12-2011

A Comparison of Fuel Efficiencies Between DC-9-30 and B-737NG Aircraft for Delta Airlines at Atlanta Hartsfield Airport

Brandon Scott Newman
Embry-Riddle Aeronautical University - Daytona Beach

A COMPARISON OF FUEL EFFICIENCIES BETWEEN DC-9-30 AND B-737NG AIRCRAFT FOR DELTA AIRLINES AT ATLANTA HARTSFIELD AIRPORT

by

Brandon Scott Newman

A Thesis Submitted to the College of Aviation Department of Applied Aviation Sciences
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Aeronautics

Embry-Riddle Aeronautical University
Daytona Beach, Florida
December 2011

A COMPARISON OF FUEL EFFICIENCIES BETWEEN DC-9-30 AND B-737NG AIRCRAFT FOR DELTA AIRLINES AT ATLANTA HARTSFIELD AIRPORT

by

Brandon Scott Newman

This Thesis was prepared under the direction of the candidate's Thesis Committee Chair, Dr. Guy M. Smith, Associate Professor, Daytona Beach Campus, and Thesis Committee Member, Carlos A. Castro, Associate Professor, Daytona Beach Campus, and has been approved by the Thesis Committee. It was submitted to the Department of Applied Aviation Sciences in partial fulfillment of the requirements for the degree of Master of Science in Aeronautics

Thesis Committee:

Guy M. Smith, Ed.D.
Committee Chair

Carlos A. Castro
Committee Member

Marvin L. Smith, Ed.D.
Graduate Program Chair
Applied Aviation Sciences

Guy M. Smith, Ed.D.
Department Chair
Applied Aviation Sciences

Tim Brady, Ph.D.
Dean, College of Aviation

Robert Oxley, Ph.D.
Associate Vice President of Academics

1-31-2012
Date

Acknowledgements

First, I would like to manifest my sincere and deep gratitude to my parents, Robert and Elaine Newman, who have done the impossible to support my dreams of an education at Embry-Riddle Aeronautical University. I would like to thank all of my friends who supported me throughout the thesis process.

I also manifest a special thanks to Dr. MaryJo Smith and Dr. Guy M. Smith, without whom this project would not have been possible. I thank coworkers, Carlos A. Castro, Todd H. Waller, and all the other NEAR lab faculty members, and all the Embry-Riddle Aeronautical University collaborators, whose hard work has helped me pursue my dream.

Abstract

Researcher: Brandon Scott Newman

Title: A Comparison of Fuel Efficiencies Between DC-9-30 and B-737NG Aircraft for Delta Airlines at Atlanta Hartsfield Airport

Institution: Embry-Riddle Aeronautical University

Degree: Master of Science in Aeronautics

Year: 2011

Improved fuel efficiency is one of aviation's top priorities, as it impacts the economy and the National Airspace System's environment. This descriptive study used data generated by the Total Airspace and Airport Modeler (TAAM) to show that the Boeing 737 Next Generation series aircraft would be more fuel-efficient than the McDonnell-Douglas DC-9-30 aircraft on various routes used by Delta Airlines out of Atlanta's Hartsfield-Jackson International Airport. Databases, such as Aircraft Situation Display to Industry (ASDI) and Base of Aircraft Data (BADA), were used to simulate the baseline flight route information. Simulations were performed on Boeing 737NG (-700, -800, -900) and the DC-9-30 aircraft. Statistically significant improvements were found in the fuel burn for the Boeing 737 aircraft, with an estimated yearly savings of about $26 million dollars.

Table of Contents

List of Tables

List of Figures

Chapter I

Introduction

In 2008, nearly forty-four million passengers flew domestically on commercial airlines through the Hartsfield-Jackson Atlanta International Airport (KATL), the fourth highest number in aviation history. The airlines flew 10.6% of the total US vehicle miles traveled in 2008 (Research and Innovative Technology Administration (RITA), 2009). This mode of transportation continues to grow rapidly. Commercial passenger flights have increased 26% since 1980 (Labich, 1987).

The more passengers who fly, the more airplanes that are needed to accommodate those passengers; thus, putting even more emphasis on fuel efficiency. One way to accommodate more airplanes for a specific airline is a merger, such as Delta Airlines merger with Northwest Airlines in 2008 (Delta Airlines, 2011a). Most of the airplanes that are flying today, some of which date back to the 1960's, are not fuel-efficient, greatly pollute the air, and create ozone. Change is needed in all aspects of the National Airspace System (NAS) (Federal Aviation Administration, 2011a). One of the changes needed is more fuel-efficient aircraft that can meet or exceed today's environmental standards and technologies. The Federal Aviation Administration is giving the NAS a facelift with the help of their NextGen program (Federal Aviation Administration, 2011a). One portion of the NextGen program is newer airplanes with stricter environmental standards. By using newer aircraft, such as Boeing's Next Generation series, ozone-causing pollutants can be reduced. The Next Generation line includes Boeing's 737-600/700/800/900 series (Boeing Company, n.d.).

Significance of the Study

Aviation plays a key role in the United States' transportation system. The environment is changing and, as the number of domestic flights increase monthly, the need for more efficient aircraft becomes one of aviation's top priorities. This study is relevant to those involved in the aviation industry, such as airline operators, airport operators, and airplane manufacturers. This study specifically involved Delta Airlines, the Atlanta Hartsfield- Jackson Airport, the former McDonnell-Douglas Corp., and the Boeing Company. The research took place in Daytona Beach, Florida. The researcher was a full time graduate student at Embry-Riddle Aeronautical University.

Statement of the Problem

In 2006, the Federal Aviation Administration established the NextGen Program to transform the United States' National Airspace System by using new technologies (Federal Aviation Administration, 2011a). One of the biggest economic issues in aviation was fuel-inefficient airplanes. Engine design and aerodynamics are important contributors to fuel efficiency. The aviation industry uses tools such as Total Airspace and Airport Modeler (TAAM) (Jeppesen, 2011a) to examine fuel efficiencies for airline operators. TAAM was used in this study to examine the fuel burn of Delta Airlines to determine how aircraft fleet changes could improve overall operations. In addition, fuel efficiency data from TAAM was combined with data from aircraft manufacturers and the Base of Aircraft Data (BADA) to determine if Delta Airlines can attain improved fuel efficiency if the DC-9-30 aircraft fleet was replaced by Boeing 737NG aircraft at Delta's main hub of operation at the Hartsfield-Jackson International Airport in Atlanta.

Purpose Statement

The purpose of this study was to examine the difference in fuel efficiencies between the McDonnell-Douglas DC-9-30 aircraft and the Boeing 737NG aircraft by modeling flight routes using TAAM, from Atlanta Hartsfield-Jackson International Airport for one typical day.

Hypotheses

The review of the literature associated with the importance of aviation fuel efficiency led to the following hypotheses:

H1. There was a difference in fuel efficiency based on lb/nm, between McDonnell-Douglas DC-9-30 aircraft and Boeing's 737-700 aircraft.

H2. There was a difference in fuel efficiency based on lb/nm, between McDonnell-Douglas DC-9-30 aircraft and Boeing's 737-800 aircraft.

H3. There was a difference in fuel efficiency based on lb/nm, between McDonnell-Douglas DC-9-30 aircraft and Boeing's 737-900 aircraft.

H4. There was a difference in fuel efficiency based on lb/hr, between McDonnell-Douglas DC-9-30 aircraft and Boeing's 737-700 aircraft.

H5. There was a difference in fuel efficiency based on lb/hr, between McDonnell-Douglas DC-9-30 aircraft and Boeing's 737-800 aircraft.

H6. There was a difference in fuel efficiency based on lb/hr, between McDonnell-Douglas DC-9-30 aircraft and Boeing's 737-900 aircraft.

Delimitations

The following four delimitations existed throughout the design and completion of the study. The fleet of Delta Airlines was the only one used for data analysis. Data were limited to 2008, because Delta Airlines did not start DC-9 operations until 2008, the year of the Northwest Airlines and Delta Airlines merger. The DC-9-30 aircraft was the only aircraft examined for fuel efficiencies because the DC-9-30 was the largest fleet within the DC-9 series of aircraft at Delta Airlines. Hartsfield-Jackson Atlanta International airport was the only Delta hub that was examined because it was their largest hub of operations. The Boeing 737-600 was part of the Boeing Next Generation 737 aircraft line, but it was not analyzed in this study because TAAM treats that aircraft's performance characteristics the same as the Boeing 737-700.

Limitations and Assumptions

TAAM uses data from several sources to assume software reliability and validity. The aircraft performance database, Base of Aircraft Data (BADA), was from EuroControl, the European Organization for the Safety of Air Navigation (Jeppesen, 2011c). BADA is an aircraft performance model with corresponding databases. BADA aircraft performance databases use aircraft type, mass, performance envelope, aerodynamics, engine thrust and fuel consumptions. TAAM uses BADA data, along with calculated speeds for the aircraft's climb, cruise, and descent profiles from airline procedure manuals to provide realistic aircraft performance during simulation.

Other sources of data that were used with TAAM are TARGETS, ASDI and OAG. Terminal Area Route Generation Evaluation and Traffic Simulation (TARGETS) (MITRE Aviation Institute, 2011), was used to generate route, airport and waypoint data. Aircraft Situation Display to Industry (ASDI) (Federal Aviation Administration, 2011C) and Official Airline Guide (OAG) (OAG Aviation, 2011) were used to gather data on airline flight plan information that was needed to generate TAAM Timetables.

Definition of Terms

Boeing Next Generation Aircraft: The 737-600, 737-700, 737-800, 737-900 aircraft which are part of Boeing's new fuel-efficient aircraft line (Boeing Company, 2011a).

Fuel Burn: The cumulative fuel burned from the start of the flight to the end of the flight (Jeppesen, 2011c).

Fuel Efficiency: The efficiency of processing a chemical energy into kinetic energy or work (Jeppesen, 2011c).

NextGen NextGen program is a wide-ranging transformation of the entire National Air Transportation system to meet future demands and avoid gridlock in the sky and in the airports. It moves away from legacy ground-based technologies to a new and more dynamic satellite-based technology. These new capabilities and technologies that support them will change the way the system operates, reduce congestion, enhance passenger experience, and improve the environment (Federal Aviation Administration, 2011a).

List of Acronyms

ADS-B	Automatic Dependent Surveillance Broadcast
ASDE-X	Airport Surface Detection Equipment Model X
ASDI	Aircraft Situation Display to Industry

ATM	Air Traffic Management
BADA	Base of Aircraft Data
CEO	Chief Executive Officer
DC	Douglas Corporation
ETD	Estimated Time of Departure
FAA	Federal Aviation Administration
FE (lb/min)	Fuel Efficiency in pounds per minute
FE (lb/nm)	Fuel Efficiency in pounds per nautical mile
IDIS	Interactive Data Input System
IPCC	Intergovernmental Panel on Climate Change
KATL	Hartsfield-Jackson Atlanta International Airport
NAS	National Airspace System
NG	Next Generation
NAL	National Aerospace Laboratory
NEAR	Next Generation Applied Research Lab
NRDC	Natural Resources Defense Council
OAG	Official Airline Guide
RITA	Research and Innovative Technology Administration
RNAV	Area Navigation
SID	Standard Instrument Departure
SPSS	Statistical Package for the Social Sciences
STAR	Standard Terminal Arrival Route
TAAM	Total Airspace and Airport Modeler

TARGETS	Terminal Area Route Generation Evaluation and Traffic Simulation
ASNP	Air Navigation Service Providers
CAA	Civil Aviation Authorities

Chapter II

Review of the Relevant Literature

Importance of Aviation Fuel Efficiency to the Environment

The transportation sector is one of the largest industries contributing to pollution that affects global warming, and by 2025 this sector is expected to increase its share of the pollutants by 60 percent (West, 2009). It is clear that airlines must make environmental changes based on increased fuel efficiency to decrease greenhouse gases (West). The Natural Resources Defense Council (NRDC) advised CEOs from fifteen airlines and airfreight corporations to improve fuel efficiencies by embracing clean, renewable fuels (NRDC, 2011a). Figure 1 shows the Percentage of US Greenhouse gas emissions by industry in 2006.

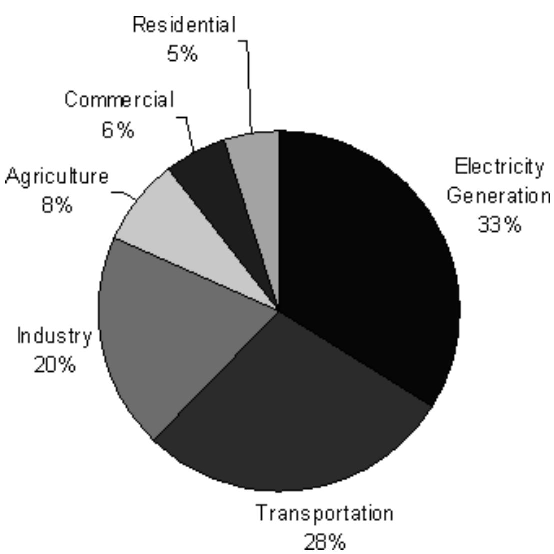

*Figure 1***.** Percentage of US greenhouse gas emissions by industry in 2006. *Note. From the US Department of Transportation.*

When asked about environmental improvements in aviation, the general population indicated that they are concerned about noise pollution, air quality, and climate impacts (NRDC, 2011b). As pointed out by both the NRDC and the FAA, fuel consumption, fuel burn, and fuel inefficiency continue to have some of the highest impacts on the environment in the twenty-first century; the importance of these factors has been missed by most of the population (West, 2009).

Airlines must take two steps to improve the environment. First, airline companies must join the push for research and development in creating fuels that result in a cleaner burn, such as an algae-based fuel from items like sugar beets, corn, wheat, and straw (Cutche-Gershenfeld, Greitzer, Kerrebrock, Townswend, & Waitz, 2004). Secondly, airlines must improve their overall fuel efficiency by purchasing more fuel-efficient airplanes, such as Boeing's 737-NG.

The US airlines have worked hard to improve fuel efficiency over the past 10 years (RITA, 2009). Looking ahead, the airlines need to continue to improve this efficiency, and one possibility is the NextGen program. In light of the environmental issues, the FAA has taken a direct approach to the problem by implementing the NextGen program, which impacts every sector of the United States National Airspace System (NAS).

Fuel efficiency improvements from 1998 to 2008. Delta Airlines has improved fuel efficiency over the last ten years (RITA, 2009). During this time, airlines have developed many different ways to save on fuel consumption. A list of operational fuel consumption savings was compiled from Federal Aviation Administration (2011a), International Air Transportation Association (2011), and Airlines for America (2011):

- Employ single-engine taxi procedures during normal operations and selective engine shutdown during ground delays.
- Reduce and measure more accurately onboard weight while redistributing the belly cargo.
- Cruise longer at higher altitudes and employ shorter, steeper approaches.
- Work with FAA to change en-route fuel reserve requirements to reflect state-of-the-art navigation, communication, surveillance and wind forecast systems.
- Employ self-imposed ground delays to reduce airborne holding.
- Modernize fleets with more fuel-efficient airplanes.
- Invest in winglets to reduce aircraft drag and thereby increase fuel conservation.
- Redesign hubs and schedules to alleviate congestion.
- Advocate expanded and improved airfield capacity.
- Use airport power rather than onboard auxiliary power units when at the gates. Change paint schemes to minimize heat absorption.

The Research and Innovative Technology Administration (RITA) (2009) data show that, as the number of Next Generation airplanes are added to a company's fleet, the fuel efficiency increases (RITA, 2009). Based on the number of miles flown by an airline in 2008, Atlas Airlines has the highest fuel efficiency with 10.63 revenue ton miles per gallon. Atlas' fleet is made up of mostly Boeing 747s. Southwest's fleet, with an all-Boeing 737 aircraft, has the highest fuel efficiency of all airlines that have only 737s (RITA, 2009).

Improving US aviation fuel efficiency in the future. It is clear that airlines must make environmental changes based on increased fuel efficiency to decrease greenhouse gases. The use of the Boeing 737, as an example of the Next Generation program, offers an important way to improve fuel efficiency (Federal Aviation Administration, 2011a). Action by the aviation industry also plays a key role in making progress to improve aircraft emissions. New engine designs emit lower nitrogen dioxide (NO_2) emission levels. The aviation industry has a target by 2020 to reduce NO_2 emissions by 80 percent compared to aircraft in production in 2000 (Department of Transport, n.d.).

Next Generation Program

The NextGen program encompasses air traffic control and improved aircraft. As defined by the FAA, NextGen at its most basic level represents an evolution from a ground-based system of air traffic control to a satellite-based system of air traffic management. This evolution is vital to meeting future demand and avoids gridlock in the sky and at our nation's airports. NextGen will open America's skies to continued growth and increased safety while reducing aviation's environmental impact (Federal Aviation Administration, 2011a).

NextGen goals are being achieved by using aviation-specific applications and state-of-the-art technologies, such as Global Positioning Satellite (GPS), Automatic Dependent Surveillance – Broadcast (ADS-B), Airport Surface Detection Equipment Model-X (ASDE-X), improved airport infrastructure, and new procedures that shift certain decision-making responsibilities from the ground to the flight deck. When fully implemented, the NextGen program will allow for more efficient aircraft to fly closer together without compromising safety, which will allow for more direct routing, reduced delays, and unprecedented benefits to the environment though the reduction of carbon emissions, fuel burned, and noise (Federal Aviation Administration, 2011a).

Change is needed in the NAS. Simply stated, it is because current and future passenger demand is increasing at an alarming rate, and every year the government pays approximately 9.4 billion dollars for delays in the National Airspace System (US Department of Transportation, 2009). With the Next Gen program, the FAA expects the NAS to meet the current and future demands while increasing safety, efficiency, and capacity of airplanes (Federal Aviation Administration, 2011a).

As emphasis is placed on improving fuel efficiency, it is essential to improve safety. Since 2001, the United States has enjoyed the safest period in the history of aviation, at least from a statistical perspective. As the number of airplanes increase yearly, new systems and procedures are needed to improve higher levels of safety. NextGen satellite technologies will deliver information to pilots and controllers quicker and with levels of accuracy and precision unattainable by the current radar system. Even though planes will be flying closer, the precise information provided by NextGen will significantly improve safety by allowing pilots to know exactly where other aircraft are located (Federal Aviation Administration, 2011a). Aviation authorities say that NextGen enables precise, direct-routed approaches, which decrease noise pollution, fuel burn, and aviation's environmental impact. The NextGen program is expected to be complete by 2025 (Federal Aviation Administration, 2011a).

Total Airspace and Airport Modeler

Total Airspace and Airport Modeler (TAAM) is an industry-leading tool from Jeppesen that models airspace and airports to facilitate planning, analysis and decision-making (Jeppesen, 2011a). Airports and airspace can be modeled, and then the impact of changes to infrastructure, operations and schedules can be evaluated. TAAM is recognized as a standard in the aviation industry and is widely used by airspace planners, airport operators, service providers, and major air carriers. TAAM, is a fast-time gate-to-gate simulation tool that enables operators to accurately predict and analyze the impact of present and future airspace and airport operations, while maintaining safety and efficiency (Jeppesen, 2011a). This sophisticated software tool presents realistic 4D models of airspace and airports to facilitate decision support, planning and analysis. TAAM simulations are processed in fast-time, enabling users to obtain results quickly and to evaluate a wider range of scenarios (Jeppesen, 2011a).

Fuel burn. TAAM estimates at the start of the flight the fuel burn that would likely occur over the duration of an entire flight. Based on this information and the landing mass specified for the aircraft type in the Aircraft Characteristics file, TAAM estimates the initial weight of the aircraft. As the flight progresses, TAAM continually determines the actual fuel burn. Periodically, TAAM calculates the new decreased mass of the aircraft based on this fuel burn and assesses the cruising altitude and rate of climb that the aircraft can achieve (Jeppesen, 2011c). Accordingly, the aircraft climbs to the determined level at the determined rate and cruises there until the next assessment. This is done repeatedly until the aircraft reaches its predetermined final cruise level (Jeppesen, 2011b).

Estimated total fuel burn. TAAM calculates the fuel burn that is likely to occur over the initial flight plan if the aircraft were to fly the entire plan with the initial take-off mass (Jeppesen, 2011c). TAAM also calculates the fuel burn that is likely to occur over the initial flight plan if the aircraft were to fly the entire plan with the landing mass specified in the Aircraft Characteristics file. These two numbers are the extreme cases (maximum and minimum likely fuel burn respectively). TAAM estimates the total fuel burn that is likely to occur in the simulation as 55% of the sum of these two values

(Jeppesen, 2011b).

Fuel Efficiency and Other TAAM Studies

Fuel efficiency of commercial aircraft. The National Aerospace Laboratory (NAL) completed research in 2005 on fuel efficiencies of commercial aircraft (Hoolhorst, Middel, Peeters, 2005). The report assessed how the fuel efficiency of commercial aircraft had developed since their introduction in the 1930s. Existing estimates, such as the often-cited 70% improvement from the Intergovernmental Panel on Climate Change (IPCC) Special Report on Aviation and the Global Atmosphere, ignore the record of the pre-jet era. Based on bottom-up (micro) and top-down (macro) analyses of aircraft fuel efficiency, it can be concluded that the last piston-powered aircraft were as fuel-efficient as the current average jet (Hoolhorst, Middel, & Peeters, 2005). This result was obtained by comparing several large piston-engined aircraft with both old and new jet airliners and was confirmed by the macro analysis, which reveals a sharp increase in fuel consumption per seat-kilometer as piston-engined aircraft were replaced by jet-engined aircraft. The last piston-powered airliners were at least twice as fuel-efficient as the first jet-powered aircraft (Hoolhorst et al.).

Aircraft fuel efficiency is just one of the design parameters of interest to aircraft designers and the market. The common practice of defining future cuts in energy consumption per seat-kilometer in terms of a constant annual percentage reduction is therefore not very accurate. It ignores the fact that current aircraft configurations can never achieve zero fuel consumption. Nor does it take into account that the annual reduction rate is not a constant, but is itself also falling, as clearly demonstrated by both macro and micro analysis (Hoolhorst et al., 2005).

Korean airspace case study. Embry-Riddle Aeronautical University worked with the South Korean government in 2010 to analyze airspace procedures at three major airports: Incheon International, Gimpo International, and Jeju International. The challenge of this project was to provide simulations that resembled proper, safe, and efficient flight procedures due to strong military airspace control. TAAM simulation was used to estimate the benefits, capacity augmentation, fuel savings, flight time efficiency and safety enhancements achieved by transforming current SID and STAR procedures to Area Navigation (RNAV) procedures.

Delta Airlines airport expansion case study. Delta Airlines used TAAM to analyze alternative airport layouts to prove that making changes in airport physical structures would benefit the airport's future traffic demand. The project examined new taxiway and runway structures for its hub of operations KATL (Jeppesen, 2011a).

Delta Airlines

Delta Airlines is based in Atlanta, Georgia. This airline operates a hub-and-spoke route structure with extensive domestic and international destinations. Delta Airlines, founded in 1928, employs more than 80,000 people that operate 1,017 aircraft, which serve 356 destinations in 65 countries (Delta Airlines, 2011a). Delta's fleet has an average age of 13.4 years. Delta merged with Northwest Airline in 2008 to become the largest air carrier in the world. Next Generation Aircraft account for 17% of Delta Airlines fleet (Noack, 2009).

Delta Airlines has been one of the largest air carriers in the United States per yearly passenger enplanements and net income (Delta Airlines, 2011a). Delta Airlines, was originally founded as a crop dusting service in the early 1920's when Collet

Woolman joined a conversation with Louisiana farmers who were concerned about the threat to their crops from boll weevils. Woolman and an associate dropped calcium arsenate from the Flying Jennys to kill the insects. As a result, the world's first crop dusting service was born (Delta Airlines, 2011a).

Delta Airlines, originally headquartered in Monroe, Louisiana, used a streamlined operation business plan to maintain dominance throughout the US. This forced smaller airlines to go bankrupt resulting in buyouts, which increased Delta's dominance in many regions (Delta Airlines, 2010b).

In the 1960's, Delta Airlines moved into the jet age with the DC-9. Delta had a total of 63 DC-9 -32s by the year 1971 (Delta Airlines, 2011b). These efficient aircraft were used to fill routes of 500 miles, typically routes that were serviced by propeller aircraft. By 1993, all the DC-9 aircraft were sold and replaced by more efficient Boeing 727 aircraft (Delta Airlines, 2011). While it boasted one of the most modern jetliner fleets in domestic service, the company developed a reputation for purchasing new airplanes, often in a costly way, only after they had been proven at other airlines. This "wait-and-see" policy saved the company a large amount of money. Only after competing airlines had used the Lockheed 1011 for several years did Delta purchase the plane, and Delta began replacing its fleet of Boeing 727s with the 757, 767, and MD-88 in the late 1980s, later than most, with the intention of using these technologically advanced and fuel-efficient planes for at least 20 years (Delta Airlines, 2011b).

Although the company did not invent it, Delta was the first airline to widely employ the so-called "hub-and-spoke" system, in which a number of flights are scheduled to land at a hub airport within approximately 30 minutes, enabling passengers to make connections for final destinations conveniently and quickly (Delta Airlines, 2011b). By the early 1990s, the "big push," as it was called, was occurring about ten times a day at the Atlanta hub.

As with many mergers, Delta Airlines acquired many older airplanes as a result of merging with Northwest Airlines in 2008. Most of the DC-9 aircraft that were acquired were originally sold by Delta in 1993. By 2008, these aircraft were less efficient when compared with the Next Generation aircraft, and had an average fleet age of 33 years (Delta Airlines, 2011b).

Hartsfield-Jackson Atlanta International Airport

On April 16, 1925, Walter Sims, then mayor of Atlanta, signed a lease for an abandoned auto racetrack which had 287 acres of land and committed Atlanta to develop that city's first commercial airport (KATL, 2011). By 1998, Hartsfield-Jackson Atlanta International Airport was recognized as the busiest passenger airport in the world, accommodating more than 78 million passengers annually. Since 2005, KATL has been recognized as the busiest operations airport in the world (KATL, 2011). In 2011, the airport was owned and operated by the Department of Aviation for the city of Atlanta and was still recognized as the busiest airport in the world, handling nearly 90 million passengers annually (KATL, 2011).

KATL's vision is to be the global leader in airport efficiency and customer service excellence. In 2011, KATL was named the world's most efficient airport by providing passengers the Plane Train, which is an underground automated people mover connecting all six terminals (KATL, 2011). Twenty-six domestic and eleven international airlines service KATL providing service to 151 US and more than 80 international destinations. (KATL, 2011).

KATL averages more than 240,000 passengers on nearly 2,700 flight operations a day (KATL, 2011). KATL is within a two-hour flight of 80 percent of the US population, which is one reason why Delta Airlines has chosen KATL as its major hub of operation (KATL, 2011).

Delta Operations. KATL is Delta's largest hub airport, serving 205 destinations worldwide. (Delta Airlines, 2010b). More than 600 Delta employees work at Delta's Operations Control Center in Atlanta to coordinate approximately 800 aircraft and 2,000 daily flights, with 980 departures daily from KATL (Delta Airlines, 2010b).

McDonnell-Douglas Aircraft

McDonnell-Douglas DC-9 aircraft was one of the best selling and most enduring commercial jetliners ever built. Launched in 1963 without a single firm commitment, McDonnell-Douglas eventually produced 976 DC-9 airplanes in six variants (Delta Airlines, 2010a). At the beginning of 2010, there were still 179 DC-9s in active service (Delta Airlines, 2010a).

DC-9 Aircraft. The DC-9 was a highly reliable, quiet and economical short-range jet. It had the ability to operate from runways as short as 5,000 feet and bring speed and comfort of the jet age to hundreds of smaller towns and cities (Delta Airlines, 2010a) The DC-9 operated on routes of 1,500 miles or less in length and that typically had less traffic demand. When engineers designed the DC-9, the length of runways was considered. Most airports at the time were adapted to the needs of piston aircraft and lacked the longer runways necessary for jets. Short-field performance was critical to the success of the DC-9 (Delta Airlines, 2010a). Figure 2 shows the McDonnell-Douglas DC-9-30 aircraft specifications. The length of the DC-9-30 is 119 feet 4 inches and the tail height is approximately 28 feet.

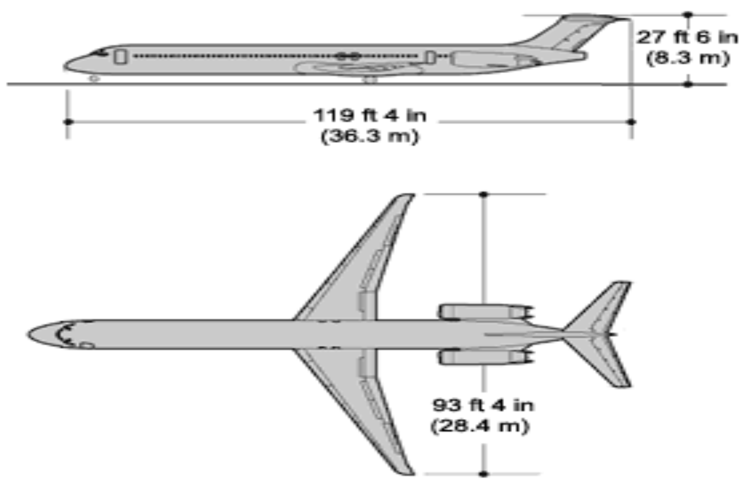

Figure 2. DC-9 specifications. *Note.* From Delta, *Aircraft Specifications* (2010a).

Boeing Next Generation Aircraft

The Next Generation Boeing 737 is defined as the 737-600/-700/-800/-900 series (Boeing Company, 2011a). The 737 was a narrow-body jetliner utilized for short to medium range flights, but which now can be used for extended range flights with the 737-700ER/-900 models. The 737 was a single-aisle airplane with two rows on either side, and held up to 215 seats in a single class configuration (Boeing Company).

Since Boeing started production of the Next Generation airliner in 1996, over 2,800 of the 737-NG aircraft have been sold (Boeing Company, 2011a). Boeing's latest addition to the Next Generation lineup is the B737-900. (Boeing Company) This aircraft was introduced to meet the range and passenger capacity of the discontinued 757-200 model and directly competes with the Airbus A-321. The launch of this aircraft was August 8, 2006, and the first airplane rolled off the production line in April 2007 to Lion Air. As of April 2009, a total of 47 of the 737-900 models had been delivered, and there were more than 200 orders for the aircraft to be filled (Boeing Company) The 737-600/-700/-800/-900 models incorporate a new, advanced-technology wing design that helps increase fuel capacity and efficiency, both of which increase range (Boeing Company). On each wing, the chord was increased by about 20 inches and the total span by approximately 18 feet. The wing area provided thirty percent more fuel capacity for a total of 6,875 US gallons (Boeing Company).

737-600 Aircraft. The 737-600 was the smallest member of the family, which carries 110 to 132 passengers (Boeing Company, 2011a). The maximum fuel capacity was 6,875 gallons. Maximum range was 3,225 nautical miles. Figure 3 shows the Boeing 737-600 aircraft specifications. The length of the Boeing 737-600 is 97 feet 9 inches and the engine width is approximately 8 feet (Boeing Company).

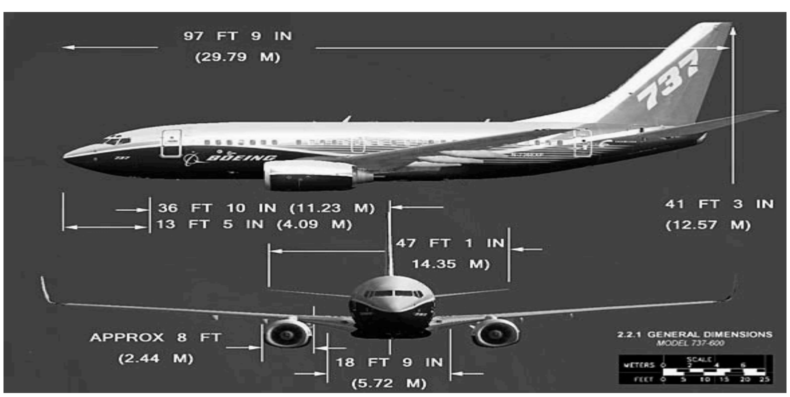

Figure 3. Boeing's 737-600 specifications. *Note.* From Arian Design. (2009a).

737-700 Aircraft. The 737-700 was capable of carrying 126 to 149 passengers. The maximum fuel capacity was 6,875 gallons. Maximum range was 3,440 nautical miles. Figure 4 shows the Boeing 737-700 aircraft specifications. The length of the Boeing 737-700 is 105 feet 7 inches and the engine width was approximately 8 feet.

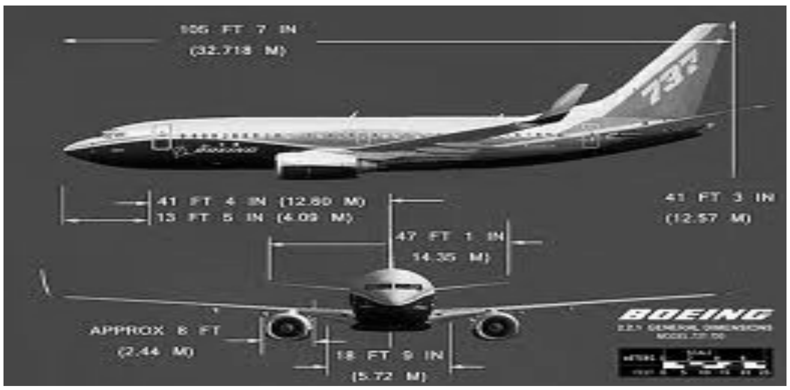

Figure 4. Boeing's 737-700 specifications. *Note.* From Arian Design. (2009b).

737-800 Aircraft. The 737-800 can seat 162 to 189 passengers. The maximum fuel capacity was 6,875 gallons. Maximum range was 3,115 nautical miles. Figure 5 shows the Boeing 737-800 aircraft specifications. The length of the Boeing 737-800 was 133 feet 5 inches and the engine width was approximately 8 feet.

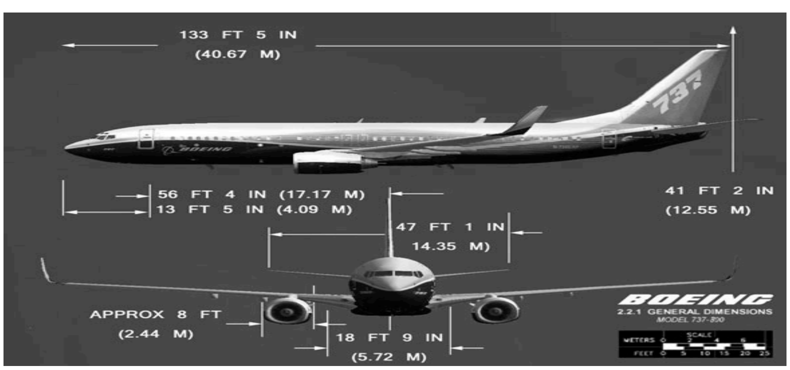

Figure 5. Boeing's 737-800 specifications. *Note.* From Arian Design. (2009c).

737-900 Aircraft. The 737-900 was the longest 737, capable of carrying up to 220 passengers. The maximum fuel capacity was 7,837 gallons. Maximum range was 3,265 nautical miles. *Figure 6* shows the Boeing 737-900 aircraft specifications. The length of the Boeing 737-900 is 138 feet 2 inches and the engine width was approximately 8 feet.

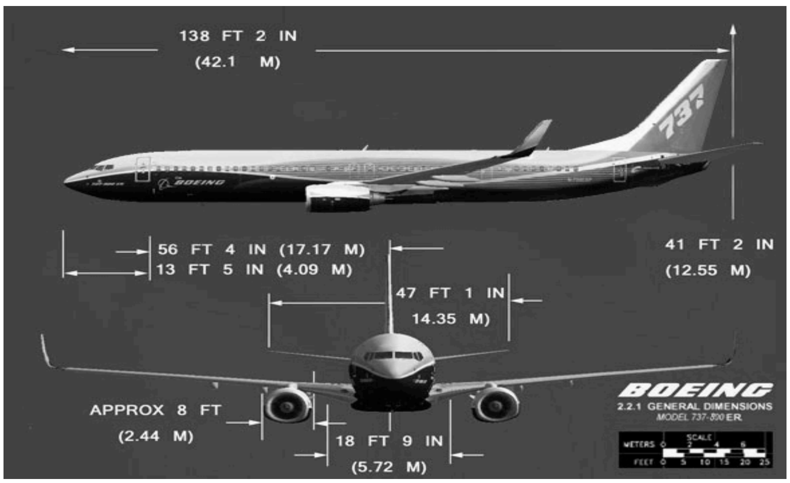

Figure 6. Boeing's 737-900 specifications. *Note.* From Arian Design. (2009d).

Summary

In 2008, Delta Airlines was at the forefront of addressing environmental concerns, by using methods, such as, aircraft replacement to increase fuel efficiency and decrease greenhouse gases. US airlines have made significant improvements in fuel efficiency over the past 10 years. Airlines need to take two steps towards an environmentally improved future. First, airline companies must join the push for research and development to create a fuel that burns cleaner; and second, airlines must improve their overall fuel efficiency by purchasing more fuel-efficient airplanes, such as Boeing's 787 Dreamliner or 737-NG.

One way for airlines to improve fuel efficiency is to follow the implantation of NextGen. This program will decrease commercial jet fuel consumption, fuel costs, noise pollution, greenhouse gas emissions and other environmental impacts.

With the use of TAAM and aircraft manufacturer data, Delta Airlines has the tools to model existing operations and compare those with models of Boeing Next Generation aircraft to determine how much fuel efficiency can be improved with the replacement of aircraft.

Chapter III

Methodology

Now more than ever airlines are trying to find ways to save money while maintaining environmental regulations and technological leadership. By using more efficient airplanes, like the Boeing 737 Next Generation series aircraft, airlines can save millions of dollars year round.

Research Approach

This study provides information related to replacement of aircraft, based on fuel efficiency. The study was a descriptive study using historical and future fuel efficiency data for existing aircraft in Delta's fleet and for three Next Generation aircraft. The researcher examined the data and simulated the fuel advantages that would come from replacing an existing aircraft line with three possible new aircraft; if other factors, such as routes, number of trips, and weather factors remained constant.

Design and procedures. The researcher collected information regarding air traffic in the NAS from a valid source. Delta Airlines was selected for conducting this project. In order to gather the information regarding the schedule and air traffic impacting the airport selected (KATL), databases such as ASDI and OAG were used. Based on the availability and accessibility of the information needed for this study, the ASDI data were chosen. It must be highlighted that Embry-Riddle Aeronautical University's Next Generation Applied Research Lab (NEAR) has extensive ASDI archives that have been collected and stored since 1999; and it was available to support academic research, such as this project. By having these archives, ERAU had the capability to replicate any NAS condition from 1999 to the present. In addition to the air traffic information, the waypoint and airport files were generated. These files were created with the support of the FAA's Air Traffic Management (ATM) tool called Terminal Area Route Generation Evaluation and Traffic Simulation (TARGETS). Once the information related to air traffic, waypoints, and airports were complied; the researcher proceeded to create the flight route data from the flight schedule previously obtained from the ASDI file. The flight routes were generated from TARGETS and then loaded into TAAM. The researcher created a schedule file in TAAM format. This file was named "Timetable" and its format extension presented as follows ".ACF". The Timetable file was generated using the ASDI airline flight data and the TAAM route file ".RTS".

Once all the files needed for running the simulation were completed, the researcher generated KATL air traffic control sectors. The sectors were built following the digitizing procedure, which is basically adding the information of the Atlanta Terminal Chart to the software in a digital format. These files were loaded into TAAM to replicate actual airspace conditions, which supports the validation of the model. In addition to the airspace sectors, other map files could be loaded into the simulation. For this specific case, the researcher used a world map to depict visual effects in the simulation. Once the operational files were created, the researcher entered them into TAAM Interactive Data Input System (IDIS). Through IDIS the investigator organized and processed the information that was required for running the simulation. After completing the data creation and input processes, the researcher conducted the initial running of the TAAM simulation in order to perform a debugging procedure. This procedure was executed to evaluate and correct the potential errors, or differences, that were found in the simulation. By doing this, the model provided a result of zero terminations. Subsequent to the validation process, the simulation was executed again to completion, with the purpose of allowing TAAM to produce the report files.

It must be highlighted that a new project was created for every scenario in order to avoid rewriting over the report files, and at the same time insuring the projects did not present any differences, except for one variable, aircraft replacement. The researcher generated a new timetable based on the DC-9 timetable and replaced all the DC-9 flights from KATL with the B737-700 aircraft type. The researcher ran the simulation to completion and debugged the simulation to result in zero termination. The simulation was run again to completion and then closed to allow TAAM to record report files. The researcher generated a new timetable based on the DC-9 timetable and replaced all the DC-9 flights from KATL with the B737-800 aircraft type. The researcher ran the simulation to completion and debugged the simulation to result in zero termination. The simulation was run again to completion and then closed to allow TAAM to record report files. The researcher generated a new timetable based on the DC-9 timetable and replaced all the DC-9 flights from KATL with the B737-900 aircraft type. The researcher ran the simulation to completion and debugged the simulation to result in zero termination. The simulation was run again to completion and then closed to allow TAAM to record report files. After all simulations were completed, the researcher entered the TAAM Reporter on the TAAM main window to collect the raw data files needed for Distance Flown, Flight Time, and Fuel Burned. The two report files were extracted from each of the four projects. These files were the .GFDR and .RPT files. The researcher opened these files in Excel and extracted all data from each project for only the 69 flights for comparison. The researcher extracted the DC-9-30 aircraft data (First simulation), the B737-700 aircraft data (Second Simulation), the B737-800 aircraft data (Third Simulation) and the B737-900 aircraft data (Fourth Simulation). Microsoft Excel was used for data comparison and to prepare the data for SPSS. Next, the researcher used SPSS for statistical analysis. The statistical methods, descriptive and paired *t* test, were used to analyze the data.

Apparatus and materials. Total Airspace and Airport Modeler (TAAM) was an industry-leading tool from Jeppesen that modeled airspace and airports to facilitate planning, analysis and decision-making. Airports and airspace can be modeled, and then the impact of changes to infrastructure, operations and schedules can be evaluated. TAAM was recognized as a standard in the aviation industry and was widely used by airspace planners, airport operators and major air carriers. TAAM, was a fast-time gate-to-gate simulation tool that enables operators to accurately predict and analyze the impact of present and future airspace and airport operations, whilst maintaining safety and efficiency. This sophisticated software tool presents realistic 4D models of airspace and airports to facilitate decision support, planning and analysis. TAAM simulations were processed in fast-time, enabling users to obtain results quickly and to evaluate a wider range of scenarios.

Base of Aircraft Data (BADA) is an aircraft performance model with a corresponding database. BADA was maintained and developed by the EUROCONTROL Validation Infrastructure Centre of Expertise. The main application of BADA was trajectory simulation and prediction within the domain of air traffic management. TAAM used this database for aircraft performance characteristics.

Population/Sample

The population of this research was all Delta Airlines DC-9-30 flight routes. The convenience sample was only the DC-9-30 flight routes from Atlanta Hartsfield-Jackson International Airport (KATL) on June 8, 2008. These same routes were used to run the simulations for the Boeing 737-700, 737-800, and 737-900.

Data Collection Device

TAAM was an aviation industry-leading tool that modeled airspace and airports to facilitate current day and future planning, analysis and decision-making. TAAM was created from Jeppesen, a wholly owned subsidiary of The Boeing Company and was recognized as one of the worlds foremost providers of information and business solutions to the transportation industry (Jeppesen, 2011a). TAAM was used to gather distance, time and fuel data for the DC-9, Boeing 737-700, Boeing 737-800, Boeing 737-900.

Instrument reliability and validity. TAAM was a software suite that modeled and evaluated the impact of changes to infrastructures, operations and schedules. TAAM was recognized as a standard in the aviation industry and was widely used by Air Navigation Service Providers (ANSPs), Civil Aviation Authorities (CAAs), airspace planners, airport operators (KATL) and major air carriers (Delta Airlines). Airlines use TAAM to plan operations, fleet changes, aircraft substitution, deicing and other procedures in the most cost effective way. Airlines also use TAAM to enhance competitiveness and profitability through reduced fuel use, shorter delays and efficient block times.

ASDI was a data stream service that has been available through the US Department of Transportation since 1991. ASDI shows the position and flight plans of all aircraft in the U.S and U.K airspaces. OAG provides comprehensive flight schedules, airport data and aircraft fleet information for any airline in the world since 2006. Since TAAM uses these sources for the software performance, the data were assumed to be valid and reliable.

TAAM customers. Many aviation providers, airports, airlines and entities are customers of TAAM. The list of CAAs and ANSP's that use TAAM consisted of: Australia, Brazil, Canada, Dubai, EuroControl, Hong Kong, Italy, Japan, Netherlands, New Zealand, Spain, Switzerland, South Africa, United Kingdom, and the United States. The list of airports and airlines that use TAAM is as follows: Auckland, Bangkok, Beijing, Chicago, Las Vegas, Dubai, Hong Kong, Kuala Lumpur, Perth, Vienna, and American Airlines, British Airways, FedEx, Delta Airlines, Japan Airlines, and UPS. The list of aviation entities that used TAAM consisted of The Boeing Company, Centre for Aviation Safety Technology, Department of Defense, DMJM Aviation, Embry-Riddle Aeronautical University, ENRI Japan, George Mason University, Landrum & Brown, MITRE, Jacobs Consultancy, and To70 (Jeppesen, 2011a).

Treatment of the Data

The researcher arranged the TAAM report files to create a data set that could be analyzed through statistical methods. The results of the four simulations were compared by the researcher. The data set contained only qualitative variables. The confidence level for all tests of significance was 95%, regardless of parametric or non-parametric statistics.

Descriptive statistics. The variables, Distance Flown and Minutes Flown was described by a table depicting mean, standard deviation, minimum, maximum, and count

(*N*) for each of the following aircraft; DC-9-30, B-737-700, B737-800, B-737-900. The variable, Fuel Burn, was described by a table depicting mean, standard deviation, minimum, maximum, and count (*N*) for each of the following aircraft; DC-9-30, B-737-700, B737-800, B-737-900. The variables, Fuel Efficiency (lb/nm) and Fuel Efficiency (lb/hr) were described by a table depicting mean, standard deviation, minimum, maximum, and count (*N*) for each of the following aircraft; DC-9-30, B-737-700, B737-800, B-737-900.

Hypothesis testing. For the hypothesis concerning Distance Flown, three *t*-tests was run to compare the DC-9-30 to the Boeing 737 variants (-700, -800, -900). For the hypothesis concerning Minutes Flown, three *t*-tests were run to compare the DC-9-30 to the Boeing 737 variants (-700, -800, -900). For the hypothesis concerning Fuel Burn, three *t*-tests were run to compare the DC-9-30 to the Boeing 737 variants (-700, -800, -900). For the hypothesis concerning Fuel Efficiency (lb/nm), three *t*-tests were run to compare the DC-9-30 to the Boeing 737 variants (-700, -800, -900). For the hypothesis concerning Fuel Efficiency (lb/hr), three *t*-tests were run to compare the DC-9-30 to the Boeing 737 variants (-700, -800, -900).

Chapter IV

Results

Descriptive Statistics

Table 1 describes Distance Flown for each of the following aircraft; DC-9-30, B-737-700, B737-800, B-737-900.

Table 1

Descriptive Statistics for Distance Flown

	DC-9-30	737-700	737-800	737-900
N	69	69	69	69
Mean	464.87	465.00	464.94	464.94
Std. Deviation	203.228	203.580	203.597	203.597
Minimum	170	168	168	168
Maximum	828	829	829	829

Table 2 describes Minutes Flown for each of the following aircraft; DC-9-30, B-737-700, B737-800, B-737-900.

Table 2

Descriptive Statistics for Minutes Flown

	DC-9-30	737-700	737-800	737-900
N	69	69	69	69
Mean	85.38	88.17	86.86	84.52
Std. Deviation	27.309	28.803	27.890	26.235
Minimum	45	46	47	43
Maximum	138	146	139	135

Table 3 describes Total Fuel used for each of the following aircraft; DC-9-30, B-737-700, B737-800, B-737-900.

Table 3

Descriptive Statistics for Total Fuel Used

	DC-9-30	737-700	737-800	737-900
N	69	69	69	69
Mean	7,321.60	5,048.71	5,037.27	4,949.33
Std. Deviation	2,366.56	1,263.57	1,347.09	1,300.96
Minimum	3,936	3,223	3,150	2,783
Maximum	11,983	7,632	7,581	7,630
Sum	75,741	52,228	52,110	51,200

Table 4 describes Fuel Efficiency (lb/nm) for each of the following aircraft; DC-9-30, B-737-700, B737-800, B-737-900.

Table 4

Descriptive Statistics for Fuel Efficiency (lb/nm)

	DC-9-30	737-700	737-800	737-900
N	69	69	69	69
Mean	16.71	11.95	11.83	11.65
Std. Deviation	2.59	2.84	2.67	2.66
Minimum	14	9	9	8
Maximum	25	20	20	20

Table 5 describes Fuel Efficiency (lb/hr) for each of the following aircraft; DC-9-30, B-737-700, B737-800, B-737-900.

Table 5

Descriptive Statistics for Fuel Efficiency (lb/hr)

	DC-9-30	737-700	737-800	737-900
N	69	69	69	69
Mean	5,141.08	3,526.44	3,543.11	3,566.35
Std. Deviation	117.09	307.86	225.56	192.80
Minimum	4,785	3,104	3,230	3,215
Maximum	5,478	4,310	4,228	3,922

Hypothesis Testing

Three *t*-tests were run to test the null hypotheses; there was no difference in Distance Flown between the DC-9-30 aircraft and the Boeing 737 variants (-700, -800, -900). Table 6 shows the results.

Table 6

Comparison of the DC-9-30 and Boeing 737 Variants for Distance Flown

	DC-9-30	DC-9-30 vs. B737-700	DC-9-30 vs. B737-800	DC-9-30 vs. B737-900
Mean	464.87	465.00	464.94	464.94
t-value		-1.266	-.698	-.698
df		68	68	68
p-value		.210	.488	.488

Fail to reject the null hypotheses. There was no difference in Distance Flown between the DC-9-30 aircraft and the Boeing 737 variants (-700, -800, -900).

Three *t*-tests were run to test the null hypotheses; there was no difference in Minutes Flown between the DC-9-30 aircraft and the Boeing 737 variants (-700, -800, -900). Table 7 shows the results.

Table 7

Comparison of the DC-9-30 and Boeing 737 Variants for Minutes Flown

	DC-9-30	DC-9-30 vs. B737-700	DC-9-30 vs. B737-800	DC-9-30 vs. B737-900
Mean	85.38	88.17	86.86	84.52
t-value		-6.851	-3.488	2.527
df		68	68	68
p-value		.000	.001	.014

Reject the null hypothesis. There was a difference in Minutes Flown between the DC-9-30 aircraft and the Boeing 737 variants (-700, -800, -900).

Three *t*-tests were run to test the null hypotheses; there was no difference in Total Fuel Used between the DC-9-30 aircraft and the Boeing 737 variants (-700, -800, -900). Table 8 shows the results.

Table 8

Comparison of the DC-9-30 and Boeing 737 Variants for Total Fuel Used

	DC-9-30	DC-9-30 vs. B737-700	DC-9-30 vs. B737-800	DC-9-30 vs. B737-900
Mean	7,321.60	5,048.71	5,037.27	4,949.33
t-value		16.754	17.939	17.916
df		68	68	68
p-value		.000	.000	.000

Reject the null hypotheses. There was a difference in Total Fuel Used between the DC-9-30 aircraft and the Boeing 737 variants (-700, -800, -900).

Three t-tests were run to test the null hypotheses; there was no difference in Fuel Efficiency (lb/nm) between the DC-9-30 aircraft and the Boeing 737 variants (-700, -800, -900). Table 9 shows the results.

Table 9

Comparison of the DC-9-30 and Boeing 737 Variants for Fuel Efficiency (lb/nm)

	DC-9-30	DC-9-30 vs. B737-700	DC-9-30 vs. B737-800	DC-9-30 vs. B737-900
Mean	16.71	11.95	11.83	11.65
t-value		60.345	64.806	74.078
df		68	68	68
p-value		.000	.000	.000

Reject the null hypothesis. There was a difference in Fuel Efficiency (lb/nm) between the DC-9-30 aircraft and the Boeing 737 variants (-700, -800, -900).

Three *t*-tests were run to test the null hypotheses; there was no difference in Fuel Efficiency (lb/hr) between the DC-9-30 aircraft and the Boeing 737 variants (-700, -800, -900). Table 10 shows the results.

Table 10

Comparison of the DC-9-30 and Boeing 737 Variants for Fuel Efficiency (lb/hr)

	DC-9-30	DC-9-30 vs. B737-700	DC-9-30 vs. B737-800	DC-9-30 vs. B737-900
Mean	5141.08	3526.44	3543.11	3566.35
t-value		32.282	48.950	53.980
df		68	68	68
p-value		.000	.000	.000

Reject the null hypotheses. There was a difference in Fuel Efficiency (lb/hr) between the DC-9-30 aircraft and the Boeing 737 variants (-700, -800, -900).

Chapter V

Discussion, Conclusions, and Recommendations

This descriptive study used TAAM-generated data to determine whether the Boeing 737NG series aircraft were more fuel-efficient than Delta Airlines' DC-9-30. The TAAM software suite has proven to be effective for this study, as well as other improvement tasks used by airlines, airports, and manufacturers. The TAAM simulation model was utilized to achieve this study's goal.

Discussion

Identifying aircraft performance strengths and weaknesses within an airline might help develop recommendations for improving aircraft selection in the future. Many other concerns go along with fleet changes, such as safety, passenger-per-seat-mile costs, current aircraft fuel efficiency improvements, crew costs, and maintenance costs. The aggregated data from a fuel efficiency study, such as this one, may provide the necessary insight for airlines to make fleet changes to stay competitive.

TAAM has proven to be a essential tool for airline aircraft analysis. The capability of endless generation of "what if" scenarios provides airlines with a viable tool to make the difficult decision of changing aircraft fleets.

Other fuel efficiency improvements. Airlines have developed many different ways to save on fuel consumption. A list of operational fuel consumption savings is compiled from Federal Aviation Administration (2011a), International Air Transportation Association (2011), and Airlines for America (2011):

- Employ single-engine taxi procedures during normal operations and selective engine shutdown during ground delays.
- Reduce and measure more accurately onboard weight while redistributing the belly cargo.

- Cruise longer at higher altitudes and employ shorter, steeper approaches.
- Work with FAA to change en-route fuel reserve requirements to reflect state-of-the-art navigation, communication, surveillance and wind forecast systems.
- Employ self-imposed ground delays to reduce airborne holding.
- Modernize fleets with more fuel-efficient airplanes.
- Invest in winglets to reduce aircraft drag and thereby increase fuel conservation.
- Redesign hubs and schedules to alleviate congestion.
- Advocate expanded and improved airfield capacity.
- Use airport power rather than onboard auxiliary power units when at the gates. Change paint schemes to minimize heat absorption.

Descriptive statistics. The researcher analyzed the results of the descriptive statistics for Distance Flown. The results for Distance Flown showed no major differences in mean, standard deviation, minimum and maximum as anticipated. From examining the descriptive statistics, no discussion was generated.

The researcher analyzed the results of the descriptive statistics for Minutes Flown. The results for Minutes Flown showed no major differences in mean, standard deviation, minimum and maximum as expected. Anecdotally, only the B737-900 flew the 69 routes in a shorter mean time than the DC-9-30.

The researcher analyzed the results of the descriptive statistics for Total Fuel Used. The results for Total Fuel Used showed differences in mean, standard deviation, minimum and maximum between the DC-9-30 and the B-737NG variants, as expected. There was a large difference between the Boeing 737NG variants and the DC-9-30 aircraft with all B-737NG variants using less fuel than the DC-9-30. The B-737-900 used the least mean fuel for the 69 flights.

The researcher analyzed the results of the descriptive statistics for Fuel Efficiency (lb/nm). The results for Fuel Efficiency (lb/nm) show differences in mean, standard deviation, minimum and maximum, as expected. There was a large difference in Fuel Efficiency (lb/nm) between all Boeing 737 variants and the DC-9-30 aircraft. The results, also, show that the B-737 variants had a higher standard deviation than the DC-9-30. The Boeing 737-900 had the best mean Fuel Efficiency (lb/nm) for the 69 flights.

The researcher analyzed the results of the descriptive statistics for Fuel Efficiency (lb/hr). The results for Fuel Efficiency (lb/hr) show differences in mean, standard deviation, minimum and maximum, as expected. There was a large difference in Fuel Efficiency (lb/hr) between all Boeing 737 variants and the DC-9-30 aircraft. The results, also, show that the B-737 variants had a higher standard deviation than the DC-9-30. The Boeing 737-700 had the best mean Fuel Efficiency (lb/hr) for the 69 flights.

Hypothesis testing. The researcher analyzed the results of the *t*-test statistics for Distance Flown to determine if there were any significant differences. The results for Distance Flown show no significant differences between the Boeing 737 variants and the DC-9-30 aircraft. After examination of the *t*-test statistics for Distance Flown, no aircraft stood out as the best for the job.

The researcher analyzed the results of the *t*-test statistics for Minutes Flown to determine if there were any significant differences. The results for Minutes Flown showed a significant difference between all of the Boeing 737 variants and the DC-9-30 aircraft. After examination of the *t*-test statistics for Minutes Flown, the B737-700 aircraft stood out as the best for the job.

The researcher analyzed the results of the *t*-test statistics for Total Fuel Used to determine if there were any significant differences. The results for Total Fuel Used showed significant differences between all of the Boeing 737 variants and the DC-9-30 aircraft. After examination of the *t*-test statistics for Total Fuel Used, any of the Boeing 737 variants would be better than the DC-9-30 aircraft.

The researcher analyzed the results of the *t*-test statistics for Fuel Efficiency (lb/nm) to determine if there were any significant differences. The results for Fuel Efficiency (lb/nm) showed significant differences between all of the Boeing 737 variants and the DC-9-30 aircraft. After examination of the *t*-test statistics for Fuel Efficiency (lb/nm), any of the Boeing 737 variants would be better than the DC-9-30 aircraft.

The researcher analyzed the results of the *t*-test statistics for Fuel Efficiency (lb/hr) to determine if there were any significant differences. The results for Fuel Efficiency (lb/hr) showed significant differences between all the Boeing 737 variants and the DC-9-30 aircraft. After examination of the *t*-test statistics for Fuel Efficiency (lb/hr) any of the Boeing 737 variants would be better than the DC-9-30 aircraft.

Conclusions

The analysis of aircraft data reports using TAAM provided interesting insights about Delta Airlines' aircraft fuel efficiency. It not only identified fuel consumption, but also provided a better scope of Delta airlines aircraft usage. The design of this study made use of four simulations in order to answer the six hypotheses.

The ASDI data that was used produced expected results. Aircraft that have newer fuel-efficient technologies, such as, the Boeing Next Generation 737 aircraft series, proved to be more fuel-efficient than Delta Airlines DC-9-30. Aircraft manufacturers have been tasked, as part of NextGen, to achieve higher standards in engine efficiency.

An Airline's biggest concern when making any aircraft fleet change, is whether the change helps or hurts the company financially. A comparison of Fuel Saved between Delta's 69 DC-9-30 flights from KATL and Boeing's 69 737 Next Generation variants' flights from KATL showed daily and yearly savings. Results are shown in Table 11.

Table 11

Comparison of the DC-9-30 and Boeing 737 Variants for Fuel Saved

	FUEL (gal)	Cost of Fuel Usage	Daily Savings	Year Savings
DC-9-30	75,741	$233,281	$-	$-
737-700	52,228	$160,862	$72,419	$26,432,892
737-800	52,110	$160,498	$72,784	$26,566,009
737-900	51,200	$157,696	$75,585	$27,588,677

Note. Fuel cost calculated at $3.08/gal, the average cost of fuel for Delta Airlines in July 2008 (Research and Innovative Technology Administration, 2011).

The variable, Individual Fuel Cost Differences was described by a table depicting mean, standard deviation, minimum, maximum, and count (*N*) for DC-9-30 individual flight cost minus the Boeing 737NG variant. Table 12 describes Fuel Cost Differences in comparison of the DC-9-30 and the B-737NG variants.

Table 12

Comparison of the DC-9-30 and Boeing 737 Variants for Individual Fuel Cost Differences.

	DC-9-30 vs. B737-700	DC-9-30 vs. B737-800	DC-9-30 vs. B737-900
N	69	69	69
Mean	7,000.49	7,035.75	7,306.59
Std. Deviation	3,470.74	3,257.88	3,387.71
Minimum	1,877	2,270	2,385
Maximum	14,961	14,067	14,277

The null hypothesis was that there was no difference between the DC-9-30/ Boeing 737-700, DC-9-30/ Boeing 737-800, and DC-9-30/ Boeing 737-800 for individual fuel cost. The researcher performed an ANOVA to determine if there were any significant differences in the Individual Fuel Cost Differences. The results are shown in Table 13.

Table 13

ANOVA for the DC-9-30 and Boeing 737 Variants for Individual Flight Cost Differences

	SS	*df*	*MS*	*F*	*Sig.*
Between groups	3,870,794.39	2	1,935,397.19	.170	.844
Within groups	2.321E9	204	11,378,804.40		
Total	2.325E9	206			

There was no difference in Individual Fuel Cost Differences between the DC-9-30/ Boeing 737-700, DC-9-30/ Boeing 737-800, and DC-9-30/ Boeing 737-800. After examining the ANOVA, the researcher recommends any of the Boeing 737 Next

Generation variants as a viable replacement for the DC-9-30 aircraft.

Recommendations

Airlines need to take two steps to an environmentally-improved future. First, airline companies must join the push for research and development to create a fuel that produces a cleaner burn, such as an algae-based fuel, from items like sugar beets, corn, wheat, and straw (Natural Resource Defense Council, 2011b). Secondly, airlines must improve their overall fuel efficiency by purchasing more fuel-efficient airplanes, such as Boeing's 737 Next Generation series. This supports the need for more research on airline fuel efficiency and the payout periods for upgrading to the newer aircraft.

Further TAAM research studies, like this one, should be done, along with comparing aircraft manufacturer data and airline analysis, before considering aircraft fleet changes. The researcher found an option, *Aircraft Performance Randomization*, inside of TAAM to resemble more realistic flight operations during simulation (Jeppesen, 2011b). When aircraft performance randomization is enabled, small random variations are introduced to some of the input data; most notably, the aircraft performance characteristics and the Estimated Time of Departures (ETD) across the set of flights in the flight schedule. This makes for a more realistic simulation. Studies should be done with this option turned on, to compare those results with the results of this study.

Aircraft performance characteristics for each aircraft can be randomized in TAAM. If randomization is disabled, the performance is always fixed for the same type of aircraft, as used in this study. For example, each B737 flies in exactly the same way. If the randomization is enabled, aircraft takeoff weight can vary and becomes greater or less than 100%. Just before each flight starts, the random values of the performance variation for this aircraft are obtained. If the weight is more than 100%, the aircraft is heavier and slower; if it is less than 100%, this aircraft is lighter and faster. The characteristics that are randomized for aircraft performance are: cruising indicated airspeed (IAS) and Mach, fuel consumption, climbing IAS and Mach, descent IAS and Mach, take off acceleration, landing deceleration, and cruising altitude (Jeppesen, 2011b).

Another recommendation includes doing the same study using other Next Generation aircraft for comparison. This includes other manufacturer's aircraft, as well as, other Boeing Next Generation aircraft. Delta Airlines has other DC-9 series aircraft and those should be modeled against real Boeing 737NG variants along with other Next Generation aircraft. For this study, the DC-9-30 was selected because it was Delta's largest series of DC-9 aircraft.

This study included sixty-nine flights of each aircraft type for data analysis. The researcher would recommend another study with more flights that includes ASDI or OAG flight information covering at least a one-week duration. The benefits of extending the timeframe are larger databases that include all DC-9 flights to better understand the scope of use for the DC-9 aircraft and to choose an alternative aircraft that is used for these flight purposes, i.e., distance, high altitude, and landing and takeoff performance. Also, this study could take place at more airline hub airports. The researcher choose KATL because that was Delta Airlines' largest hub, further studies using Northwest Hubs might be considered for comparison, since Delta and Northwest merged in 2008.

References

Aerospace Technology. (n.d.). *Boeing 737 new generation twin-engine airliner.* Retrieved from http://www.aerospace-technology.com/projects/ boeing737_NG

Arian Design. (2009a). *Boeing 737-600*. Retrieved from http://www.ariandesign.com/ Content.do?state=ThreeColumn&content=specs/737-600

Arian Design. (2009b). *Boeing 737-700*. Retrieved from http://www.ariandesign.com/ Content.do?state=ThreeColumn&content=specs/737-700

Arian Design. (2009c). *Boeing 737-800*. Retrieved from http://www.ariandesign.com/ Content.do?state=ThreeColumn&content=specs/737-800

Arian Design. (2009d). *Boeing 737-900*. Retrieved from http://www.ariandesign.com/ Content.do?state=ThreeColumn&content=specs/737-900

Airlines for America. (2011). *Environment.* Retrieved from http://www.airlines.org/ Pages/Environment.aspx

American Psychological Association. (2010). *Publication manual of the American Psychological Association* (6th edition). Washington, DC: Author.

Boeing Company. (n.d.). *737 family.* Retrieved from http://www.boeing.com/ commercial/ 737family/background.html

Bradly, C. (n.d.). *The Boeing 737 technical site*. Retrieved from http://www.b737.org.uk/

Cutche-Gershenfeld, J., Greitzer, E., Kerrebrock, J., Townswend, J., & Waitz, I. (2004). *Aviation and the environment.* Cambridge, MA: Federal Aviation Administration.

Delta Airlines. (2010a). *Aircraft specifications.* Retrieved from http://www.delta.com/ planning_reservations/plan_flight/aircraft_types_layout/dc9_50/index.jsp

Delta Airlines. (2010b). *Operations.* Retrieved from http://news.delta.com/index.php?s= 18&cat=45

Delta Airlines. (2011a). *History.* Retrieved from http://news.delta.com/ index.php?s=18&cat=39

Delta Airlines. (2011b). *Archive for the history.* Retrieved from http://blog.delta.com/ category/history/

Delta Heritage Museum. (2003). *Northwest airlines*. Retrieved from http://deltamuseum.org/M_Education_DeltaHistory_Facts_Family_ Tree_Northwest.htm

Department of Transport. (n.d.). *Air Transport white paper progress report 2006.* Retrieved from http://www.dft.gov.uk/about/strategy/whitepapers/ air/aviationprogressreportsection/aviationprogressreport?page=4

Federal Aviation Administration. (2011a). *What is NextGen.* Retrieved from http://www.faa.gov/nextgen/why_nextgen_matters/what

Federal Aviation Administration. (2011b). *System for assessing aviations global emissons incorporated into the aviation environmental design tool.* Retrieved from http://www.faa.gov/about/office_org/headquarters_offices/apl/research/ models/sage/

Federal Aviation Administration. (2011c). *Aircraft Situation Display To Industry: Functional Description and Interface Control Document for XML Version.*

Flight Global. (2006). *The Boeing 737 story.* Retrieved from http://www.flightglobal .com/ articles/2006/01/31/204410/the-boeing-737-story.html

International Air Transport Association. (2011). *Aviation environment*. Retrieved from http://www.iata.org/whatwedo/environment/fuel_efficiency.htm

Gay, L. R., Mills, G. E., & Airasian, P. (2008). *Educational research: Competencies for analysis and applications* (9th ed.). Upper Saddle River, NJ: Merrill Prentice Hall.

Green, S. B., & Salkind, N. J. (2008). *Using SPSS for Windows and Macintosh: Analyzing and understanding data value package (includes SPSS 16.0 CD)*. Alexandria, VA: Prentice Hall.

Hartsfield-Jackson Atlanta International Airport. [KATL]. (2011). *Airport history.* Retrieved from http://www.atlanta-airport.com/Airport/ATL/ Airport_History.aspx

Hoolhorst, A., Middel, J., Peeters, P. (2005). *Fuel efficiency of commercial aircraft: an overview of historical and future trends.* Netherlands: National Aerospace Laboratory NLR.

Jeppesen. (2011a). *Total airspace and airport modeler.* Retrieved from http://www.jeppesen.com/industry-solutions/aviation/government/total-airspace-airport-modeler.jsp

Jeppesen. (2011b). *TAAM practical guide.* Atlanta, GA: Author.

Jeppesen. (2011c). *TAAM reference guide.* Atlanta, GA: Author.

Labich, K. (1987). *Why air traffic is a mess.* Retrieved from http://money.cnn.com/ magazines/ fortune/fortune_archive/1987/08/17/69428/index.htm

MITRE Aviation Institute. (2011). *Introduction to terminal area route generation, evaluation and traffic simulation.* Retrieved from http://mai.mitrecaasd.org/ MITREMAI/targets/

Natural Resource Defense Council. [NRDC]. (2011a). *Gas from coal? Even dirtier*. Retrieved from http://beyondoil.nrdc.org/news/gas-from-coal.php

Natural Resource Defense Council [NRDC]. (2011b). *Seeking friendlier skies*. Retrieved from http://beyondoil.nrdc.org/news/gas-from-coal.php

Neal, J. G. (2008). *Thesis editorial style and procedural guide second edition*. Port Orange, FL: Embry-Riddle Aeronautical University.

Noack, T. (2009). *Airline fleets index*. Retrieved from http://www.plane spotters.net/Airline

OAG Aviation. (2011). Aviation Data. Retrieved from http://www.oagaviation.com/ Solutions/Aviation-Data

Research and Innovative Technology Administration. [RITA]. (2009). *Air carrier traffic and capacity statistics by aircraft type*. Retrieved from www.transtats.bts.gov/Fields.asp?Table_ID=254

Research and Innovative Technology Administration. [RITA]. (2011) *Airline Fuel Cost and Consumption: Delta Airlines-Scheduled*. Retrieved from http://www.transtats.bts.gov/fuel.asp?pn=1

Top Speed. (2010). *1997-2010 Boeing 737 next generation.* Retrieved from http://www.topspeed.com/aviation/aviation-reviews/boeing/1997-2010-boeing-737-next-generation-ar85797.html

US Department of Transportation. (2009). *Transportation and greenhouse gas emissions.* Retrieved from climate.dot.gov/about/transportations-role/overview.html

Vogt, W. P. (2007). *Quantitative research methods for professionals*. Boston, MA: Allyn and Bacon.

West, L. (2009). Plan to turn coal into jet fuel mixes environmental, national security concerns. *Environmental Issues*. Retrieved from http://environment. about. com/b/2009/01/16/plan-to-turn-coal-into-jet-fuel-mixes-environmental-national-security-concerns.htm

Appendix A

Sample Data Set

Flight ID	1930	2339	1830	450
Flight Number	DAL1014	DAL1047	DAL1060	DAL1080
Destination	KBDL	KMCI	KGSP	KBDL
Distance Flown DC-9-30	828	639	170	828
Distance Flown 737-700	828	639	168	828
Distance Flown 737-800	828	639	168	828
Distance Flown 737-900	828	639	168	828
Minutes DC-9-30	134.55	107.15	44.55	133.88
Minutes 737-700	140.60	111.23	46.30	138.87
Minutes 737-800	137.85	109.58	48.97	135.52
Minutes 737-900	130.97	107.32	42.93	130.97
Fuel Burn (lb) DC-9-30	11,547.8	9,211.4	3,935.8	11,598.4
Fuel Burn (lb) 737-700	7,451.4	5,988.4	3,223	7,321.6
Fuel Burn (lb) 737-800	7,480	6,212.8	3,198.8	7,433.8
Fuel Burn (lb) 737-900	7,110.4	6303	2,783	7,240.2
FE (lb/nm) DC-9	13.95	14.42	23.15	14.01
FE (lb/nm) 737-700	9.00	9.37	19.18	8.84
FE (lb/nm) 737-800	9.03	9.72	19.04	8.98
FE (lb/nm) 737-900	8.59	9.86	16.57	8.74
FE (lb/hr) DC-9	5,149.52	5,158.04	5,300.74	5,197.84
FE (lb/hr) 737-700	3,179.83	3,230.18	4,176.67	3,163.44
FE (lb/hr) 737-800	3,255.71	3,401.69	3,919.56	3,291.31
FE (lb/hr) 737-900	3,257.50	3,523.96	3,889.29	3,316.97

Dollars/lb DC-9-30	$ 35,567	$ 28,371	$ 12,122	$ 35,723
Dollars/lb 737-700	$ 22,950	$ 18,444	$ 9,927	$ 22,551
Dollars DC-9 minus-700	$ 12,617	$ 9,927	$ 2,195	$ 13,173
Dollars/lb 737-800	$ 23,038	$ 19,135	$ 9,852	$ 22,896
Dollars DC-9 minus-800	$ 12,529	$ 9,236	$ 2,270	$ 12,827
Dollars/lb 737-900	$ 21,900	$ 19,413	$ 8,572	$ 22,300
Dollars DC-9 minus-900	$ 13,667	$ 8,958	$ 3,551	$ 13,423

The data contained in this sample reflects only the first four flight entries in the data set. The fuel cost was $3.08 from the Research and Innovative Technology Administration for Delta Airlines in June 2008.

TOTAL FUEL SAVINGS

	DC-9-30	737-700	737-800	737-900
Distance (nm)	32,076	32,085	32,081	32,081
Time (min)	5,891	6,084	5,993	5,832
Fuel Burn (lb)	505,190	348,361	347,571	341,504
FE (lb/mi)	1,153	824	816	804
FE (lb/hr)	354,734	243,324	244,475	246,078
FUEL (gal)	75,741	52,228	52,110	51,200
Cost of Fuel Usage	$ 233,281	$ 160,862	$ 160,498	$ 157,696
Daily Savings	$ -	$ 72,419	$ 72,784	$ 75,585
Year Savings	$ -	$ 26,432,892	$ 26,566,009	$ 27,588,677

The data contained in this sample reflects the total flight entries in the data set. The fuel cost was $3.08 from the Research and Innovative Technology Administration for Delta Airlines in July 2008.