THE IMPACT OF SOUTHWEST AIRLINE'S CONTRIBUTION TO ATMOSPHERIC CARBON DIOXIDE AND NITROUS OXIDE TOTALS

by

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ABSTRACT

Over the last century, aviation has grown to become an economical juggernaut. The industry creates innovation, connects people, and maintains a safety goal unlike any other field. However, as the world becomes more populated with technology and individuals, a general curiosity as to how human activity effects the planet is becoming of greater interest. This study presents what one domestic airline in the United States, Southwest Airlines, contributes to the atmospheric make-up of the planet. Utilizing various sources of quantifiable data, an outcome was reached that shows the amount of Carbon Dioxide and Nitrous Oxide produced by Southwest Airlines from 2002 to 2013. This topic was chosen due to the fact that there are no real quantifiable values of emission statistics from airlines available to the public. Further investigation allowed for Southwest Airlines to be compared to the overall Carbon Dioxide and Nitrous Oxide contributions of the United States for the year 2011. The results showed that with the absence of any set standard on emissions, it is vital that one should be established. The data showed that the current ICAO standard emission values showed a higher level of emissions than when Southwest Airline’s fleet was analyzed using their actual fleet mix.

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CHAPTER I: INTRODUCTION

With a continually growing global population, it is no surprise that aviation has boomed economically. The growth projections of air travel for the future seem almost guaranteed. As stewards of the environment, the aviation field must consider the atmospheric effects due to aircraft emissions. While aviation is not the sole issue when it comes to changing the atmospheric makeup of the planet, it contributes a statistically significant percentage (Organization for Economic Cooperation and Development [OECD], 2012). Weather changes are a concern that comes along with this consideration, but more importantly, scientists and researchers are becoming more intrigued with aviation's carbon footprint on the Earth's overall climate. Specifically, a standard jet engine runs on jet fuel, also known as fossil fuel kerosene. Several various propellants are emitted into the atmosphere when a jet engine burns the fuel. Of these, Carbon Dioxide (CO_2), Nitrous Monoxide (NO), and Nitrous Dioxide (NO_2) are the primary concerns of this thesis. Throughout this paper, Nitrous Monoxide and Nitrous Dioxide shall be referred to as Nitrous Oxides (NO_x).

There is beginning to be a general shift in consciousness about the effect of aviation on the planet amongst the multitude of government agencies throughout the world. Two of the biggest proponents of studying environmental impact from human activity are the Intergovernmental Panel on Climate Change (IPCC) and the European Environment Agency (EEA). From these two sources, prescribed methodologies can be utilized to analyze the effects of domestic, within the United States, aviation's contribution to CO_2 and NO_x levels. Utilizing these resources and public information for Southwest Airlines, this thesis will examine the impact of one airline's contribution to the amounts of CO_2 and NO_x in the atmosphere over the last decade.

Review of Related Literature

Aviation has a large influence on the global economy. At its most basic function it connects people. Whether that connection purpose is business, leisure, or humanitarian, it is the fastest means of travel available. Essentially, employment and commerce from a global perspective rely on the realm of aviation. The World Economic Forum (WEF) reported, in 2007, that the aviation industry contributed 426 billion (USD) to the global GDP directly and an additional 490 billion (USD) was contributed indirectly (OECD, 2012). In terms of facilitating global tourism, aviation raised an additional 490 billion (USD) which contributed an overall 3.2 percentage to the global GDP. In the same year, aviation employed 33 million workers. In the near future, demand for aviation is projected to rise 4.5% a year up to the year 2050 (OECD, 2012). While this is good news for business the annual aircraft emissions generated from aviation contribute 3% to the total planet carbon emissions. With population also on the rise, the emissions are projected to have significant increases by the year 2050 (OECD, 2012). These emissions will thereby have considerable effects on the Earth's atmospheric composition in the not-so-distant future.

Many governments, businesses, and even individuals have started to look at ways in which they can reduce their carbon footprint on the earth (Jardine, 2009). In terms of aviation, legislature began in the United States in 1967 with the Clean Air Act. This act was brought about to focus on studying what side effects were coming from aviation activities and potential pollution issues (Chicago, 2005). Not too long after this act, the United Nations could foresee the need to regulate aviation's effect on the planet. They formed the United Nations Environment Program (UNEP). From the UNEP and the World Meteorological Organization (WMO) came the organization known as the Intergovernmental Panel on Climate Change (IPCC) in 1988. The

IPCC has conducted abundant research on the changes in our world's climate over the last several decades and released their Fifth Assessment Report (AR5) in 2013 (Jardine, 2009). Within this report are a multitude of chapters analyzing the impact humans are having on the planet and its climate. In the IPCC's AR5, there is irrefutable evidence that human activity is changing the atmospheric composition on earth. The most important gases to the atmospheric make-up are known as greenhouse gases. Carbon Dioxide (CO_2), Nitrous Monoxide, and Nitrous Dioxide (NO_x) are a few most relevant to the aviation sector (Chicago, 2005). To understand why these gases are important, the difference between weather and climate must be established.

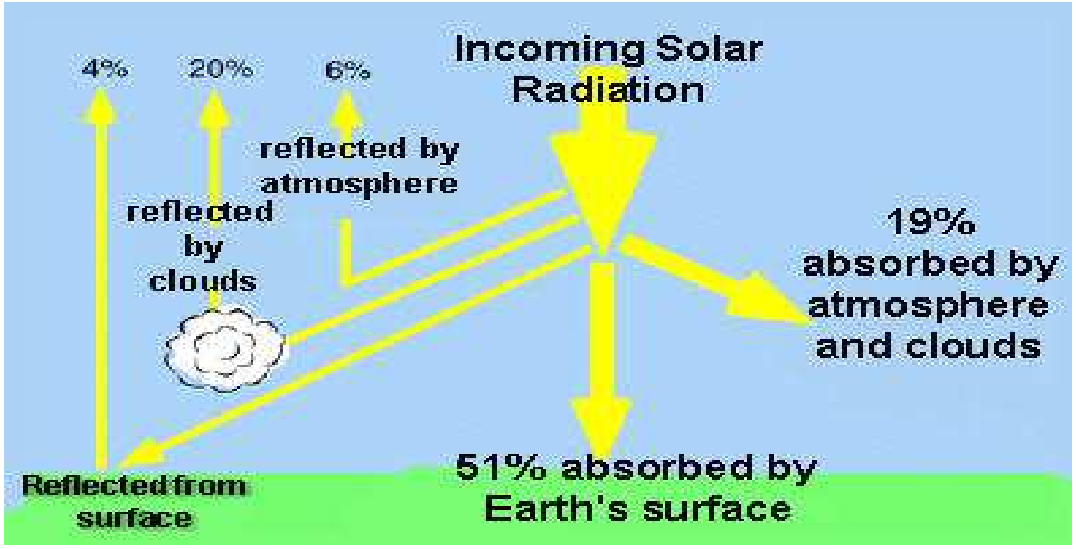
Weather and Climate

Weather is the condition of the atmosphere in a present moment, in which measurement of the key meteorological elements can occur. The main meteorological elements are wind, humidity, pressure, and temperature (Cubasch, et al., 2013). Climate, however, is the analysis of these recorded facts stretched over a specific period of time. This data can be averaged and examined in a more statistical manner, and hypotheses and projections can be made based on actual past data. Climate also delves into variables such as frequency of occurrence and trends. The seasons of the planet are natural trends. The frequency of weather occurrences can be analyzed by examining how many days it rained in the previous ten years and at what point/location in time. Thus, with factual data from the past, interpreted with present-day knowledge, the IPCC has come to realize that human interaction is definitely making a noticeable mark on the Earth's climate (Cubasch, et al., 2013). The most vital links in understanding weather and climate is seeking out the distribution of gases and solar radiation in the atmosphere.

Radiation

Natural CO_2, provides a balance that keeps the surface warm enough to grow food and keep vegetation alive. Unnatural CO_2 is formed from burning fuel. If the CO_2 content within the atmosphere begins to increase, then warming occurs. This overall warming affects the globe by increasing the temperature and melting Polar ice caps which then increases the level of the sea. CO_2 grants access for the Sun's light rays to heat the planet. It then keeps the heat trapped on the planet so it cannot be released back into the atmosphere. This process is known as the greenhouse effect (NASA, 2008). NO_x is another important gas that forms when engines combust at high temperatures. NO_x directly affects the gas known as ozone. Ozone is constantly created and destroyed. As long as this balance of the ozone is maintained by the ultraviolet radiation that destroys it, then ozone helps to shield the planet from this radiation. However, at higher altitudes, aircraft emit NO_x which contributes to manufacturing more ozone. When engines idle during taxi or when engines utilize high-power settings at takeoff and landing, NO_x is created. If there is more ozone than that which is needed it attacks the respiratory system of living creatures (NASA, 2008). All of these described effects are compared using a concept known as "radioactive forcing" (RF) (OECD, 2012).

RF looks at the balance of energy within the Earth and its atmosphere. Radiation itself comes in different forms and has different effects based on the balance of this energy. As shown in *Figure 1* below, all weather is affected by solar radiation from the Sun and infrared radiation released from the Earth's surface.



Source: http://www.solpass.org/6-8Science/6s/standards/study6.3.htm

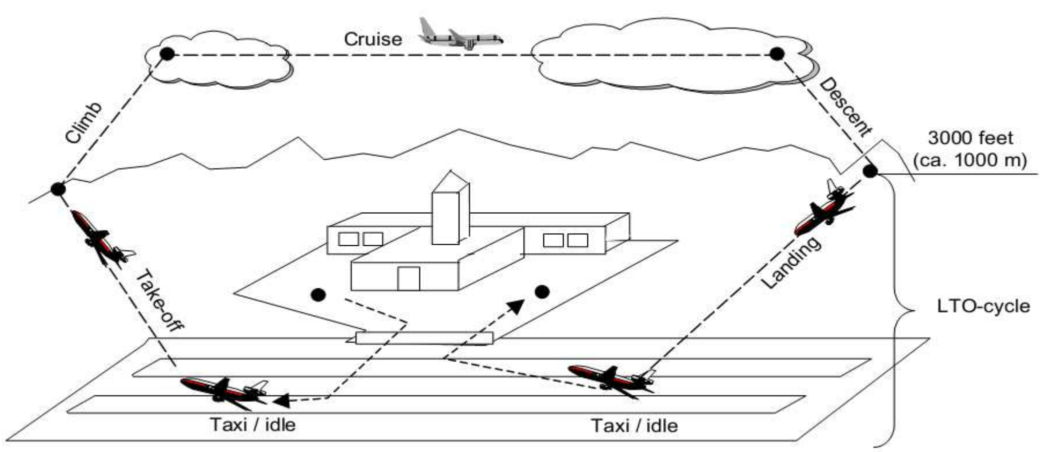
Figure 1. Earth's Energy Budget

The radiation that comes from the sun is known as solar shortwave radiation (SWR). Fifty-one percent of the SWR is absorbed by the Earth's surface while the remaining 49 percent is either absorbed by the atmosphere and clouds (19 percent), or reflected by the surface, clouds, and atmosphere (30 percent). The absorbed portion of SWR by the Earth's surface is then released back into the atmosphere over time via longwave radiation (LWR or infrared radiation) (Cubasch, et al., 2013). If these are balanced, the temperature across the global climate remains the same; if there is an imbalance, the temperature either warms or cools. This sway from the Earth's normal state is where the term forcing originates (OECD, 2012). Thus, RF is a factor's influence on climate change. Basically, to make emissions calculable with numbers, RF is established by taking a given amount of CO_2 or NO_x and assigning it a standard metric so it can be given a comparable unit. This is usually done in weight or parts per million (ppm). Thus, researchers can analyze if aviation is having positive-RF or negative-RF. Positive RF means that the result is warming, while negative-RF yields a cooling result (OECD, 2012). While CO_2

yields a positive-RF, NO_x plays no real part in warming or cooling the Earth's temperature, yet it destroys life if it contributes too heavily to the formation of ozone. Therefore, when engineers tweak engines, they are trying to reach a healthy equilibrium between the byproducts of fuel burn (OECD, 2012). This of course is the main issue amongst technology advances currently trying to be attained. If an item is changed in an engine, what will the other effects be? Designers are currently striving to meet the requirement. This requirement would create more efficient engines in terms of reducing noise pollution, pollutant emission, and fuel burn (NASA, 2008). For there to be any emission data to be analyzed, it must first be able to be measured.

Several tools are now available for emission calculation. Of these various tools, they each have different approaches, but they tend to incorporate the same variables for flight. First, a relationship must be determined. This is most commonly done via the mass of the emission or the units of consumed electricity multiplied by the amount of fuel burned. From this data, a standard can be deveoped. In other words, every gram of CO_2 released from the fuel burn of one gallon of jet fuel equals (x). This standard now can be multiplied by an appropriate emissions factor. However, there is no standard in the aviation industry currently regarding what an accurate emissions factor is (Jardine, 2009). Thus, emission calculators can vary greatly. While the IPCC has an updated multiplier of 1.9, this has been questioned as well. The most detrimental problem in gaining accurate data from CO_2 and NO_x emissions is all of the assumptions that must be made. Some of the considerations that are hard to gather unless one is piloting an aircraft are wind, flight distance, holding time, weight, plane type, engine type, etc. All of these factors contribute to the accuracy of the data gathered. While having the distance flown may give an individual how much fuel was roughly burned, one plane may be more efficient then the next. This contributes greatly to the uncertainty value (Jardine, 2009). Several organizations have made emission calculators. ICAO has developed a calculator in hopes of reaching an eventual standard that can be used on an international level for aviation. ICAO's calculator encompasses 50 different aircraft types and their associated fuel burn data. Sabre Holdings Model is a calculator that airlines are more commonly using. Another is the System for assessing Aviation's Global Emissions (SAGE). SAGE was developed by the office of Environment and Energy within the FAA. While it was developed to analyze emissions on a global level, it has been retrofitted to handle a multitude of scenarios that yield relatively accurate results (Jardine, 2009).

Of all the calculators, SAGE currently appears to be the most user-friendly available. It has the most aircraft stored in its database. It also utilizes the standard linear equation of y=mx+b. The SAGE calculator also factors in the differences of the Landing and Take Off cycle (LTO) and the Climb, Cruise, and Descent cycle (CCD). The LTO include all activities below an altitude of 3,000 ft and is depicted below in *Figure 2* along with the CCD cycle. The CCD contains the activities at altitudes greater than 3,000 ft. (Jardine, 2005).



Source: www.intechopen.com

Figure 2. LTO Cycle

However, the methodology that this thesis will follow is clearly laid out in the European Monitoring and Evaluation Program's (EMEP) guidebook. The most recent was released by the European Economic Area (EEA) in 2013 as the EMEP/EEA guidebook. It lays out the proper steps and a multitude of formulas to follow to calculate emissions.

Since the formation of the IPCC and their compiled findings, the world has come to see the effects of aviation on the planet more clearly. Therefore, several initiatives have risen up to raise money to further research and learning on aviation's effect on the atmosphere. One of the biggest known pieces of legislature was the Kyoto Protocol in 1997. Unfortunately, aviation was left out of the focus of this protocol (OECD, 2012). Instead, the Kyoto Protocol left the ICAO in charge to create some sort of global framework for aviation's contribution of greenhouse gases. In 2006, when the Kyoto Protocol began to encompass aviation as well, this framework had yet to be set up. Not long after, in 2011, the ICAO received pressure from the Emissions Trading System of the European Union (EU ETS). The EU is responsible for setting up an emissions trading system and potentially a carbon tax. While taxes are easy to implement, the main problem with the carbon tax is if it will be able to predict emission reductions accurately. The emissions trading system idea is to allow the market to determine at what point the cap on emissions is reached. This system's main problem is it would be hard to manage, yet it would yield the best results in measuring differences in emissions (OECD, 2012). There has also been emerging ideas to combat emissions within the private sector, as well.

The International Air Transport Association (IATA) represents most of the world's airlines. Due to the Kyoto Protocol's applied pressure on aviation, IATA began to make plans in 2007 to reduce emissions. Essentially, a four pillar strategic plan was built focused on improving technology, and a goal was set to build a zero-emission aircraft that can operate commercially within 50 years (OECD, 2012). Most private industries thrive on and continually strive for innovation, making them leaders in the formation of alternative biofuels. When delving into the creation of biofuels, inventors must question if these fuels will also contribute an emission byproduct (OECD, 2012). While the emission problem still remains to be conquered, furthering understanding and taking action are what will need to take place to rectify the emission situation. While no agreement has been reached on standardizing emission protocols, there has been a worldwide admittance that aviation is affecting the planet. The facts given by NASA in 2008 stated that aircraft contribute a total of 4% to the total emission release into the atmosphere at the surface. The IPCC latest publication in 2013, showed that the amount of CO_2 in the air had risen to 390.5 ppm in 2011. This was 40% higher than in 1750. NO_x in the atmosphere, from the same study, has been reported to have risen 20% since 1750, up to 324.2 parts per billion (ppb). More importantly is the rate in which these gases are increasing. The same increase observed from 1996 to 2005, 9 years, equaled the increase from the time period of 2005 to 2011, 6 years (Hartmann et al., 2013). These facts state that the overall global temperature is steadily increasing, which is in turn raising the sea level due to melting ice caps. This could eventually lead to extreme climate variations.

Airframe and Engine Manufacturing

The main reason aircraft emit such a great amount of CO_2 and NO_x is directly related to fuel consumption. This is especially true with CO_2. ICAO is the leading organization in trying to fight for decreased aircraft emissions. It does this by constantly reviewing their standards and promoting newer, more efficient aircraft (ICAO, 2010). The basic approach, to making aircraft more efficient, hinges on changing an aircraft's weight, drag, and thrust. Essentially, to be most efficient, aircraft designers seek to reduce the weight of the aircraft and attempt to maximize the payload, thrust, and fuel burn. Aerodynamically, the airframe is designed to reduce drag and thrust tied to that drag. For the engine, it is no different than any vehicle; designers want the most thrust for the least fuel burn (ICAO, 2010).

The skin of the aircraft has developed from wood, to metal, to composite, and now there are talks of nanotechnology use in aircraft skin. The reason for these technologic advances is to develop aircraft frames that are smooth and maintain laminar flow over the aircraft's skin. Any sort of exterior piece that is protruding from of an airplane creates drag, which slows the plane down. Also, as aircraft go to more composite materials, the weight of the aircraft is reduced allowing for a greater payload via a lower fuel burn. In terms of engine development, engineers are faced with many obstacles in aviation (ICAO, 2010). These manufacturers have to meet the demand of producing a clean, quiet, reliable, affordable, and efficient engine. To maintain engines better, programs have been put into place to make airlines regularly clean engines out, keeping them at top performance. In addition to the scheduled maintenance, experimentation with alternative fuels is being researched. Some of the most talked about alternatives are the biofuels. The main thing keeping biofuels from being utilized more prominently is certifying them to meet regulatory standards (ICAO, 2010).

Given these facts, transportation fields are beginning to realize the impact that is taking place on the environment and are beginning to take steps to combat this. This is especially true in the aviation industry. Due to the fiscal value of aviation, it is one of the most scrutinized industries in terms of what is being done to become more efficient and green in operations. Therefore, utilizing Southwest Airline fleet and operation information, this thesis will investigate whether newer aircraft are becoming cleaner and more efficient in terms of contributing to emission output into the Earth's atmosphere by answering the following research questions:

Research Questions

1. What is Southwest Airline's contribution to the CO_2 and NO_x levels during the LTO cycles experienced at KMDW from 2002 to 2013?
2. What is Southwest Airline's contribution of CO_2 and NO_x levels at all major United States airports from 2002 to 2013?
3. From this data, what is the impact of Southwest Airlines on the overall CO_2 and NO_x contribution levels compared to the entire United States aviation industry?

CHAPTER II: METHODOLGY

Southwest was chosen for this study since all of their flights are domestic, within the 48 contiguous states of the United States. In addition, all of their data was available, in terms of type of aircraft, number of operations, and fleet statistics. This information was pulled from a multitude of sources. For the number of LTO cycles, the Research and Innovative Technology Administration's (RITA) website provided all flight details for Southwest Airlines (RITA, 2014). Utilizing this source, information was compiled for the years 2002 to 2013. The information contained flight operations totals for each year from Chicago Midway International Airport, (KMDW), which is Southwest's hub, and for all the major airports Southwest operates to. Next, fleet statistics were gathered from Southwest Airline's website based on September 2014 data (Southwest, 2014). Having the number of operations, and emission factor values provided by ICAO and the EMEP/EEA emission inventory guidebook, the amount of emission contribution by Southwest airlines was achieved.

Instruments

This study used data gathered from the IPCC, ICAO and EEA studies. It also utilized the formulas laid out in the EMEP/EEA guidebook. Southwest's fleet data was gathered from their website, while flight data was gathered from RITA.

Design

An analysis of Southwest Airlines emission contribution was achieved through a look at quantitative data available. The data was compiled into various tables. From these tables, the data was then put into several figures showing emission data progress over time. This was then compared to the entire contribution of the United States emission totals via commercial aviation. The variables were: 1) CO_2. 2) NO_x. 3) Number of Flights. 4) Airports (Midway and then all Major Airports)

Procedures

CO_2 Emission Calculations (KMDW only)

The first step was to gather data from the Southwest website, in which Southwest has their entire Boeing fleet listed. Southwest operates only domestically within the United States. Next, data was compiled from their main hub airport of KMDW, along with all major United States airports, via the combination of two statistic search engines: RITA and the Bureau of Transportation Statistics (BTS). From these statistic sites, Southwest and KMDW were input with a variety of selectable outputs. Of these outputs, the concern of this research was that of domestic flights. Next, the flight data was used in two formulas from the Tier 1 methodology laid out in the EMEP/EEA guidebook (European Economic Area [EEA], 2014). The first formula is:

LTO fuel = number of LTOs x fuel consumption per LTO

For this study, the number of LTOs is equal to the number of domestic flights. To get the fuel consumption per LTO, ICAO uses a standard national fleet mix. To ensure the most accuracy possible, Southwest was chosen since they operate all Boeing 737s. In addition, the national average that ICAO chose is older and newer 737s. Therefore, they have a basic factor for fuel for the 737 per LTO cycle. This is table 3-3 in the EMEP/EEA guidebook (See Appendix A). The emission factors are also on this table for CO_2 and NO_x. The second formula is manipulated to encompass only the LTO fuel:

Original Formula: $E_{pollutant} = AR_{fuel\ consumption} \times EF_{pollutant}$

New Formula for LTO cycles only: $E_{pollutant} = AR_{LTO\ Totals} \times EF_{pollutant}$

In the new formula, $E_{pollutant}$ is equal to the total pollutant, such as, the totals of CO_2 and NO_x. $AR_{LTO\ Totals}$ is the total amount of LTO cycles, which is equal to the number of Southwest flights for one LTO cycle. $EF_{pollutant}$ is the emission factor of the pollutant, such as CO_2 or NO_x in kgs/LTO. For example, the amount of CO_2 emissions from10 flights by Southwest contributed, utilizing the fuel factor for the newer fleet mix, can be seen below:

1. Fuel burn per LTO for newer B737 fleet mix = 825 kg/LTO
    a. This number is taken from table 3-3 in the EMEP/EEA handbook (Appendix A)
2. LTO fuel = number of LTOs x fuel consumption per LTO
    a. LTO fuel = 10 LTOs x 825 kg/LTO
    b. LTO fuel = 8,250 kgs
3. $E_{pollutant} = AR_{LTO\ Totals} \times EF_{pollutant}$
4. $EF_{pollutant}$ for CO_2 = 2600kg/LTO
    a. This number is taken from table 3-3 in the EMEP/EEA handbook (Appendix A)
    b. The fuel burn of kgs/LTO can be eliminated since the emission factor for the pollutant is also based on kg/LTO, therefore the formula simply is the number of LTOs times the EF.
    c. $E_{pollutant}$ = 10 LTOs x 2600kg/LTO
    d. $E_{pollutant}$ = 26,000 kgs of CO_2
5. To convert to kilograms to metric tons: 1kg = 0.001 metric tons
    a. 26,000kgs x 0.001 metric tons = 26 metric tons of CO_2 produced for 10 LTO cycles

In order to relate the data to each specific aircraft, a formula was devised based on the ICAO standards laid out in the guidebook. The fuel burned for each LTO cycle is different for each aircraft. However, ICAO makes a fleet average of these amounts. Therefore, a more accurate data bank on fuel emission data was used, via the ICAO Engine Exhaust Emission Data Bank. This data bank show the amount of fuel burned for the specific engine in the aircraft. Therefore, it was possible to obtain a slightly more accurate amount of fuel burn emission data for newer aircraft. To achieve this, the emission factor of 2600 for CO_2 was utilized and a simple cross-multiplication formula was devised:

Actual Fuel burn (LTO)/ICAO average fuel burn = X/ICAO emission factor

Using this formula, a more accurate emission factor could be achieved. Southwest's fleet, according to their website as updated on June 30, 2014, contains 47 717-200s, 122 737-300s, 14 737-500s, 434 737-700s, and 66 737-800s. This gives Southwest a grand total fleet number of 683 aircraft. As an example of utilization of the formula, a 717-200 will be used. For one JT8D-7 series engine, the fuel burn for an LTO cycle totals 419 kg. This value was obtained from the ICAO Engine Exhaust Emissions Data Bank. This is multiplied by two, since the aircraft has two engines, giving a new total for the LTO cycle of 838 kg. The ICAO standard fuel burn in the EMEP/ EEA guidebook was 825 kg. The emission factor in the EMEP/EEA guidebook is 2600 kg. Therefore:

1. 838 kg/825 kg = X/2600 kg
2. 838 kg x 2600 kg = 825 kg x (X)
3. 2,178,800kg = 825 kg x (X)
4. 2,178,800 kg/825 kg = X
5. 2641kg = X

Thus, a new emission factor was calculated. This emission factor is greater than the average fleet mix emission factor that ICAO utilizes. This was not a surprise; however, considering the 717-200 is an older aircraft. After calculating the new emission factor and utilizing the ICAO standard, the results for all aircraft types versus the ICAO standard were put into a series of figures (*Figures 3* through *5* in Chapter III). One set of data will show the results of using the

ICAO standardization, located in Appendix B, Table 1. These Tables contain all CO_2 emission data totals for the years of 2002 to 2013 for KMDW only, which utilized the ICAO standardization. The other data will show Southwest's actual fleet with individually calculated CO_2 emission totals for each aircraft type. This data is located in Appendix B, Tables 3 and 4. In order to achieve these calculations, the assumption was made that the aircraft of the highest quantity was flown more often. So, in terms of percentages, the 717-200 makes up 6.88% of the Southwest fleet. In order to get this number:

1. Southwest's total fleet is 683 aircraft
2. Southwest has 47 717-200s
    a. 47/683 = 0.0688
    b. 0.0688 x 100% = 6.88%

Therefore, to get the final amount of CO_2 emissions per aircraft type, the formula used was:

$$CO_2 \text{ emissions} = \% \text{ of fleet type} \times AR_{LTO\ Totals} \times EF_{pollutant}$$

NO_x Emission Calculations (KMDW only)

The calculations for NO_x emissions are nearly identical to the aforementioned calculations for CO_2 emissions. The only factor that will change is the emission factors for NO_x.
The ICAO standard emission factor for NO_x is 8.3 kg, taken from table 3-3 of the EMEP/EEA handbook (Located in Appendix A). Once again, the calculated formula above was used:

$$\text{New Formula for LTO cycles only: } E_{pollutant} = AR_{LTO\ Totals} \times EF_{pollutant}$$

As an example, 10 LTOs were used to gain the total amount of NO_x emissions using the ICAO standard.

1. $E_{pollutant}$ = 10 LTOs x 8.3 kg/LTO
    a. $E_{pollutant}$ = 83 kg/LTO

2. To convert to kilograms to metric tons: 1kg = 0.001 metric tons
    a. 83 kg/LTO x 0.001 metric tons = 0.083 metric tons

In order to calculate the individual emission factor, the 717-200 was used as an example. The ICAO standard from table 3-3 of the EMEP/EEA handbook was 8.3 kg. For the 717-200 engine, taken from the ICAO Engine Exhaust Emissions Data Bank, the emission factor is 3.281 kg. The value of 3.281 kg is then multiplied by two, since the aircraft has two engines, resulting in the emission factor calculated to be 6.562 kg. Unlike the calculations for CO_2 emissions, the NO_x emission factors are already calculated in the ICAO Engine Exhaust Emissions Data Bank. Therefore, no fuel burn cross-multiplication formula is needed as it was beforehand with the CO_2 emissions. Thus, the final, individual emission factor for NO_x is 6.562.

After all calculations for NO_x emissions were made for KMDW only, the data was put into figures (*Figures 6* through *8* located in Chapter III). These figures represent data totaling all NO_x emissions for the ICAO standard, as well as the total NO_x emissions for the individually calculated emission factors. This data is located in Appendix B, Table 2, for the ICAO standard totals, and Appendix B, Tables 5 and 6 for the individually calculated emission factors.

CO_2 and NO_x Emission Calculations (All Airports)

The calculations for CO_2 and NO_x emissions were made using the exact same methodology as there were for KMDW only, except for the fact that the number of flights (LTOs) increased significantly. This is due to the fact that the number of flights were to all major United States airports that Southwest Airlines utilizes, instead of just their main hub airport. After making all of the calculations, the CO_2 emission totals were put into *Figures 9* through *11*. The ICAO standard data is located in Appendix B, Table 7, while the individual emission data is located in Appendix B, Tables 9 and 10. The NO_x emission totals were placed in *Figures 12* through *14*. The ICAO standard data for NO_x at all airports is located in Appendix B, Table 8, while the individual emission factor totals for NO_x emissions are located in Appendix B, Tables 11 and 12.

CHAPTER III: RESULTS

CO_2 and NO_x Emission Results (KMDW only)

Figure 3 shown below contains the total Southwest flights per year from 2002 to 2013 from KMDW, versus the total amount of CO_2 emissions for the same time frame. The CO_2 data was calculated via the ICAO standard emission factor for a 737 fleet mix and can be located for reference in Appendix B, Table 1. The circle connected lines represent the CO_2 emission totals in metric tons, while the square connected lines the total number of flights in LTO cycles. From this figure, one can ascertain the average rate of increase over time for both flights and CO_2 emissions for KMDW. In order to make the calculation, the values from 2002 and 2013 are used:

1. Number of Flights in 2002: 43,405 LTOs
2. Number of Flights in 2013: 78,863 LTOs
3. 78,863 LTOs – 43,405 LTOs = 35,458 LTOs
4. 35,458 LTOs / 12 years = 2,954.83 LTOs/year

The end result shows that on average, Southwest Airlines has had an increase of about 2,955 flights per year from 2002 to 2013. In terms of CO_2 increase, one can simply use the same formula to gain this value:

1. Amount of CO_2 in 2002: 112,853.00 metric tons
2. Amount of CO_2 in 2013: 205,043.80 metric tons
3. 205,043.80 metric tons – 112,853.00 metric tons = 92,190.80 metric tons
4. 92,190.80 metric tons / 12 years = 7,682.57 metric tons of CO_2/year

Therefore, Southwest Airlines has increased their carbon output, on average, by about 7,683 metric tons per year from 2002 to 2013. In terms of percentage, the number of flights and amount of CO_2 has increased annually by 6.81%. Since the relationship between the amount of

LTOs and CO_2 is the same in the ICAO average methodology, the percentage of increase is the same for flights and carbon emission. One final calculation can show on average, how many metric tons of CO_2 are released per LTO:

1. (7,682.57 metric tons of CO_2/year) / (2,954.83 LTOs/year)
2. Years will cancel, leaving metric tons of CO_2/ LTO
3. The result: 2.60 metric tons of CO_2/LTO

This value simply states, that on average, Southwest Airlines releases 2.60 metric tons of CO_2 per LTO cycle. This number can also be reached by taking the total amount of CO_2 output for a given year, and dividing it by the number of flights for any given year, to get the CO_2 per LTO.

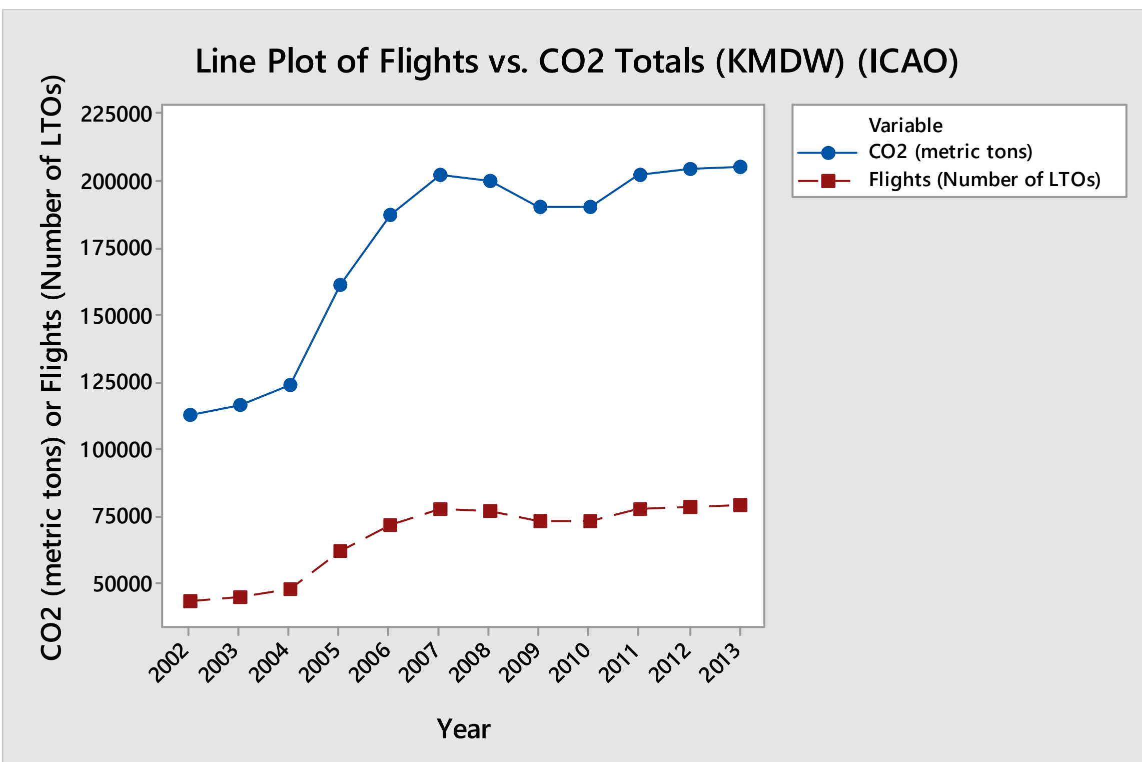


Figure 3. Line Plot of Flights vs. CO2 Totals (KMDW) (ICAO)

Figure 4 depicts the amount of CO_2 created by Southwest Airlines for KMDW by aircraft fleet. Instead of using the ICAO standard; this graph utilizes the aforementioned calculated individual emission factors. The CO_2 emissions calculated for each aircraft by year is located in Appendix B, Table 3. These emission factors vary from aircraft to aircraft, except for the Boeing 737-700 and -800, which have the same emission factor. However, this graph is demonstrating a more accurate portrait as to which aircraft Southwest utilizes most often, and the fact that they are more efficient on average in terms of how much CO_2 they produce. Of course, Southwest's fleet has constantly changed over the years but, this is what the emissions curve would have looked like had the fleet stayed the same from 2002 to 2013. As mentioned previously in Chapter II, the fleet was made into a percentage based on how many aircraft of a certain type over the entire fleet. This assumption was made since there would be no feasible way with the public data available to document how many flights each aircraft actually made.

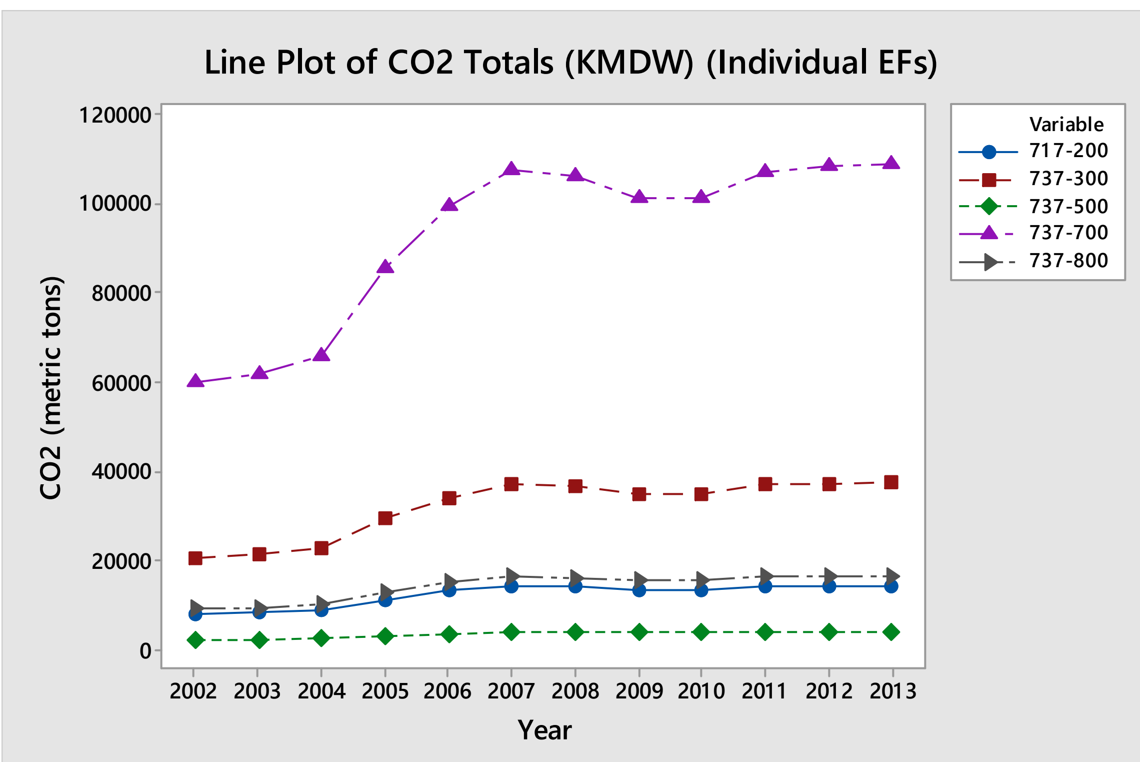


Figure 4. Line Plot of CO2 Totals (KMDW) (Individual EFs)

Figure 5 is the total CO_2 emissions from KMDW but depicts the totals in two forms. One is that of the ICAO average fleet mix, shown by the blue line, while the other is the actual Southwest fleet mix from 2014, shown by the red line. These totals can be located in Appendix B, Tables 1 and 4. Mentioned above, the amount of CO_2 emissions contributed by Southwest Airlines has been steadily increasing annually by 6.81%. While this holds true with the more accurate emission factors as well, the total amount of CO_2 is less. On average, the ICAO average showed that 7,682.57 metric tons of CO_2 was the annual increase released into the atmosphere. The individual emission factors, however, reduce this value to 6,778.59 metric tons of CO_2 annually. Per LTO cycle, that would be 2.29 metric tons of CO_2 versus the 2.60 of the ICAO standard. Again, this is not the most accurate portrayal, considering the fact that Southwest's fleet for 2014 has been projected across these years, when in reality they had different airplanes throughout the time frame.

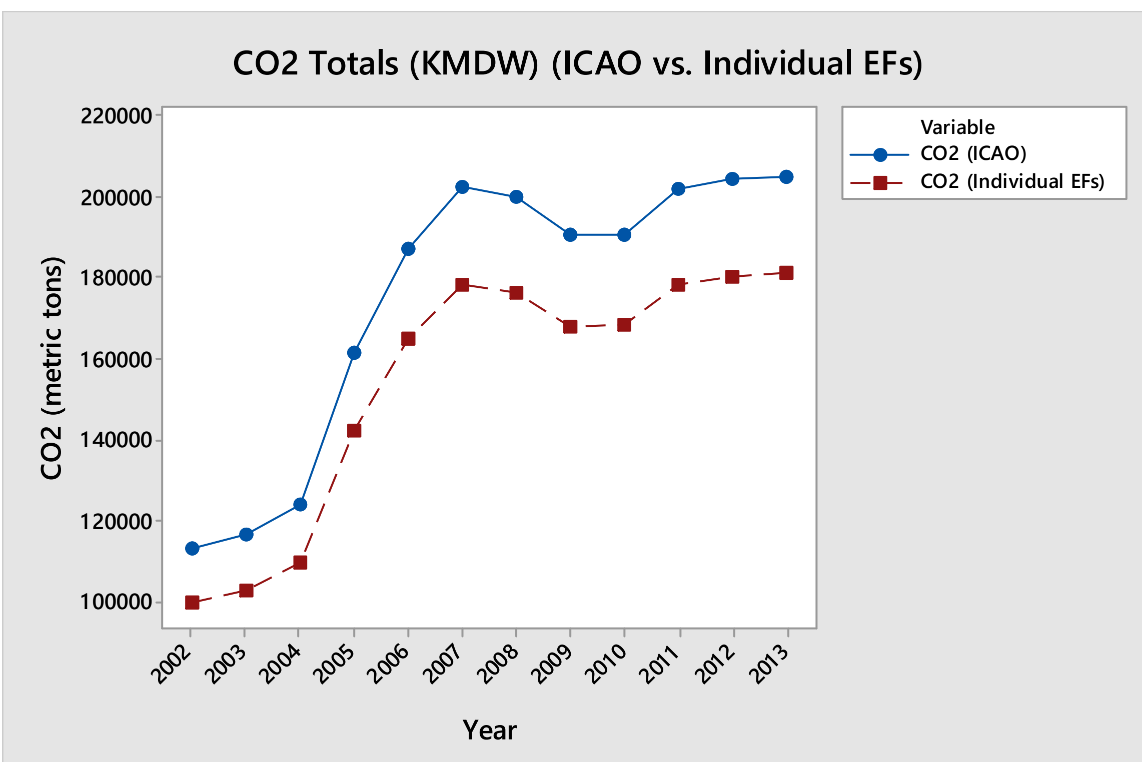


Figure 5. CO2 Totals (KMDW) (ICAO vs. Individual EFs)

Figure 6 is the examination of NO_x totals for the years from 2002 to 2013 at KMDW using the ICAO average fleet mix calculations. The totals calculated can be found in Appendix B, Table 2. As can be seen, the amount of NO_x production is significantly smaller than that of CO_2 production. The amount of NO_x produced on average annually is 25.53 metric tons. The rate of increase is, like CO_2 emissions is 6.81%. Also, on average, the amount of NO_x produced per LTO is 0.0086 metric tons. Of course, this value is much smaller than that produced by CO_2 emission.

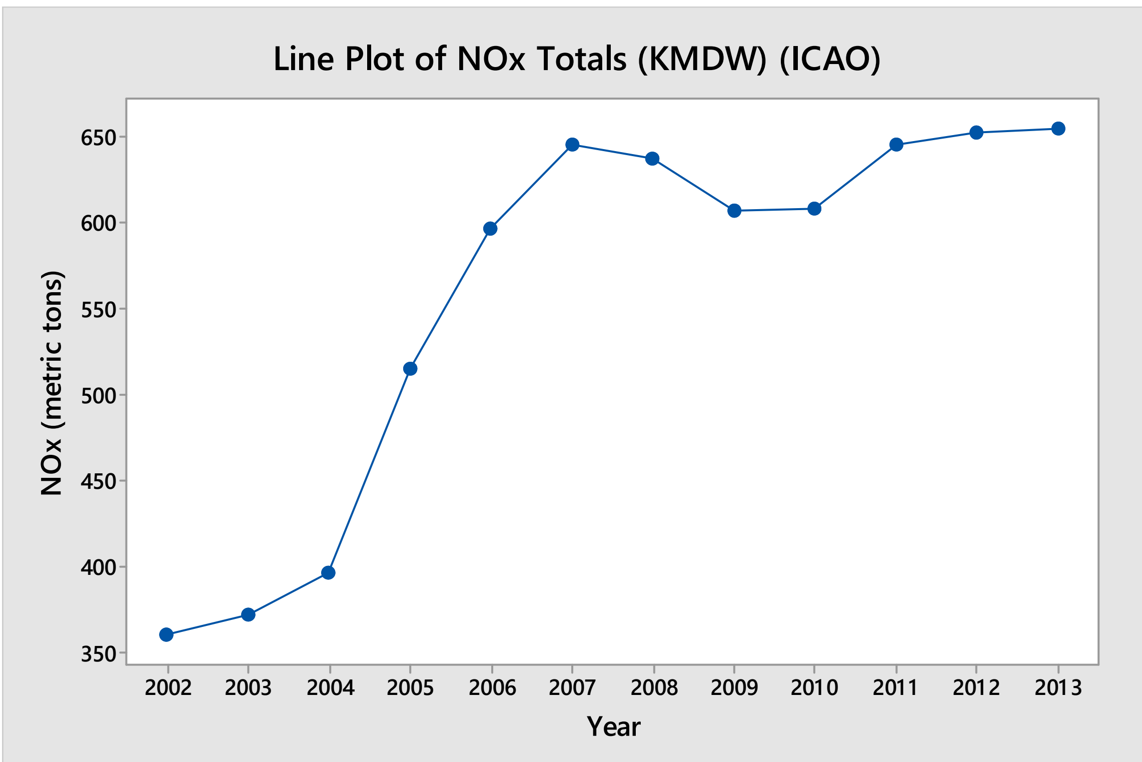


Figure 6. Line Plot of NOx Totals (KMDW) (ICAO)

Figure 7 below analyzes the NO_x totals of Southwest's fleet through individual emission factors. Once again, one can see which aircraft is in the greatest quantity and thus produces the most NO_x emissions. The calculated emission data is in Appendix B, Table 5.

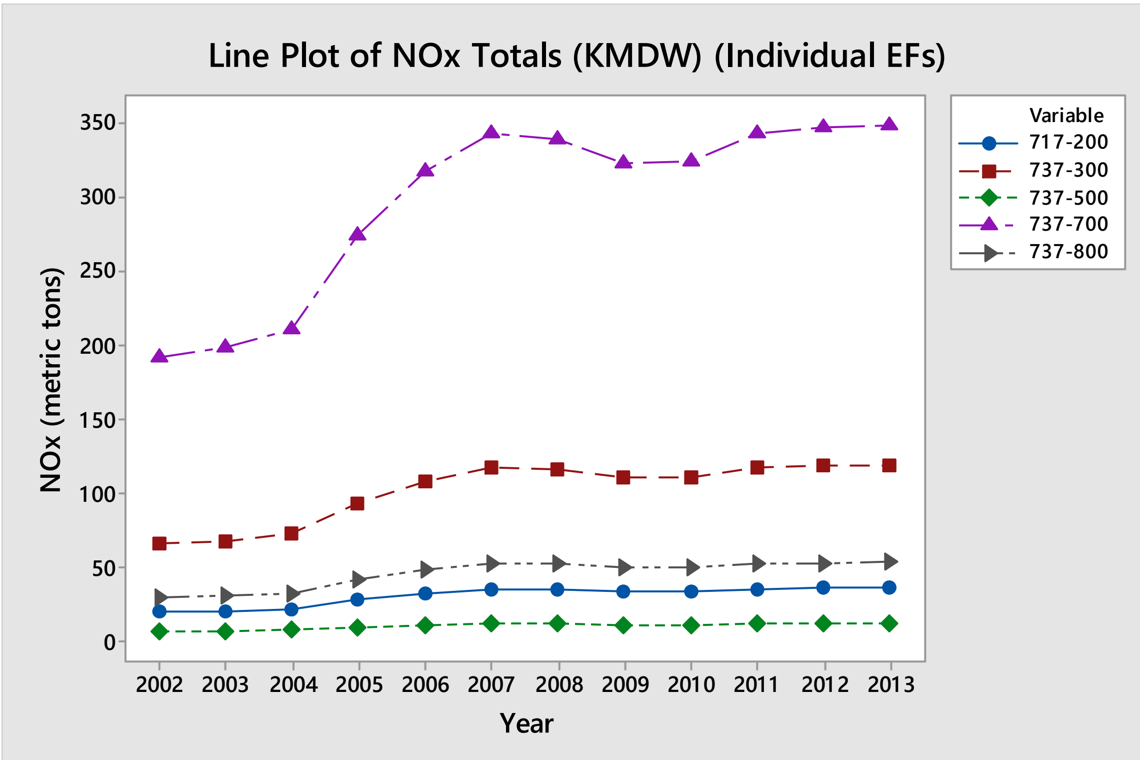


Figure 7. Line Plot of NOx Totals (KMDW) (Individual EFs)

Figure 8 below is similar to that of *Figure 5*, the main difference that this analyzes the NO_x emissions rather than CO_2 emissions. Using the ICAO average, 25.53 metric tons is the average annual increase of NO_x released into the atmosphere, while the individual emission factors produce an annual average increase of 21.23 metric tons. This is not as significant of a difference as that of the CO_2 values considering the fact that the values are much smaller than that of the CO_2 amounts. For the individual emission factors, the amount of NO_x produced per year on average per LTO cycle is 0.0072 metric tons. Of course, this value is less than that of the ICAO standard. The data of NO_x emission totals for this figure are located in Appendix B, Tables 2 and 6.

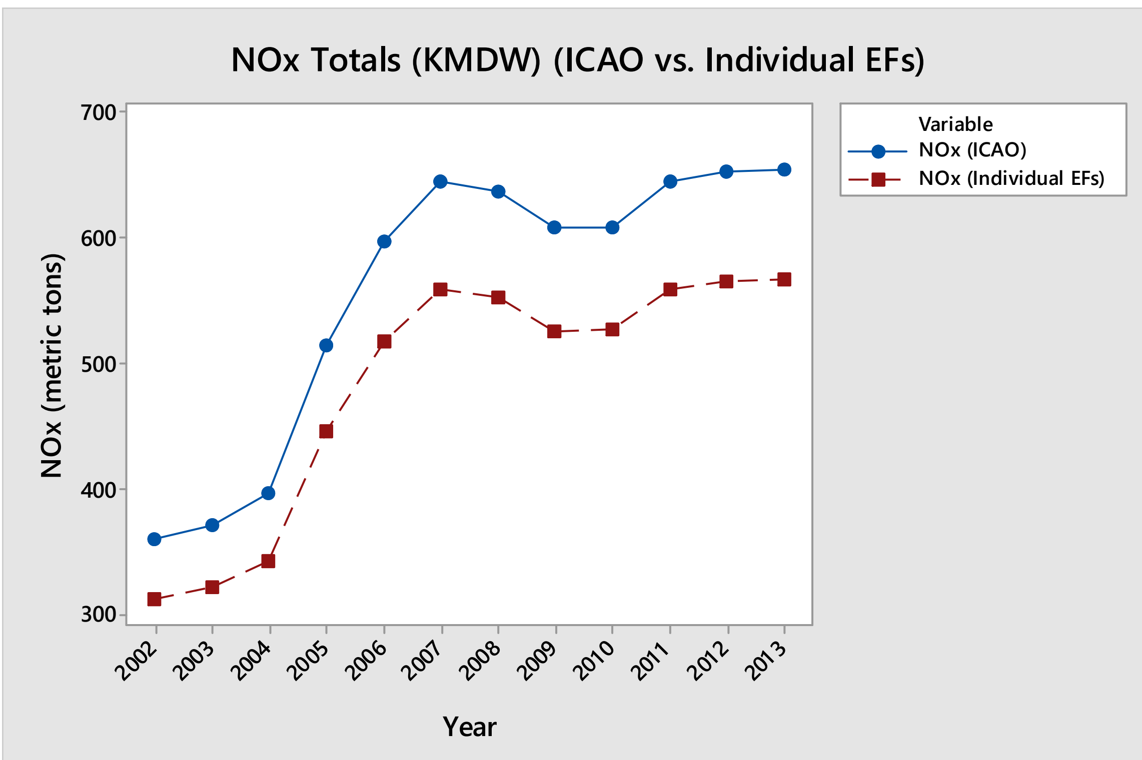


Figure 8. NOx Totals (KMDW) (ICAO vs. Individual EFs)

CO_2 and NO_x Emission Results (All Airports)

Figure 9 has the same data presented as *Figure 3*, but instead of being the LTOs from just KMDW, *Figure 9* contains the LTOs for every major airport Southwest operated out of from 2002 to 2013. The amount of emissions and flights per year are located in Appendix B, Table 7. On average, the amount of flight LTOs and CO_2 emissions are increasing for Southwest annually. In terms of amount of LTOs, the increase is 15,710 per year. Emission-wise, the amount of CO_2 increases on average by 40,734 metric tons a year. Annual percentile growth of CO_2 emissions and LTOs is about 4.13 percent. The increase was greater at KMDW than overall for Southwest, more than likely due to the fact that it is the airline's hub airport. Also, unlike that of KMDW, at all major airports, Southwest had a dip in flights from 2011 to 2013, while at KMDW flights continued to increase after 2010.

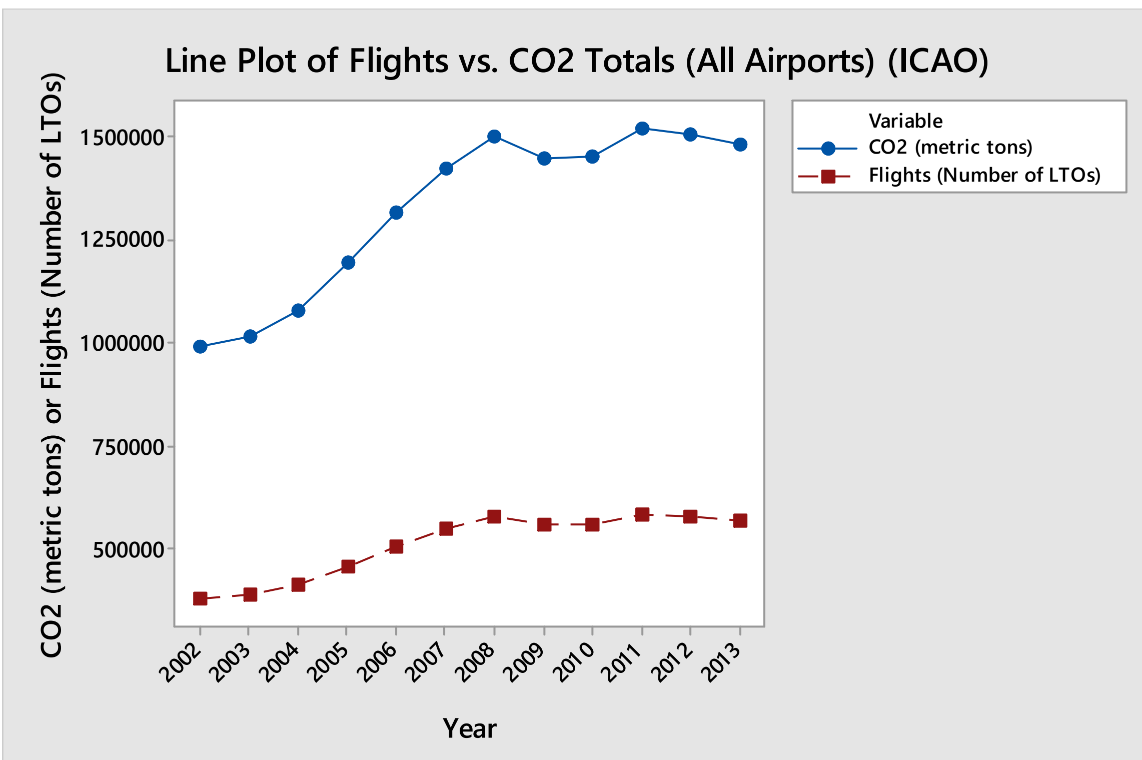


Figure 9. Line Plot of Flights vs. CO2 Totals (All Airports) (ICAO)

Figure 10 represents the individual emission factors via the fleet mix for Southwest Airlines at all major airports. Once again, the aircraft contributing to the most emissions was the 737-700, not due to engine efficiency, but rather the quantity of that specific aircraft being the highest. Emission data is located in Appendix B, Table 9.

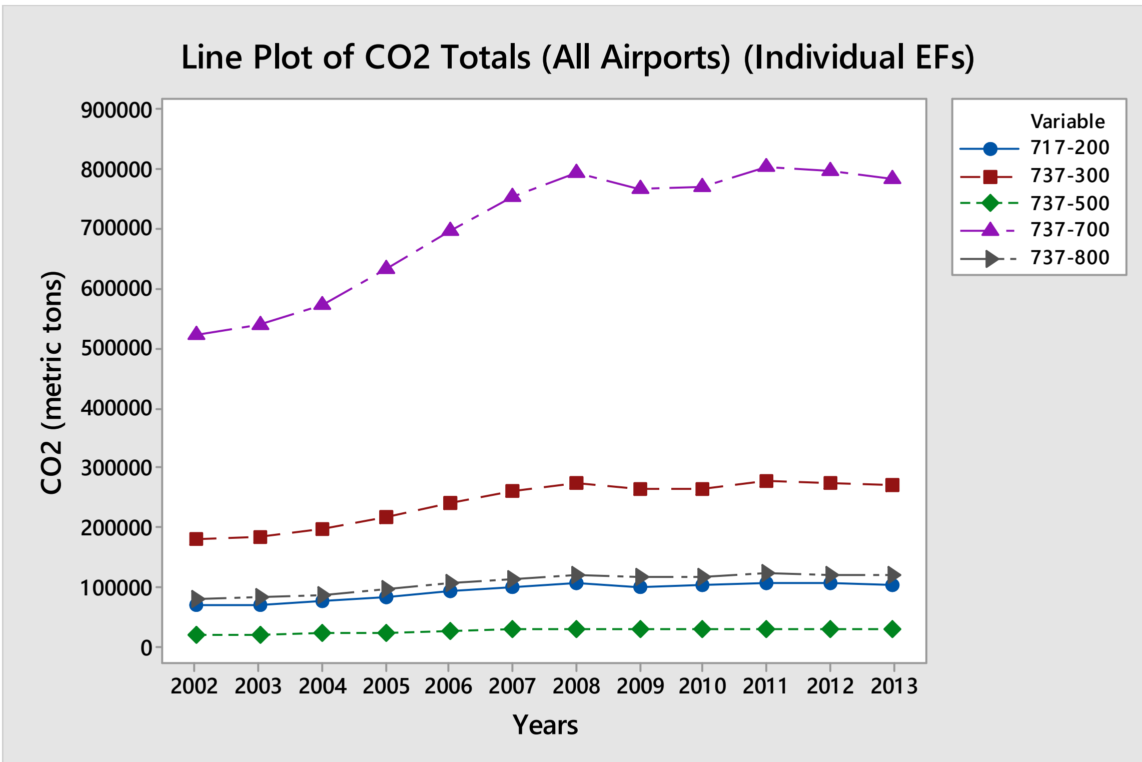


Figure 10. Line Plot of CO2 Totals (All Airports) (Individual EFs)

Figure 11 shows the total CO_2 contribution by Southwest at all major airports. It pairs the ICAO average versus individually calculated emission factors for each aircraft type used by Southwest. Calculated previously, the ICAO totals showed that CO_2 emissions rose by 40,734 metric tons a year. For the individual emission factors, the CO_2 emissions rose by 36,040 metric tons a year. Of course, this is significantly less over time. If Southwest had had this fleet mix since 2002, by 2013 the total emission reduction would have been around 56,328 metric tons. The emission totals are located in Appendix B, Tables 7 and 9.

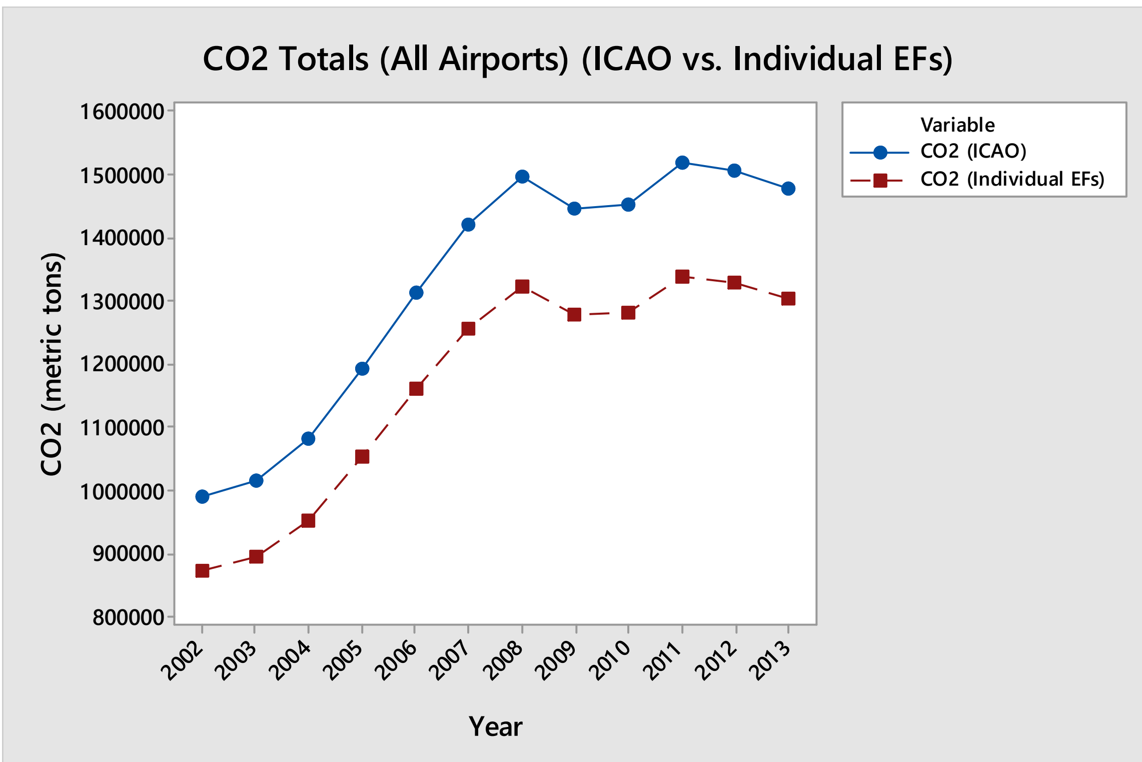


Figure 11. CO2 Totals (All Airports) (ICAO vs. Individual EFs)

Figure 12 represents the amount of NO_x emission totals from Southwest at all major airports utilizing the ICAO average fleet mix emission factors. Per year, the NO_x has increased by 130 metric tons. In terms of percentage, the increase would be the same as CO_2 production at all major airports: 4.13 percent. The emission data is located in Appendix B, Table 8.

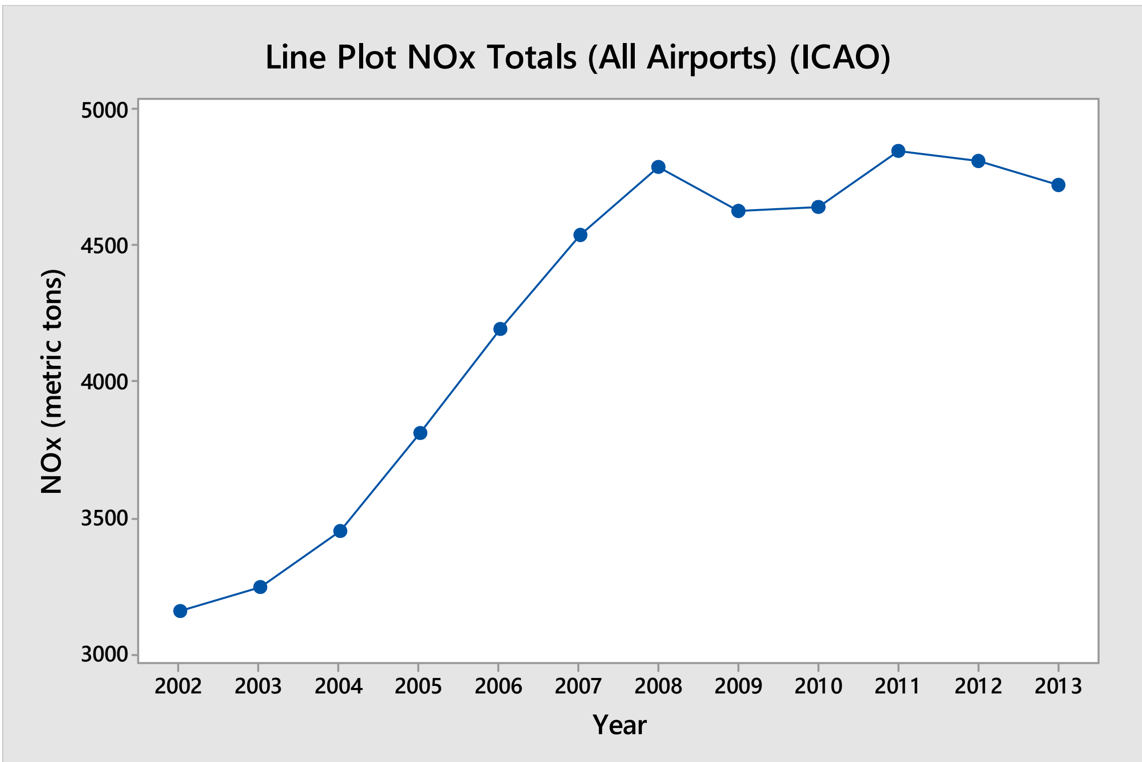


Figure 12. Line Plot of NOx Totals (All Airports) (ICAO)

Figure 13 is a representation of the Southwest fleet broken apart into their individual aircraft emission factors for NO_x emission contribution. Emission data for this figure is in Appendix B, Table 11.

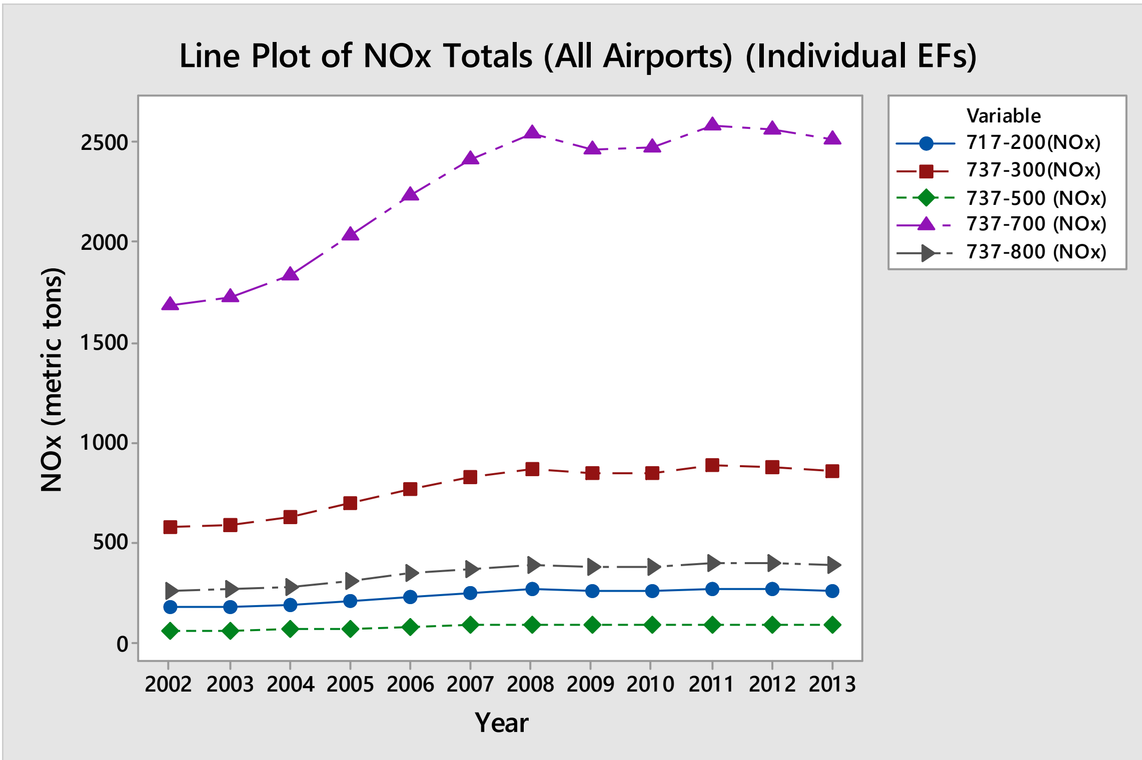


Figure 13. Line Plot of NOx Totals (All Airports) (Individual EFs)

Figure 14 is a comparison featuring the ICAO standard versus the individual emission factors for NO_x contribution. For the ICAO standard, this is an annual increase of 130 metric tons a year, while for the individual emission factor, NO_x emission increases 113 metric tons a year. Again, if Southwest had this fleet mix since 2002, the emission reduction total by 2013 would have been 204 metric tons. Emission data for this figure is located in Appendix B, Tables 8 and 12.

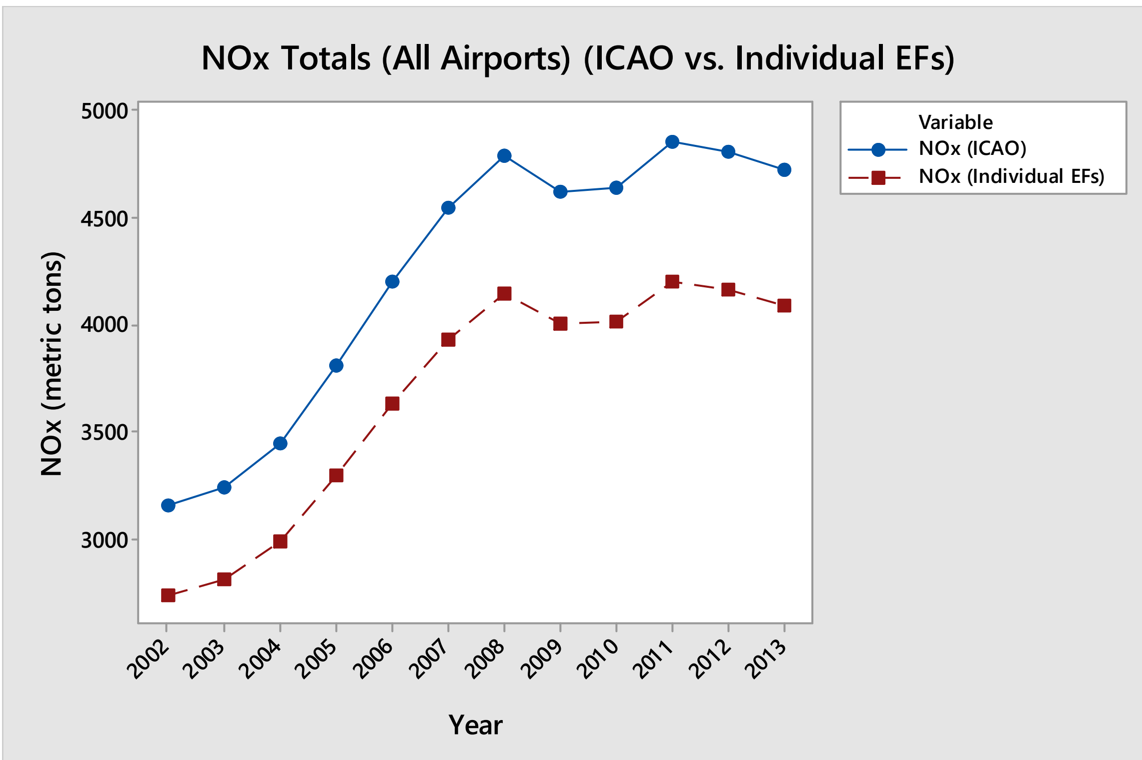


Figure 14. NOx Totals (All Airports) (ICAO vs. Individual EFs)

Southwest Airlines Emission Totals vs. United States Emission Totals

The most accurately recorded information for emission data in the United States is done by the Environmental Protection Agency (EPA). According to their most recent study, conducted in 2013, the transportation sector contributes the most Greenhouse Gases (GHG) emissions in the United States. Of the 27 percent that the transportation sector contributes, 8 percent of this amount is contributed by aircraft (EPA, 2013). There are a multitude of tables in the EPA study, and they are broken down by vehicle types. The one of interest for this study is that of commercial aviation. The EPA study shows CO_2 and NO_x totals from the years 1990 to 2011. In 2011, commercial aviation contributed a total of 114.6 teragrams of CO_2 to the United States overall emission contribution (EPA, 2013). In terms of metric tons, 1 teragram is equivalent to 1,000,000 metric tons. Therefore, 114,600,000 metric tons of CO_2 was released into the atmosphere by aircraft in the United States in 2011 (Located in Appendix C). Southwest Airlines total CO_2 emission total, utilizing the ICAO standard at all airports, was 1,519,785.80 metric tons (located in Appendix B, Table 7). The CO_2 emission total for Southwest Airlines using the individual emission factor totals of the Southwest fleet in 2011 was 1,340,958.85 metric tons (located in Appendix B, Table 10). Using this data, one can ascertain the percentage that Southwest Airlines contributed to the overall emission contribution of the United States.

1. 1,519,785.80 metric tons / 114,600,000.00 metric tons = 0.0133
    a. 0.0132 x 100% = 1.33%
2. 1,340,958.85 metric tons / 114,600,000.00 metric tons = 0.0117
    a. 0.0117 x 100% = 1.17%

Thus, Southwest Airlines contributed, via the ICAO standard, 1.33% to the overall United States CO_2 emissions totals. In terms of individual emissions factors, Southwest Airlines contributed 1.17% to the emission total for the United States in 2011.

In terms of NO_x, the EPA study concludes, that in 2011, 1.1 teragrams of NO_x was released into the atmosphere by the United State's commercial aviation industry (Located in Appendix C) (EPA, 2013). In metric tons, 1.1 teragrams becomes 1,100,000 metric tons. Utilizing the ICAO standard, the NO_x emission totals for all airports in 2011 was 4,851.62 metric tons (located in Appendix B, Table 8). In terms of individual emission factors, the NO_x emission totals for all airports in 2011 were 4,200.97 metric tons (located in Appendix B, Table 12). Once again, this data can be used to see the overall contribution to the NO_x total by Southwest Airlines.

1. 4,851.62 metric tons / 1,100,000 metric tons = 0.0044
    a. 0.0044 x 100% = 0.44%
2. 4,200.97 metric tons / 1,100,000 metric tons = 0.0038
    a. 0.0038 x 100% = 0.38%

Thus, via the ICAO standard in comparison to the United States overall NO_x emission total, Southwest Airlines contributed 0.44% in 2011. Utilizing the individual emission factors, Southwest Airlines contributed 0.38% in 2011 to the United States NO_x emission total.

CHAPTER IV: CONCLUSION AND DISCUSSION

The purpose of this study was to establish the impact of atmospheric CO_2 and NO_x emissions on the United States via Southwest Airline's fleet. The first question to answer was Southwest Airline's contribution to the CO_2 and NO_x levels during LTO cycles at KMDW from 2002 to 2013. In this twelve year time frame, the total amount of CO_2 contributed by Southwest Airlines was 2,095,654.60 metric tons when using the ICAO standard. This total was reached by adding the total CO_2 amounts per year, located in Appendix B, Table 1. In order to make this data more comparable, it was broken down into annual average increase, which was 7,682.57 metric tons for the ICAO standard, versus 6,778.59 metric tons with actual fleet data. The grand total of CO_2 emission over the twelve year period using Southwest's actual fleet was 1,848,666.98 metric tons (data located in Appendix B, Table 4). This showed that when Southwest's actual fleet data was calculated, the production of CO_2 is 246,987.62 metric tons less than the ICAO standard, which utilizes a fleet mix of 737-400s. Using the same method for NO_x, the total amount contributed from 2002 to 2013 was 6,689.99 metric tons, data located in Appendix B, Table 2. In terms of the ICAO standard, the average annual increase of NO_x was 25.53 metric tons, versus the individual fleet emission factors, which yielded an average annual increase of 21.23 metric tons of NO_x. The total amount of NO_x contributed via Southwest's actual fleet was 5,266.59 metric tons, which is 1,423.40 metric tons less than that of the ICAO standard (data located in Appendix B, Table 6).

The second research question was to look at Southwest Airline's contribution of CO_2 and NO_x at all major United States airports from 2002 to 2013. Quite similar to the relationships experienced at KMDW, the main difference at all major United States airports was the increase of flights. This increase led to a significant increase in emissions, and therefore the overall contributions of CO_2 and NO_x. In terms of CO_2, the total amount contributed from 2002 to 2013 using the ICAO standard was 15,929,672.95 metric tons (data located in Appendix B, Table 7). When using Southwest's fleet, the amount of CO_2 dropped to 14,054,113.17 metric tons (data located in Appendix B, Table 10), a difference of 1,875,559.78 metric tons. Again, to make the data more comparable, the average increase per year of CO_2 using the ICAO standard was 40,734 metric tons versus Southwest's fleet annual average increase of 36,040 metric tons. Once again, this shows that the actual fleet data is lower than that of ICAO's standard. When analyzing the totals of NO_x, the difference is only the numbers. Using the ICAO standard, the total NO_x at all major airports from 2002 to 2013 was 50,848.10 metric tons (data located in Appendix B, Table 8). Compared to the actual fleet, the NO_x total is 44,028.14 metric tons (data located in Appendix B, Table 12). This is a difference of 6,819.96 metric tons, again showing that the actual fleet data is more favorable than that of the ICAO standard.

The final research question was to analyze the impact of Southwest Airlines on the overall CO_2 and NO_x contribution levels to the entire United States aviation industry. The year 2011 was chosen to show the comparison, since it was the most recent data available at the time of the study that showed the United States CO_2 and NO_x emission totals. Also, since totals were being used, using data for all airports would provide the most accurate representation of Southwest's overall contribution to the amount of CO_2 and NO_x emitted by the United States aviation industry. Using the data from Appendix C, the data provided for CO_2 and NO_x emission totals for the commercial aviation industry are available. In terms of CO_2 the total for 2011 for all of commercial aviation was 114,600,000.00 metric tons, versus the ICAO standard total for Southwest Airlines of 1,519,785.80 metric tons (located in Appendix B, Table 7). In terms of Southwest's fleet, the total shrinks to 1,340,958.85 metric tons (located in Appendix B, Table

10). Thus, via the ICAO standard, the total emission contribution of Southwest Airlines is 1.33% based on ICAO data, or 1.17% when using the actual fleet data, compared to the grand total of the United State's commercial aviation emission contribution. The total amount of NO_x contributed in 2011 by the United States commercial aviation industry was 1,100,000 metric tons (data located in Appendix C). When compared to the ICAO standard of 4,851.62 metric tons of NO_x produced in 2011 (data located in Appendix B, Table 8), Southwest's contribution was 0.44%. The actual fleet data produced a different value, 0.38%. The grand total in 2011 of NO_x for the actual fleet was 4,200.97 metric tons (data located in Appendix B, Table 12).

From these calculations, a vital discovery can be seen in the amount of emission produced per LTO cycle. The ICAO standard emission factor utilized was 2.60 metric tons of CO_2 per LTO for a Boeing 737-400 fleet mix (this number can be found in Appendix A). However, when calculating Southwest Airline's actual fleet data, the amount of CO_2 became 2.29 metric tons per LTO. Thus, Southwest Airlines could create their own emission factor from this data. In terms of NO_x via the ICAO standard, the amount produced was 0.0086 metric tons per LTO. When using the Southwest fleet with individual emission factors, the amount of NO_x production was 0.0072 metric tons per LTO. Again, this allows a method to which Southwest could create a more accurate emission factor.

Limitations

The biggest limitation throughout the study was data access. The data was limited to only that which can be accessed by the public. Therefore, assumptions had to be made. The fleet chosen in September of 2014 will not be the same fleet in 2015. Airlines are businesses and their fleets are always being changed, added to, or taken away from in some way. Therefore, the data could only be standardized over the time frame from 2002 to 2013 by using the same fleet, which is unrealistic considering the aircraft in 2002 were not the same that Southwest utilized in 2013. Furthermore, the engine types can vary from plane to plane. Once again to standardize, a main engine type was chosen for each plane type and used to keep consistency in the data. Also, the ICAO standard utilizes assumed sets of parametric data such as load factors and taxi times. Airlines or airports are the only entities that could actually have this data per flight per aircraft and be able to give the most accurate portrayal.

Recommendations for Future Research

For more complete emission data analysis, more research needs to be conducted. There are several factors that are left out of the calculated data in this study. For example, the ICAO standard is utilizing set parameters such as load factor and thrust settings to make the numbers standardized. Gaining the fleet data of Southwest and the engine emission outputs helped to hone in a slightly more accurate portrayal of emission data, yet it still leaves out a multitude of issues. Any weather phenomenon resulting in holds or diversions would instantly burn more fuel and thus create more emissions. As mentioned previously, fuel burn is directly related to the amount of emission production. However, this study utilized a methodology utilizing only LTO cycles.

Another interesting aspect of the research that is not really touched on is the effect of these emission increases on airports. For example, at Southwest's hub at KMDW, if Southwest is increasing their flights and emissions, what is being done to reconcile environmental issues, if there are any? Usually, cities tend to grow around airports. This could lead to more significant environmental impacts at this specific airport versus others across the world that have less air traffic. Also, this research is only contains data on one U.S. airline, so further study utilizing additional carriers is needed.

The most vital aspect of this study that was demonstrated is that there are currently no clear emissions standards. While aviation does not contribute the most to emission totals, it does contribute a decent percentage. Many studies support the theory that human activity is affecting the way in which our planet behaves. Aviation is part of that human activity, and while the industry does not contribute nearly as much as other industries do, aviation is one of the most scrutinized industries. Studies that delve into actual numbers and values can support evidence that aviation is actually on the forefront of environmentally friendly technology. Thus, if an agreed-upon standard can be reached by the organizations supporting and regulating the aviation industry, this would both further support aviation’s value to the economy and help the planet, as well.

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APPENDICES

APPENDIX A: ICAO Standard Emission Factors

Table 3–3 Emission factors and fuel use for the *Tier 1* methodology using jet kerosene as fuel. Emission factors are given on a representative aircraft basis

Tier 1 emission factors									
Domestic	**Fuel**	**SO_2**	**CO_2**	**CO**	**NO_x**	**NMVOC**	**CH_4**	**N_2O**	**$PM_{2.5}$**
LTO (kg/LTO) — average fleet (B737-400)	825	0.8	2600	11.8	8.3	0.5	0.1	0.1	0.07
LTO (kg/LTO) — old fleet (B737-100)	920	0.9	2900	4.8	8.0	0.5	0.1	0.1	0.10
Cruise (kg/tonne) — average fleet (B737-400)	-	1.0	3150	2.0	10.3	0.1	0	0.1	0.20
Cruise (kg/tonne) — old fleet (B737-100)	-	1.0	3150	2.0	9.4	0.8	0	0.1	0.20
International	**Fuel**	**SO_2**	**CO_2**	**CO**	**NO_x**	**NMVOC**	**CH_4**	**N_2O**	**$PM_{2.5}$**
LTO (kg/LTO) — average fleet (B767)	1617	1.6	5094	6.1	26.0	0.2	0.0	0.2	0.15
LTO (kg/LTO) — average fleet (short distance, B737-400)	825	0.8	2600	11.8	8.3	0.5	0.1	0.1	0.07
LTO (kg/LTO) — average fleet (long distance, B747-400)	3400	3.4	10717	19.5	56.6	1.7	0.2	0.3	0.32
LTO (kg/LTO) — old fleet (DC10)	2400	2.4	7500	61.6	41.7	20.5	2.3	0.2	0.32
LTO (kg/LTO) — old fleet (short distance, B737-100)	920	0.9	2900	4.8	8.0	0.5	0.1	0.1	0.10
LTO (kg/LTO) — old fleet (long distance, B747-100)	3400	3.4	10754	78.2	55.9	33.6	3.7	0.3	0.47
Cruise (kg/tonne) — average fleet (B767)	-	1.0	3150	1.1	12.8	0.5	0.0	0.1	0.20
Cruise (kg/tonne) — old fleet (DC10)	-	1.0	3150	1.0	17.6	0.8	0.0	0.1	0.20

APPENDIX B: Calculated Emission Data

Table 1

Total Amount of CO_2 Emissions for Southwest (ICAO) (KDMW only)		
Year	*Flights*	*Amount of CO_2 (in metric tons)*
2002	43,405.00	112,853.00
2003	44,792.00	116,459.20
2004	47,712.00	124,051.20
2005	61,989.00	161,171.40
2006	71,898.00	186,934.80
2007	77,747.00	202,142.20
2008	76,807.00	199,698.20
2009	73,204.00	190,330.40
2010	73,275.00	190,515.00
2011	77,709.00	202,043.40
2012	78,620.00	204,412.00
2013	78,863.00	205,043.80

APPENDIX B (cont.): Calculated Emission Data

Table 2

Total Amount of NO_x Emissions for Southwest (ICAO) (KMDW only)		
Year	*Flights*	*Amount of NO_x (in metric tons)*
2002	43,405.00	360.26
2003	44,792.00	371.77
2004	47,712.00	396.01
2005	61,989.00	514.51
2006	71,898.00	596.75
2007	77,747.00	645.30
2008	76,807.00	637.50
2009	73,204.00	607.59
2010	73,275.00	608.18
2011	77,709.00	644.98
2012	78,620.00	652.55
2013	78,863.00	654.59

APPENDIX B (cont.): Calculated Emission Data

Table 3

Total Amount of CO_2 Emissions for Southwest (Per Aircraft) (KMDW) (metric tons)					
Year	*717-200*	*737-300*	*737-500*	*737-700*	*737-800*
2002	7,886.72	20,574.16	2,198.70	59,820.02	9,094.45
2003	8,138.74	21,231.61	2,268.96	61,731.56	9,385.06
2004	8,669.31	22,615.70	2,416.88	65,755.85	9,996.88
2005	11,263.45	29,383.06	3,140.08	85,432.16	12,988.27
2006	13,063.92	34,079.97	3,642.03	99,088.57	15,064.46
2007	14,126.69	36,852.42	3,938.31	107,149.56	16,289.97
2008	13,955.89	36,406.87	3,890.70	105,854.07	16,093.02
2009	13,301.23	34,699.02	3,708.19	100,888.48	15,338.10
2010	13,314.13	34,732.67	3,711.78	100,986.33	15,352.97
2011	14,119.79	36,834.41	3,936.39	107,097.19	16,282.01
2012	14,285.32	37,226.23	3,982.54	108,352.72	16,472.89
2013	14,329.47	37,381.41	3,994.84	108,687.61	16,523.80

APPENDIX B (cont.): Calculated Emission Data

Table 4

Total Amount of CO_2 Emissions for Southwest (Indiv. EFs) (KMDW)		
Year	*Flights*	*Amount of CO_2 (in metric tons)*
2002	43,405.00	99,574.05
2003	44,792.00	102,355.32
2004	47,712.00	109,454.62
2005	61,989.00	142,207.02
2006	71,898.00	164,938.95
2007	77,747.00	178,356.95
2008	76,807.00	176,200.55
2009	73,204.00	167,935.02
2010	73,275.00	168,097.88
2011	77,709.00	178,269.79
2012	78,620.00	180,359.7
2013	78,863.00	180,917.13

APPENDIX B (cont.): Calculated Emission Data

Table 5

Total Amount of NO_x Emissions for Southwest (Per Aircraft) (KMDW) (metric tons)					
Year	*717-200*	*737-300*	*737-500*	*737-700*	*737-800*
2002	19.60	65.32	6.40	191.51	29.12
2003	20.22	67.41	6.60	197.63	30.05
2004	21.54	71.80	7.03	210.52	32.00
2005	27.99	93.29	9.14	273.51	41.58
2006	32.46	108.20	10.60	317.23	48.23
2007	35.10	117.00	11.46	343.04	52.15
2008	34.68	115.59	11.32	338.89	51.52
2009	33.05	110.16	10.79	322.99	49.10
2010	33.08	110.27	10.80	323.31	49.15
2011	35.08	116.94	11.45	342.87	52.13
2012	35.49	118.31	11.59	346.89	52.74
2013	35.60	118.68	11.62	347.96	52.90

APPENDIX B (cont.): Calculated Emission Data

Table 6

Total Amount of NO_x Emissions for Southwest (Indiv. Efs) (KMDW)		
Year	*Flights*	*Amount of NO_x (in metric tons)*
2002	43,405.00	311.95
2003	44,792.00	321.91
2004	47,712.00	342.89
2005	61,989.00	445.51
2006	71,898.00	516.72
2007	77,747.00	558.75
2008	76,807.00	552
2009	73,204.00	526.09
2010	73,275.00	526.61
2011	77,709.00	558.47
2012	78,620.00	565.02
2013	78,863.00	566.76

APPENDIX B (cont.): Calculated Emission Data

Table 7

Total Amount of CO_2 Emissions for Southwest (ICAO) (All Airports)		
Year	*Flights*	*Amount of CO_2 (in metric tons)*
2002	380,351.00	990,260.15
2003	390,722.00	1,015,877.20
2004	415,742.00	1,080,929.20
2005	459,381.00	1,194,390.60
2006	505,836.00	1,315,173.60
2007	547,411.00	1,423,268.60
2008	576,917.00	1,499,984.20
2009	557,442.00	1,449,349.20
2010	559,124.00	1,453,722.40
2011	584,533.00	1,519,785.80
2012	579,947.00	1,507,862.20
2013	568,873.00	1,479,069.80

APPENDIX B (cont.): Calculated Emission Data

Table 8

Total Amount of NO_x Emissions for Southwest (ICAO) (All Airports)		
Years	*Flights*	*Amount of NO_x (in metric tons)*
2002	380,351.00	3,156.91
2003	390,722.00	3,242.99
2004	415,742.00	3,450.66
2005	459,381.00	3,812.86
2006	505,836.00	4,198.44
2007	547,411.00	4,543.51
2008	576,917.00	4,788.41
2009	557,442.00	4,626.76
2010	559,124.00	4,640.73
2011	584,533.00	4,851.62
2012	579,947.00	4,813.56
2013	568,873.00	4,721.65

APPENDIX B (cont.): Calculated Emission Data

Table 9

Total Amount of CO_2 Emissions for Southwest (Per Aircraft) (All Airports) (metric tons)					
Year	*717-200*	*737-300*	*737-500*	*737-700*	*737-800*
2002	69,110.08	180,288.05	19,266.87	524,193.13	79,693.20
2003	70,994.50	185,203.95	19,792.22	538,486.26	81,866.18
2004	75,540.65	197,063.54	21,059.62	572,968.39	87,108.51
2005	83,469.90	217,748.62	23,270.17	633,110.90	96,260.22
2006	91,910.81	239,768.49	25,623.38	697,134.37	105,985.49
2007	99,465.02	259,475.22	27,729.38	754,432.32	114,696.51
2008	104,826.28	273,461.20	29,224.02	795,096.97	120,878.77
2009	101,287.66	264,229.96	28,237.50	768,256.86	116,798.26
2010	101,593.28	265,027.24	28,322.71	770,574.97	117,150.68
2011	106,210.11	277,071.21	29,609.81	805,593.21	122,474.51
2012	105,376.83	274,897.43	29,377.51	799,272.86	121,513.63
2013	103,364.68	269,648.31	28,816.55	784,010.87	119,193.34

APPENDIX B (cont.): Calculated Emission Data

Table 10

Total Amount of CO_2 Emissions for Southwest (Indiv. EFs) (All Airports)		
Years	*Flights*	*Amount of CO_2 (in metric tons)*
2002	380,351.00	872,551.33
2003	390,722.00	896,343.11
2004	415,742.00	953,740.71
2005	459,381.00	1,053,859.81
2006	505,836.00	1,160,422.54
2007	547,411.00	1,255,798.45
2008	576,917.00	1,323,487.24
2009	557,442.00	1,278,810.24
2010	559,124.00	1,282,668.88
2011	584,533.00	1,340,958.85
2012	579,947.00	1,330,438.26
2013	568,873.00	1,305,033.75

APPENDIX B (cont.): Calculated Emission Data

Table 11

Total Amount of NO_x Emissions for Southwest (Per Aircraft) (All Airports) (metric tons)					
Year	*717-200*	*737-300*	*737-500*	*737-700*	*737-800*
2002	171.72	572.38	56.06	1,678.19	255.13
2003	176.40	587.99	57.59	1,723.95	262.09
2004	187.70	625.64	61.28	1,834.34	278.88
2005	207.39	691.31	67.71	2,026.89	308.15
2006	228.37	761.22	74.56	2,231.86	339.31
2007	247.14	823.79	80.69	2,415.30	367.20
2008	260.46	868.19	85.03	2,545.48	386.99
2009	251.67	838.89	82.16	2,459.56	373.93
2010	252.43	841.42	82.41	2,466.98	375.06
2011	263.97	879.65	86.16	2,579.09	392.10
2012	261.83	872.75	85.48	2,558.85	389.02
2013	256.83	856.09	83.85	2,509.99	381.59

APPENDIX B (cont.): Calculated Emission Data

Table 12

Total Amount of NO_x Emissions for Southwest (Indiv. Efs) (All Airports)		
Year	*Flights*	*Amount of NO_x (in metric tons)*
2002	380,351.00	2,733.48
2003	390,722.00	2,808.02
2004	415,742.00	2,987.84
2005	459,381.00	3,301.45
2006	505,836.00	3,635.32
2007	547,411.00	3,934.12
2008	576,917.00	4,146.15
2009	557,442.00	4,006.21
2010	559,124.00	4,018.30
2011	584,533.00	4,200.97
2012	579,947.00	4,167.93
2013	568,873.00	4,088.35

APPENDIX C: United States Total Emission Data for 2011

U.S. Transportation GHG Emissions by Gas, 2011

(Tg CO_2 Equivalent)

Source	CO_2	CH_4	N_20	HFCs	Total	Percent
On-Road Vehicles	**1,470.4**	**1.3**	**14.5**	**54.8**	**1,540.9**	**75.5**
Light-Duty Vehicles	1,061.6	1.1	13.4	42.7	1,118.8	54.8
Passenger Cars	759.0	0.8	9.4	18.3	787.4	38.6
Light-Duty Trucks	302.6	0.3	4.0	24.5	331.4	16.2
Motorcycles	3.6	0.0	0.0	0.0	3.7	0.2
Buses	16.9	0.0	0.0	0.4	17.4	0.9
Medium- and Heavy-Duty Trucks	388.3	0.1	1.0	11.7	401.1	19.7
Aircraft	**148.4**	**0.0**	**1.4**	**0.0**	**149.9**	**7.3**
Commercial Aviation	114.6	0.0	1.1	0.0	115.7	5.7
Military Aircraft	12.6	0.0	0.1	0.0	12.7	0.6
General Aviation	21.2	0.0	0.2	0.0	21.5	1.1
Ships and Boats	**47.4**	**0.0**	**0.7**	**0.0**	**48.2**	**2.4**
Rail	**45.3**	**0.1**	**0.4**	**2.3**	**48.0**	**2.4**
Pipelines*	**37.7**	**0.0**	**0.0**	**0.0**	**37.7**	**1.8**
Lubricants	**9.0**	**0.0**	**0.0**	**0.0**	**9.0**	**0.4**
Transportation Total	**1,758.3**	**1.4**	**16.9**	**57.1**	**1,833.7**	**89.9**