE}$ | 30 | 2-3 |  |  |  |  |  |  | 14:16:36 | 14:18:30 | 14:21:06 | 04:30 | 14:18:18 |  | 0.755 |  |  | 14:18:25 | 7 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 15:01:27 | 04:09 | 15:05:36 | 15:01:27 |  |  | 15:00:42 |  | 15:07:38 | 06:56 | 15:05:36 | LBF AMW038/65 AMY | 0.737 | 0.027 | 0.71 | 15:05:30 | -6 | 19,000 | 0 | 250 | 0 |  |
|  | F2 | UAL320 | B737$^{GE}$ | 30 | 2-3 |  |  |  |  |  |  | 14:03:37 | 14:06:57 | 14:07:14 | 03:37 | 14:07:00 |  | 0.659 |  |  | 14:07:05 | 5 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 14:58:06 | 04:00 | 15:02:06 | 14:58:06 |  |  | 14:50:51 |  | 15:05:29 | 14:38 | 15:02:06 | YANKI SNY098/65 SNY | 0.670 | 0.020 | 0.65 | 15:02:10 | 4 | 19,000 | 0 | 250 | 0 |  |
|  | F3 | AA456 | B752$^{RL}$ | 50 | 2-3 |  |  |  |  |  |  | 14:19:10 | 14:22:36 | 14:26:14 | 07:04 | 14:22:36 |  | 0.766 |  |  | 14:22:54 | 18 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 15:01:36 | 05:48 | 15:07:24 | 15:01:36 | 05:28 | 15:07:04 | 15:02:54 | 15:07:04 | 15:10:19 | 07:25 | 15:07:24 | LBF AMW044/61 AMW | 0.757 | 0.017 | 0.74 | 15:07:27 | 3 | 19,000 | 0 | 248 | 2 |  |
|  | F4 | UAL946 | B752$^{RL}$ | 50 | 2-3 |  |  |  |  |  |  | 14:04:00 | 14:05:06 | 14:06:00 | 02:00 | 14:05:00 |  | 0.778 |  |  | 14:05:04 | 4 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 14:44:39 | 02:45 | 14:47:24 | 14:44:39 | 00:38 | 14:45:17 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | FMS Emulation FAILED |
|  | F5 | AAL789 | B752$^{BL}$ | 50 | 2-3 |  |  |  |  |  |  | NA | 14:24:12 | NA | NA | 14:24:36 |  | 0.778 |  |  | 14:24:46 | 10 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 15:06:52 | 02:20 | 15:09:12 | 15:06:52 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | FMS Emulation FAILED |
|  | F6 | UAL279 | B752$^{BL}$ | 50 | 2-3 |  |  |  |  |  |  | NA | 14:07:00 | NA | NA | 14:07:00 |  | 0.821 |  |  | 14:07:06 | 6 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 14:55:01 | 04:59 | 15:00:00 | 14:55:01 | 04:01 | 14:51:00 | NA | 14:51:00 | NA | NA | 15:00:00 | PP AMW049/119 AMW | 0.715 | 0.035 | 0.68 | 15:00:01 | 1 | 19,030 | 30 | 254 | 4 |  |

| Run | Flt | ACID | Type | CI | Meter | TMA Analysis |  |  | TMA | Δt | FMS | FMS Analysis |  |  |  | RTA Assignment |  | RTA | ΔM | EDA | Cross Fix - Time |  | Cross Fix - Altitude |  | Cross Fix - Speed |  | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  | ETA | Δt | STA | ETA |  | ETA | First | ETA | Last | Window | Time | Path | Spd |  | Spd | Time | Δt | Alt | ΔAlt | Speed | ΔSpd |  |
| 13-1 D2R2 [C / TW] | F1 | SWA255 | B737$^{GE}$ | 30 | 2-3 |  |  |  |  |  |  | 16:06:40 | 16:08:07 | 16:09:44 | 03:04 | 16:08:12 |  | 0.752 |  |  | 16:08:25 | 13 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 16:40:32 | 04:28 | 16:45:00 | 16:40:32 |  |  | 16:41:45 |  | 16:46:41 | 04:56 | 16:45:00 | LBF AMW039/69 AMY | 0.733 | 0.023 | 0.71 | 16:45:12 | 12 | 19,000 | 0 | 250 | 0 |  |
|  | F2 | UAL350 | B737$^{GE}$ | 30 | 2-3 |  |  |  |  |  |  | 15:59:49 | 16:00:58 | 16:02:34 | 02:45 | 16:01:00 |  | 0.745 |  |  | 16:01:00 | 0 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 16:35:57 | 04:33 | 16:40:30 | 16:35:57 |  |  | 16:35:55 |  | 16:43:36 | 07:41 | 16:40:30 | YANKI SNY093/62 SNY | 0.681 | 0.031 | 0.65 | 16:40:47 | 17 | 19,000 | 0 | 250 | 0 |  |
|  | F3 | AAL923 | B752$^{RL}$ | 50 | 2-3 |  |  |  |  |  |  | 16:07:52 | 16:09:50 | 16:10:50 | 02:58 | 16:10:00 |  | 0.706 |  |  | 16:10:05 | 5 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 16:41:57 | 05:03 | 16:47:00 | 16:41:57 | 04:47 | 16:46:44 | 16:43:31 | 16:46:44 | 16:48:54 | 05:23 | 16:47:06 | LBF AMW029/72 AMW | 0.752 | 0.012 | 0.74 | 16:47:13 | 7 | 19,012 | 12 | 249 | 1 |  |
|  | F4 | AAL431 | B752$^{RL}$ | 50 | 2-3 |  |  |  |  |  |  | 16:00:19 | 16:01:00 | 16:02:17 | 01:58 | 16:01:00 |  | 0.840 |  |  | 16:01:20 | 20 |  |  |  |  | FMC Unstable in CLB |
|  |  |  |  |  | 4-5 | 16:31:16 | 03:32 | 16:34:48 | 16:31:16 | 03:33 | 16:34:49 | 16:32:00 | 16:34:49 | 16:36:00 | 04:00 | 16:34:48 |  | 0.722 | 0.022 | 0.70 | 16:34:54 | 6 | 19,015 | 15 | 255 | 5 |  |
|  | F5 | AAL256 | B752$^{BL}$ | 50 | 2-3 |  |  |  |  |  |  | NA | 16:11:00 | NA | NA | 16:14:54 |  | 0.671 |  |  | 16:15:06 | 12 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 16:47:20 | 04:28 | 16:51:48 | 16:47:20 | 02:32 | 16:49:52 | NA | 16:49:52 | NA | NA | 16:51:48 | LBF AMW030/70 AMW | 0.730 | 0.010 | 0.74 | 16:52:08 | 20 | 19,020 | 20 | 257 | 7 |  |
|  | F6 | AAL764 | B752$^{BL}$ | 50 | 2-3 |  |  |  |  |  |  | NA | 16:02:30 | NA | NA | 16:02:30 |  | 0.781 |  |  | 16:02:34 | 4 |  |  |  |  |  |
|  |  |  |  |  | 4-5 | 16:34:07 | 03:29 | 16:37:36 | 16:34:07 | 01:05 | 16:35:12 | NA | 16:35:12 | NA | NA | 16:37:36 | LBF AMW047/62 AMW | 0.698 | 0.018 | 0.68 | 16:37:47 | 11 | 19,010 | 10 | 261 | 11 |  |
| 13-1 D2R3 [C / HW] | F1 | SWA255 | B737$^{GE}$ | 30 | 3-4 |  |  |  |  |  |  |  |  |  |  | 18:32:18 |  |  |  |  | 18:32:26 | 8 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 19:15:11 | 05:25 | 19:20:36 | 19:15:11 |  |  |  |  |  |  | 19:20:36 | LBF AMW033/71 AMW | 0.713 | 0.003 | 0.71 | 19:20:38 | 2 | 19,000 | 0 | 250 | 0 |  |
|  | F2 | UAL350 | B737$^{GE}$ | 30 | 3-4 |  |  |  |  |  |  |  |  |  |  | 18:23:00 |  |  |  |  | 18:23:11 | 11 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 19:06:50 | 04:34 | 19:11:24 | 19:06:50 |  |  | 19:03:15 |  | 19:13:00 | 09:45 | 19:11:24 |  | 0.673 | 0.017 | 0.69 | 19:11:41 | 17 | 19,000 | 0 | 250 | 0 |  |
|  | F3 | AAL923 | B752$^{RL}$ | 50 | 3-4 |  |  |  |  |  |  | 18:30:49 | 18:32:21 | 18:36:39 | 05:50 | 18:35:12 |  | 0.770 |  |  | 18:35:30 | 18 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 19:14:13 | 04:47 | 19:19:00 | 19:14:13 | 57:45 | 16:16:28 | 19:13:31 | 16:16:28 | 19:22:05 | 08:34 | 19:19:00 | LBF AMW050/96 AMW | 0.749 | 0.009 | 0.74 | 19:18:50 | -10 | 19,025 | 25 | 269 | 19 |  |
|  | F4 | AAL431 | B752$^{RL}$ | 50 | 3-4 |  |  |  |  |  |  | 18:21:52 | 18:23:09 | 18:25:30 | 03:38 | 18:23:00 |  | 0.771 |  |  | 18:23:07 | 7 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 19:02:42 | 04:42 | 19:07:24 | 19:02:42 | 04:31 | 19:07:13 | 19:00:35 | 19:07:13 | 19:08:29 | 07:54 | 19:07:24 |  | 0.718 | 0.012 | 0.73 | 19:07:22 | -2 | 19,001 | 1 | 283 | 33 |  |
|  | F5 | AAL256 | B752$^{BL}$ | 50 | 3-4 |  |  |  |  |  |  | NA | 18:36:48 | NA | NA | 18:38:24 |  | 0.713 |  |  | 18:38:36 | 12 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 19:19:28 | 04:20 | 19:23:48 | 19:19:28 | 02:32 | 19:22:00 | NA | 19:22:00 | NA | NA | 19:23:48 | LBF SA029/71 SA | 0.744 | 0.004 | 0.74 | 19:24:10 | 22 | 19,014 | 14 | 252 | 2 |  |
|  | F6 | AAL764 | B752$^{BL}$ | 50 | 3-4 |  |  |  |  |  |  | NA | 18:26:00 | NA | NA | 18:26:00 |  | 0.788 |  |  | 18:25:58 | -2 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 19:06:09 | 08:21 | 19:14:30 | 19:06:09 | 01:39 | 19:07:48 | NA | 19:07:48 | NA | NA | 19:14:30 | LBF AMW046/61 AMW | 0.674 | 0.006 | 0.68 | 19:14:47 | 17 | 19,001 | 1 | 249 | 1 |  |
| 13-1 D2R4 [B / TW] | F1 | SWA325 | B737$^{GE}$ | 30 | 3-4 |  |  |  |  |  |  |  |  |  | 00:00 | 20:21:36 |  |  |  |  | 20:21:37 | 1 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 20:54:30 | 05:54 | 21:00:24 | 20:54:30 |  |  | 20:59:20 |  | 21:03:14 | 03:54 | 21:00:24 | LBF AMW039/79 AMW | 0.777 | 0.067 | 0.71 | 21:00:23 | -1 | 19,020 | 20 | 250 | 0 |  |
|  | F2 | UAL320 | B737$^{GE}$ | 30 | 3-4 |  |  |  |  |  |  |  |  |  |  | 20:15:00 |  |  |  |  | 20:15:00 | 0 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 20:48:52 | 03:38 | 20:52:30 | 20:48:52 |  |  | 20:45:00 |  | 20:56:00 | 11:00 | 20:52:36 | YANKI SNY101/67 SNY | 0.686 | 0.036 | 0.65 | 20:52:45 | 9 | 19,020 | 20 | 250 | 0 |  |
|  | F3 | AA456 | B752$^{RL}$ | 50 | 3-4 |  |  |  |  |  |  | 20:22:40 | 20:26:20 | 20:26:46 | 04:06 | 20:26:36 |  | 0.714 |  |  | 20:26:36 | 0 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 20:59:11 | 05:31 | 21:04:42 | 20:59:11 | 05:13 | 21:04:24 | 21:01:42 | 21:04:24 | 21:06:47 | 05:05 | 21:04:42 | LBF AMW024/76 AMW | 0.749 | 0.009 | 0.74 | 21:04:46 | 4 | 19,000 | 0 | 250 | 0 |  |
|  | F4 | UAL946 | B752$^{RL}$ | 50 | 3-4 |  |  |  |  |  |  | 20:19:17 | 20:19:56 | 20:21:21 | 02:04 | 20:20:00 |  | 0.782 |  |  | 20:20:24 | 24 |  |  |  |  | MEMON fix NOT loaded |
|  |  |  |  |  | 5-6 | 20:54:08 | 03:22 | 20:57:30 | 20:54:08 | 02:43 | 20:56:51 | 20:53:23 | 20:56:51 | 20:58:10 | 04:47 | 20:57:30 | LBF AMW015/45 AMW | 0.713 | 0.033 | 0.68 | 20:57:38 | 8 | 19,018 | 18 | 248 | 2 |  |
|  | F5 | AAL789 | B752$^{BL}$ | 50 | 3-4 |  |  |  |  |  |  | NA | 20:26:24 | NA | NA | 20:30:00 |  | 0.680 |  |  | 20:29:56 | -4 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 21:02:01 | 05:29 | 21:07:30 | 21:02:01 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | FMS Emulation FAILED |
|  | F6 | UAL279 | B752$^{BL}$ | 50 | 3-4 |  |  |  |  |  |  | NA | 20:15:00 | NA | NA | 20:15:00 |  | 0.783 |  |  | 20:15:12 | 12 |  |  |  |  |  |
|  |  |  |  |  | 5-6 | 20:49:13 | 05:29 | 20:54:42 | 20:49:13 | 03:29 | 20:52:42 | NA | 20:52:42 | NA | NA | 20:54:48 | LBF AMW023/78 AMW | 0.708 | 0.028 | 0.68 | 20:54:51 | 3 | 19,012 | 12 | 261 | 11 |  |

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Ph.D., Engineering Management and Systems Engineering — August 2012

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Graduate Certificate, Management Science and Engineering — March 2011

United States Air Force Academy
B.S., Engineering — May 1989

## RECENT PUBLICATIONS

Bell, A., Gheorghe, *Performance Metrics and Collision Risk Models for Time-Based Air Traffic Management,* Virginia Space Grant Consortium Conference Proceedings, Hampton University, Hampton, VA, April 11, 2014.

Bell, A., Gheorghe, A., Hester, P., *Avionics Certification for Trajectory Based Operations*, ICMIE Conference Proceedings, Politehnica University, Bucharest, Romania, October 31, 2013.

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