

SEI Discussion Paper

Carbon Offsetting & Air Travel

Part 1: CO₂-Emissions Calculations

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Introduction

May, 29, 2008

This paper was originally put in the public domain in early May 2008. Since then we have received a number of comments and questions. All three air travel emissions calculator developers were invited to comment on the paper. Atmosfair and TRX Travel Analytics have sent us detailed comments and raised a number of interesting discussion points. Therefore we have decided to revise the document to include the most important comments.

Specifically, we have added 2 appendices:

Appendix 1: Comments by Dietrich Brockhagen from Atmosfair

Appendix 2: Comments by Thomas Tomosky from TRX Travel Analytics

Throughout the document we have inserted (in red Arial font) the most pertinent points that were raised in the comments we received. In certain places, we have also inserted specific questions.

The goal is to use this paper as a discussion document in order to facilitate feedback from experts in the field and in order to gain more clarity about the issues discussed here.

You can send your comments to anja.kollmuss@sei-us.org

Aviation activities currently account for about 2-5% of total anthropogenic Greenhouse Gas (GHG) emissions. Civil aviation is growing rapidly at 5.9% per year (IPCC, 2007, p. 334) and the sector's contribution to global warming will continue to grow. Companies and individuals are increasingly interested in purchasing carbon offsets as a way to reduce their climate impact from air travel. Yet calculating air travel emissions is not simple and the current available air travel calculator estimates can vary by up to a factor of three (Kollmuss, 2007).

The following paper is the first of two which examine the key factors that have to be taken into account when calculating air travel emissions for the purpose of carbon offsetting. This paper first gives a brief overview of three emissions calculators which were chosen because they are among the most comprehensive currently available:

- Atmosfair (<http://www.atmosfair.com>)
- TRX Travel Analytics (<http://carbon.trx.com>)
- Virgin Atlantic (<https://virginatlantic.myclimate.org>)

The paper then examines the aircraft parameters that are needed to calculate emissions on a per person basis and describes how each of the three calculators accounts for these parameters. The parameters discussed are:

1. Aircraft Model
2. Flight Profile and Flight Distance
3. Cargo on Passenger Flights
4. Seat Occupancy Rate (Load Factor)
5. Seat Class

The final section of the paper analyzes emissions calculations for flights between three city pairs, and compares the results of the three emissions calculators to each other as well as to the UK's Department for Environment, Food and Rural Affairs (DEFRA) multiplier for air travel emissions calculations. The

DEFRA multiplier was included in the comparison because it is widely used by government agencies and private entities to calculate air travel emissions.

This paper does not discuss GHG emissions associated with other airport-related sources or ground travel transportation to and from airports. Greenhouse gas inventories prepared by airport operators indicate that when considering all emissions sources operating at an airport, aircraft represent 80% or more of GHG emissions (Vigilante, personal communication).

This paper does not discuss the user-friendliness of the evaluated calculators but instead focuses solely on the data sources and calculations used to account for the above listed parameters.

This paper does not include a discussion of how to account for non-CO₂ emissions from air-travel (i.e. RFI multipliers). This topic is the focus of the second paper.

1. Evaluated Air Travel Calculators

Atmosfair's Calculator

(<http://www.atmosfair.org>)

Atmosfair is a German carbon offset retailer that has developed its own carbon calculator. Detailed background information on its calculator assumptions and references are available on the Atmosfair website (Atmosfair, 2007).

There are two versions of the calculator:

- The public version is accessible for free on the Atmosfair website. This version has been designed for consumers that do not know many details about their flight, and who seek to calculate their emissions with minimum input (cities visited and number of passengers are sufficient). Details like aircraft type or seat class can also be specified by the user but are not required.
- The business version of the calculator is a more detailed reporting tool available for a fee and currently used by several international business travel agencies. The tool can be used for *ex-post* or *point-of-sale* analysis. In the *ex-post* reporting version, the impact of all travel activity (flight, car, rail, hotel) is analyzed. The level of aggregation and analytical depth are customized. The *point-of-sale* version feeds internet booking engines.

In our analysis, we looked at the public version.

TRX Travel Analytics' Calculator

(<http://carbon.trx.com>)

TRX Travel Analytics provides large businesses with data analyses to increase efficiency and reduce costs associated with business-related air travel. It draws upon a wide range of air travel industry data. Increasingly, its clients request information on air travel offsets and their calculation, and so in 2006 it developed its own air travel calculator.

There are two versions of the calculator:

- The public version is accessible for free on the TRX Travel Analytics website. This fully documented public version uses all the essential elements of its corporate calculator (see below) such as current airline schedule data, airline fleet data, fuel burn rates, allocation of emissions

between passengers and cargo, allocation of emissions for each cabin, adjustment of emissions for passenger load factors, and optional adjustments for RFI and cost of CO₂ emissions.

- The corporate version, available for a fee, offers two types of reports - the *Enterprise Report* and the *Standard Report*. The Enterprise Report is an analysis of a client's recent airline emissions inventory. Quantitative options to reduce CO₂ emissions are also provided: effects of decreasing travel, using greener carriers, and avoiding unnecessary connections. The Standard Report is optimized for establishing a client's baseline emissions and to monitor progress after a baseline has been established.

In our analysis, we looked at the public version.

Virgin Atlantic's Calculator

(<https://virginatlantic.myclimate.org>)

Virgin Atlantic is an air travel carrier. Virgin Atlantic's founder, Sir Richard Branson, is well known for his bold statements concerning Virgin Atlantic's commitment to climate protection¹. Virgin Atlantic's passengers can offset their emissions with *myclimate*, a Swiss-based carbon offset retailer. Virgin Atlantic has also developed its own air travel emissions calculator for which it uses proprietary information of its own fleet.

2. Review of Parameters

There are a number of factors related to aircraft type, flight profile, flight distance, number of seats, occupancy rate, cargo, and seat class that air travel offset calculators should take into account when determining an individual traveler's impact on climate change. The most important of these parameters are explained below, together with a discussion of how each of the three calculators accounts for them.

2.1 Aircraft Type

The aircraft fleets of most countries are dominated by aircraft produced by two major manufacturers: Boeing and Airbus². Fuel consumption varies by aircraft model and engine type. To illustrate how the weight of an airplane and its payload are distributed, the fuel burn rates of three aircraft flying between New York (JFK) and Los Angeles (LAX) were compared by TRX Travel Analytics and presented in the table below. The table also shows the typical numbers of seats (three class configuration³) and fuel burn rate per passenger. Fuel burn rate per passenger is calculated as total fuel burned divided by total number of seats. In this example, it does not take into account different seat classes or the occupancy rate of an individual flight, which is not always 100%.⁴ To illustrate differences among airplane models, the table below shows

¹ “**Sir Richard Branson to Invest \$3BN (£1.6BN) to Fight Global Warming**”

“The Virgin boss said he would commit all profits from his travel firms, such as airline Virgin Atlantic and Virgin Trains, over the next 10 years.

““We must rapidly wean ourselves off our dependence on coal and fossil fuels,” Sir Richard said. The funds will be invested in schemes to develop new renewable energy technologies, through an investment unit called Virgin Fuels.” (<http://www.virgin-atlantic.com/en/gb/allaboutus/environment/bransonpledge.jsp>)

See also: <http://www.virgin-atlantic.com/en/gb/allaboutus/environment/index.jsp>

² Detailed technical information about each airplane type can be found on their websites: www.airbus.com and www.boeing.com

³ Seat information taken from www.boeing.com/commercial/ and www.airbus.com/en/aircraftfamilies/a320/a320/specifications.html

⁴ Bureau of Transportation Statistics indicates that the current average load factor of flights in the US is about 80%, and has been increasing in recent years (see section on occupancy rates).

that the fuel burn rate per passenger is a third higher for the B747 than it is for the A320. The example does not take engine type into account. Engine type can also influence efficiency considerably⁵.

Table1: Examples of Different Aircraft Types' Fuel Burn Rate

Aircraft	Fuel burned (kg of fuel)	Number of seats	Fuel burn per passenger (kg of fuel)
A320	11,608	150	77.4
B767-300ER	21,445	218	98.4
B747-400	42,920	416	102.4

(Source: Gillespie, 2007)

Aircraft fuel efficiency, through weight reduction and progress in aerodynamic and engine design has steadily improved over the last few decades. Yet there is considerable lag time between technology development and implementation. The total time span between preliminary technology development and the retirement of an aircraft averages 45 to 65 years (IPCC, 1999). Fuel consumption considerations are a priority for the airlines because profit margins are narrow and the price of fuel has steadily increased at a time when airfares have been decreasing in response to competition. While many airlines are moving to acquire newer, more fuel-efficient aircraft or to modify their aircraft to increase fuel efficiency, due to the long service lives of passenger aircraft (approx. 30 years), a substantial number of older, less fuel-efficient aircraft remain in service.

The more accurate calculators reflect fuel burn and efficiencies associated with specific aircraft models⁶. However, in circumstances when a passenger does not know the aircraft type, the more flexible calculators identify the aircraft for the user (as is done by TRX Travel Analytics) or clearly note that they are relying on average fuel burn.

Point of Discussion 1:

Does increased specificity lead to increased accuracy?

Atmosfair claims that currently no calculator has sufficient data to allow for an airline specific calculation and thus ranking of airlines (see Appendix 1 for details). Atmosfair made the following points:

1. The available data sets (QinetiQ , DLR, Corinair) are not based on fuel consumption data for each specific aircraft but a 'representative aircraft' or aircraft family. Even if there is fuel consumption data available for a specific family of aircraft (e.g. B737) actual fuel consumption differs quite significantly between different types within a family (e.g. B737-400 and B737-200).

2. No information is available for the following factors that impact fuel burn rates:

- Engine type
- Aircraft maintenance
- Adapted fuel capacity
- Design modification (e.g. to body or wings)
- Tankering

TRX Travel Analytics has responded to this with an analysis that claims that the difference between airplane families is much larger than differences within an airplane family (for the analysis see appendix 2) therefore, despite the limited data available within airplane families, airline-specific calculations do make sense and provide an additional level of detail and accuracy.

Author's Questions:

⁵ The data was taken from the EMEP EIG document, which does not specify engine type.

⁶ Airlines sometimes change aircrafts for a particular flight. In that case the scheduled aircraft might not match the one which is actually used on that particular flight. Yet according to industry experts such changes do not happen very frequently.

How much do fuel rates vary between a specific aircraft and its 'representative family aircraft' (e.g. a Boeing 747-400 and Boeing 747-100)? In other words, does available data allow for airline-specific emissions calculation or are the above mentioned factors significant enough to offset any gained accuracy from calculations based on more detailed information? Aside from the analysis provided in the appendices, are there any other data sources available that have examined this issue?

3. Atmosfair states that because of code sharing and re-fleeting of aircraft, a traveler cannot be sure what aircraft they will travel until they are actually on board.

TRX Responded:

[...] airlines have a very strong preference for using the same equipment type for any irregular Operations for three reasons:

- 1) the flight crew assigned to the original equipment may not be certified to operate a different type of aircraft,*
- 2) the flight schedules are optimized for many factors, including fuel usage. Changing the equipment type will likely sub-optimize the operating costs of the flight, and*
- 3) by using the same type of aircraft the airline avoids having to re-assign all the passengers to a new seating configuration. Therefore, we confidently assert that the scheduled aircraft type very closely matches the actual type of aircraft used.*

Author's Questions:

How often are aircraft switched out at short notice?

Are there differences between the US, Europe and Asia for this? Is there any data available for this?

Calculator Profiles for Aircraft Type

Atmosfair

Atmosfair's aircraft database is based on the German Aerospace Center (DLR) emissions calculations for the most common jet aircraft types as a function of altitude and distance⁷. According to Atmosfair's documentation, this database contains fuel consumption figures for 43 aircraft models and covers an estimated 95% of the total worldwide air traffic (Atmosfair, 2007). When the aircraft type is unknown, the offset customer has the option to enter "aircraft type unknown." The emissions calculator then assumes a virtual "hybrid aircraft," based on the frequency with which a certain aircraft type is flown a given distance in the flight region requested by the customer. The calculation of the "hybrid aircraft" is based on a database from 2004 that includes more than 500,000 flight control records.

Atmosfair applies a factor of 3.16 kg CO₂/kg fuel based on IPCC, 1999.

TRX Travel Analytics

TRX Travel Analytics' calculator requires the user to enter the city of departure and the destination city. It then identifies all the different carriers and their flight schedules on that route. This enables the user to identify the exact flight they have traveled. Also, the calculator can be consulted before the air travel is purchased to allow the traveler to select the flight with the lowest emissions.

For determining scheduled passenger flights, TRX Travel Analytics uses information obtained from the Airline Schedule database from OAG Back Aviation Solutions⁸. According to OAG Back Aviation

⁷ Furthermore, atmosfair commissioned a study by QuinetiQ, a UK-based institute that carries out fuel calculation and simulation for research projects and the aviation industry (Brockhagen, personal communication).

⁸ OAG© - Official Airline Guides' BACK Airline Schedules and Capacity database contains information on every scheduled passenger and cargo carrier in the world filing with OAG. Its Airline Schedules database includes weekly updates on all schedule changes, additions and cancellations made by the carriers. Data access to OAG has to be purchased (<http://www.backaviation.com>).

Solutions, this database covers 100% of all carriers that distribute their schedules worldwide except for a few of the newer international low-cost carriers who do not distribute their schedules to anyone. The data is updated monthly. Fuel burn rate information is obtained from the latest version of the EMEP/CORINAIR Emission Inventory Guidebook (EIG)⁹ which provides fuel burn rates for 44 aircraft. Using an EIG equivalence chart of ICAO¹⁰ and IATA¹¹ data, the fuel burn rates for the 44 aircraft can be applied to an additional 136 aircraft, for a total of 180 aircraft for which TRX Travel Analytics has specific fuel burn rate data.

For those aircraft not covered in this data set, the TRX Travel Analytics calculator makes the closest match based on equipment class (wide-body jet, narrow-body jet, regional jet, turboprop), manufacturer, and number of seats.

TRX Travel Analytics applies a factor of 3.15 kg of CO₂/kg of fuel based on EMEP/CORINAIR.

Virgin Atlantic

Virgin does not apply specific aircraft types to its calculations- see the section below on how Virgin calculates fuel use.

Virgin Atlantic applies a factor of 3.16 kg of CO₂/kg of fuel.

2.2 Flight Profile and Flight Distance

The civil aircraft fleet average for speed and cruise altitude is 575 miles/hour and 8 miles, respectively (IPCC, 1999). Just as a car experiences different fuel efficiencies at different speeds and under different conditions, aircraft experience different burn rates in various flight profiles: taxi, takeoff, climb, cruise, landing approach, and landing. The rate of fuel burned is proportional to the drag, the force that resists motion and which therefore has to be balanced by the thrust of the engine. The take off phase requires full engine thrust, and thus the most fuel. As the aircraft ascends to higher altitudes, the drag decreases and so does the rate of fuel use. Offset calculators have to take into account the variety of flight profiles encountered throughout a given flight.

Flight distance is an essential factor as well as aircraft fuel consumption depends on distance flown. Generally speaking, the farther the route, the more fuel burned. However, since takeoff and landing demand higher fuel burn rates than level flight, shorter routes where takeoff and landing comprise a larger portion of the overall flight tend to be less efficient (i.e. require more fuel per mile). Takeoff and landing are smaller portions of the overall flight for medium range routes, so they are generally more efficient. In addition, over very long distances the fuel use per mile increases because of the greater amount of fuel that has to be carried during the early stages of flight.

Offset calculators use different methods for calculating total flight distance. Some use only the great circle distance (the shortest distance between two points on the globe) between two airports. Some account for routing and delays. Since an aircraft's route is normally not an exact great circle due to flight path routing,

⁹ The Cooperative Programme for Monitoring and Evaluation of the Long Range Transmission of Air Pollutants in Europe/Core Inventory of Air (EMEP/CORINAIR) EIG is published by the European Environment Agency (EEA) and may be found at <http://reports.eea.europa.eu/EMEP-CORINAIR4/en/page002.html>. Data access is free.

¹⁰ The International Civil Aviation Organization (ICAO) is the international version of the FAA (the Federal Aviation Administration). It is responsible for the safety and air traffic management of civil aviation.

¹¹ The International Air Transport Association (IATA) is the international airline industry trade group.

detours around weather and delays due to traffic, some calculators add an extra amount to the overall distance.

Two studies calculated the excess distances of flights as the difference between the actual flight path length and the direct route length (great circle distance). Their results indicate that intra-European flights fly around 10 percent excess distance compared to direct routes. In the US, the inefficiency was found to be around 6- 8 percent. The studies further determined that about 70 percent of the total excess distance flown takes place within terminal airspace (Kettunen et al, 2005).

Yet these studies do not address regional differences. Some airports are heavily congested and experience regular delays, such as those in New England corridor (Boston to DC), the Chicago/Great Lakes area, or the Southern California corridor. Also, these delays can vary significantly depending on the time of day, the season and the weather. Congestion is a serious problem that airports and the communities they serve typically seek to address for social, environmental, and economic reasons. This congestion also leads to increased GHG emissions. Yet calculators cannot realistically incorporate these differences or use real time data. Rather, entities that would prepare a greenhouse gas inventory for a specific airport or aviation in general would capture these conditions. It therefore makes sense for carbon offset calculators to use an average multiplier to account for routing and delays.

The most accurate air travel calculators use specific information about total fuel consumption and flight distance. This calculation can be performed in a few different ways.

Calculator Profiles for Flight Profiles and Flight Distance

Atmosfair

Atmosfair's emissions calculator accounts for both flight profile and flight distance. The emissions calculator first calculates the flight distance as the great circle route. Detour estimates are based on German data showing an average of 31 extra miles flown per flight. Atmosfair therefore adds 31 miles to the great circle distance to determine total flight distance. It then calculates fuel consumption as a function of distance based on fuel consumed during three simplified altitude profiles: climb, cruise, and descent:

The Emissions Calculator has stored these standardized altitude profiles and the associated fuel consumptions during the three flight phases for the commonest aircraft types (DLR 2002, QinetiQ 2005). These profiles and the associated fuel consumptions are available for each aircraft for standard distances of 250, 500, 750, 1,000, 2,000, 4,000, 7,000 and 10,000 kilometers (provided the aircraft has this range (Atmosfair, 2007).

In addition, Atmosfair adds 2.2 lbs of extra fuel per passenger for holding delays and detours based on the Lufthansa Environmental Report 2002, and accounts for taxiing based on the average taxi time of 15 minutes by adding 5.5 lbs of extra fuel per passenger (Atmosfair, 2007).

TRX Travel Analytics

TRX Travel Analytics obtains fuel burn rate information from the most current version of the EMEP/CORINAIR Emission Inventory Guidebook (EIG). This dataset provides fuel consumption data for different aircraft from a range of total journey lengths for each of the different fuel-consumption stages: Taxi-out, Takeoff, Climb-out, Climb/Cruise/Descent, Approach/Landing, and Taxi-in. It therefore calculates the anticipated full fuel burn rate over the entire trip. The EIG's fuel burn rates are given for a range of distance buckets (in nautical miles) and TRX Travel Analytics interpolates from there:

Fuel burn rates are given for some or all of the following distance buckets (in nm): 125, 250, 500, 750, 1,000 ...and every 500 miles up to 6,500 for long-range aircraft.

The fuel burn rate, in kg per nm, for a particular flight is interpolated using the distance buckets above and below the city pair mileage. For example, the amount of fuel burned on a flight on a Boeing 777 between ORD-LHR, a distance of 3,423 nm, would be determined by interpolating the fuel burn rates of the 3,000 and 3,500 nm distance buckets for a Boeing 777.

(Gillespie, 2007)

TRX Travel Analytics accounts for holding patterns and detours due to weather and congestion using the numbers from Kettunen et al.(2005) and applies a multiplier of 1.07 for US domestic flights and 1.10 for intra- European flights. For all other domestic and short haul city pairs, they apply the midpoint multiplier of 1.085. For long haul flights, TRX Travel Analytics decreases the multiplier from 1.07 to 1.01, dropping 0.01 for every 1,000 miles. In this manner, some correction is made for excess distance. TRX Travel Analytics states that these correction factors will be adjusted as more precise data become available (Tomosky, personal communication).

Virgin Atlantic

Virgin Atlantic is in a unique position for developing an emissions calculator since it can directly apply its own information from actual flight data. Instead of calculating total fuel burned based on average fuel burn rates and estimated distances flown, Virgin uses actual fuel use data taken from its 2006 fuel uplift figures, i.e. the amount of fuel actually put into its planes for each individual flight. This data is then averaged for the particular route over one year. The total fuel amount on a flight is multiplied by the IATA standard multiple of 3.16 to provide the total CO2 emissions for that particular flight. Virgin explains that it uses its fuel uplift figures

because they offer the most accurate record of fuel use for the flight, as we are able to take it from the fuel pump figures when the planes are filled up, which our pilots sign off and then we receive the invoices for. This is more accurate than taking the records from what is left in the tanks, as different reading may result from different factors such as the warmth of the engine or any uneven surface underneath the plane. We then compare it with fuel burn data recorded by our pilots during the flights to ensure against any discrepancies. (Virgin Atlantic Airlines, n.d.)

The authors were not able to get more detailed information on how Virgin Atlantic calculates actual fuel used from their fuel uplift figures, e.g. how it accounts for rest fuel, over what time frame the fuel use data is averaged, and which flights were used in the sample.

This approach does not account for a specific aircraft, rather it takes the average fuel burned across all aircraft flown on a given route, and reflects actual flight distances and delays that were experienced.

2.3 Cargo on Passenger Flights

Once total emissions for a flight are known, emissions per passenger can be calculated. It is important to note that calculators differ in how they take into account the factors discussed in the following sections: cargo versus passenger load, seat occupancy rate, and seat class.

The majority of a flight's total weight is the aircraft itself and the fuel it carries. Flight crew, crew luggage, steward's supplies, etc. are all considered part of aircraft weight. 'Payload' is defined as the weight of the people and items that are being transported, including passengers, their luggage, and cargo. An industry-wide standard of 220 lbs is assumed for each passenger and their luggage¹².

Table 2: Two Examples of Aircraft, Fuel and Payload Weight

Airplane type:	A 300-600 (in metric tons)	Percentage of max. takeoff weight	A320 (in metric tons)	Percentage of max. takeoff weight
Maximum takeoff weight	171.7	100%	73.5	100%
Maximum zero fuel weight	130	75.7%	61	83%
Maximum fuel capacity	55	32.2%	19	26.3%
Typical operating weight empty	90.9	52.9%	42.4	57.7%
Maximum payload	34.9	20.3%	16.6	22.6%
Estimated total maximum passenger weight in single class configuration	298 passengers * 100kg = 29.8	17.4%	164 passengers * 100kg = 16.4	22.3%

(Source: [Airbus](#))

Passenger airplanes usually also carry additional cargo. Cargo consists of freight and mail. Thus, cargo should be allocated some of the GHG emissions associated with the flight. There are several ways that this cargo can be accounted for in an air travel emissions calculator. Two such approaches are described below:

1. The responsibility for the airplane travel lies with the passengers. This approach assumes that the airplane flies because of the passengers and not because of the freight. The calculator therefore only subtracts the emissions associated with marginal increase in fuel consumption caused by the weight of the cargo: The increase in fuel burn due to the extra cargo is divided by the number of passengers and subtracted from each traveler's carbon footprint. Note that this increase in fuel burn is low because most of the weight of the airplane is its airframe and the fuel it transports.

2. The responsibility for the air travel lies proportionally with the passengers and with the cargo. The total emissions are assigned to cargo and to passengers based on their percentage of total cargo weight. For example, if 80% of the payload weight is passengers and luggage and 20% is cargo, then 20% of total flight emissions are subtracted from the passengers' carbon footprint.

¹² According to industry experts, this estimate might be lower than the actual average weight of a passenger and his/her luggage (Tomosky, personal communication).

Both of these approaches are valid, although the authors argue that if the cargo cannot be shipped with a particular passenger flight, it would be shipped in another passenger flight or in a cargo flight. Also, revenues from cargo are a significant source of income for most large passenger carriers. Because of this, the authors find the second approach more appropriate.

Point of Discussion 2: How are cargo, fuel weight and number of passengers correlated?

Atmosfair (see appendix 1 for detailed comments) pointed out that over long distance flights the weight of the required fuel limits the additional cargo that can be taken on board since the plane cannot exceed maximum takeoff weight:

On long distance flights, more fuel has to be taken on board, limiting or eliminating capacity for additional cargo. E.g. in the example of the A300-600 (section 2.3), if used on maximum distance, payload must be reduced by about one third. This means, that the maximum payload is about 25 metric tons, just allowing for a maximum of about 250 passengers and thus no additional cargo at all.

Author's questions:

How does additional fuel weight on very long distance flights (or because of tankering) impact cargo? In other words, how large are the differences in amount of cargo that airlines report for each airplane type (i.e. what is the variance)?

Calculator Profiles for Cargo versus Passengers

Atmosfair

Atmosfair's calculator uses the first approach and assumes an average cargo load of 8% of total payload on all flights. This number was calculated from data from the 2003 report of the *Arbeitsgemeinschaft deutscher Verkehrsflughäfen* (ADV)¹³. Atmosfair also uses the industry standard of 220 lbs per passenger, including their luggage. Atmosfair estimates the resulting increase in fuel burn due to cargo to be 2%. The calculator then subtracts 2% of total emissions to account for increased fuel burn due to cargo (Atmosfair Emissions Calculator, 2007).

TRX Travel Analytics

The TRX Travel Analytics calculator applies the second approach with the following data and assumptions. Cargo and passenger data are gathered for US carriers from the US Dept. of Transportation, Bureau of Transportation Statistics¹⁴. Both domestic and international flights are included. To avoid seasonality issues, data from the most recent calendar year is used and is updated annually.

TRX Travel Analytics applies the industry-wide standard of an average weight per passenger and their luggage of 220 lbs. Cargo estimates are based on aircraft type: TRX Travel Analytics allocates emissions between cargo and passengers for narrow-body and wide-body jets only. The amount of cargo weight relative to passenger weight is assumed to be negligible for regional jets and turboprops, because they are so small that there is not enough space for much additional cargo. Because of space constraints in Low Cost Carriers, these are also not allocated any cargo weight. If specific data is available for a flight, then the cargo proportion is calculated using that data. Otherwise, the following averages are used:

- Narrow-body jets: 1.7% cargo, 98.3% passengers
 - Wide-body-jets: 19.9% cargo, 80.1% passengers
- (Gillespie, 2007)

¹³ Cooperation of German Airports, ADV; see http://www.adv-net.org/de/gfx/daten_nat.php

¹⁴ <http://www.transtats.bts.gov>, BTS, Air Carrier Statistics: Form 41 Traffic (All Carriers), T-100 Segment (All Carriers)

Virgin Atlantic

Virgin Atlantic uses the second approach. According to Virgin Atlantic, precise figures of actual flown cargo gross weight are used. The authors were unable to obtain more specific information on how Virgin Atlantic calculates and accounts for cargo.

2.4 Seat Occupancy Rate (Load Factor)

Not all flights take off fully occupied. Seat occupancy rate (also called *passenger load factor*) is the ratio of passengers to available seats on board a given flight.

The overall weight of a passenger aircraft is determined primarily by the airframe and amount of fuel carried. Therefore the number of passengers on board has a smaller impact on total fuel consumption (see Table 3 for examples of aircraft weights). Aircraft use less fuel per passenger the more passengers there are on board. The Royal Commission on Environmental Protection uses the following example to illustrate this: with an occupancy rate of 51%, the fuel burned per passenger-km is 0.176 lb. In comparison, a load factor of 100% corresponds to fuel burned per passenger-km of only 0.112 lb (RCEP, 2003).

Occupancy rates have fluctuated significantly over the last two decades. In the 1990s, the average load factor was around 65%¹⁵. Based on the Bureau of Transportation Statistics web site, the average load factor was 77.2% in 2005, increased to 79.2% in 2006 and further rose to 80.3% by Nov 2007¹⁶. These fluctuating occupancy rates show the need for regularly updated figures to increase the accuracy of air travel carbon emissions calculators.

The most accurate air travel calculators take occupancy rates into account. Ideally occupancy data would be available by route and not just by air carrier. Such data is to our knowledge not available to date.

Calculator Profiles for Occupancy Rates

Atmosfair

Atmosfair applies seat occupancy rates for scheduled flights based on German aircraft data from 2002 according to flight region: Germany 60%, EU 62%, and intercontinental traffic 75%. As these rates are lower than the average US load factor rates, this calculator would likely slightly overstate US-based flight emissions (Atmosfair, 2007).

Atmosfair makes a further distinction between scheduled and charter flights. Based on a study from 2004, Atmosfair states that chartered flights normally have higher occupancy rates than scheduled flights due to the longer booking period of charter flights. Atmosfair emissions calculator therefore applies a common average of 80% occupancy for chartered flights. If the flight type is not known, an average of 75% is applied (Atmosfair, 2007).

TRX Travel Analytics

TRX Travel Analytics currently uses the 2006 annual data from ICAO, which contains load factor data from 274 passenger-carrying airlines: 33 from the US, and 241 non-US. The values are updated annually and data from the calendar year is used to avoid seasonality issues. For carriers not among the 274 carriers,

¹⁵ www.pata.org/patasite/fileadmin/docs/general/MORRISPeterApr15PAC03.ppt

¹⁶ http://www.bts.gov/press_releases/2008/bts008_08/html/bts008_08.html

TRX Travel Analytics uses either a US average (75.93%) or a non-US average (67.35%), depending on the country of the airline¹⁷.

To evaluate the percentage of flights for which they have specific occupancy data available, TRX Travel Analytics analyzed all flights from December 2007 (a total of 178,804 flights) with the following result:

- For 70.8% of all flights they had specific occupancy rate data available
- For 3.1% of all flights they used the US average value of 75.93%.
- For 26.1% of all flights they used the non-US average value of 67.35%.

Virgin Atlantic

Virgin's calculator does not account for occupancy rates. No further information was available.

2.5 Seat Class

Seat class is another key factor in determining the emissions an individual is accountable for on a given flight. Seating area is limited in an aircraft. A plane that is configured with all economy-class seats accommodates the highest number of passengers. First- and business-class seats take up more space and fit fewer passengers. Weight is another consideration: the seats and entertainment systems for business- and first-class are larger and heavier than for economy seats. On the other hand, anecdotal evidence indicates that families traveling in economy often have more luggage. It might be possible to generalize that vacation and pleasure travelers tend to travel economy class and with more luggage, whereas upper-class seats are usually occupied by business travelers who aim to minimize their luggage.

Some calculators consider weight to be the primary determinant with regards to seat class. However, since an aircraft's weight is determined largely by the airframe and fuel on board, the weight of passengers on board has a small impact on the marginal increase in fuel consumption. What is true for occupancy rates applies to seat class also: more passengers means lower per person emissions. Since higher class passengers de-facto replace more economy passengers, emissions should be allocated by space (i.e. each upper-class passenger is allocated the emissions of the number of economy passengers that could have been seated in the same space).

To illustrate this with an example: A Boeing 767-300ER accommodates 350 passengers if it is configured as an all economy-class flight. The same airplane only accommodates 269/218 passengers in a two/three-class configuration¹⁸. In other words, in a three-class setup there are 132 fewer passengers (38% less) and the emissions therefore have to be divided among fewer people. To do so fairly, business and first class passengers should be allocated the emissions in proportion to the space they occupy relative to economy passengers they displace. In the table below, for example, an international first class passenger takes up an average of 3.13 economy seats and is therefore responsible for 3.13 times the emissions of an economy traveler. The most accurate air travel emissions calculators take seat class into account.

¹⁷ The discrepancy between the occupancy rates quoted by the US Bureau of Transportation Statistics (BTS, quoted above) and the numbers used by TRX Travel Analytics can be explained as follows: TRX Travel Analytics uses data from ICAO, which includes non-US carriers. BTS only has data for non-US carriers when the origin or destination of the flight is in the US. This leads to biased data since these are long-haul flights only. For US carriers only, BTS data and ICAO data are in general agreement.

¹⁸ Information taken from www.boeing.com/commercial

Table 3: Average Seat Room Based on Seat Class*

Seat Class	Average Seat Pitch (inches)	Average Seat Width (inches)	Smallest Seat Area (square inches)	Largest Seat Area (square inches)	Average Area (square inches)	Average Area as Percentage of Economy Class
U.S. Domestic Economy	31.8	17.4	520	648	554	100%
International Economy	32.2	17.3	512	630	555	100%
Premium Economy	38.5	18.9	677	1029	729	131%
U.S. Domestic First/ Business Class	40.0	20.4	663	1462	816	147%
International or Long-Haul Business Class**	57.6	20.4	684	2054	1163	210%
International First Class	77.9	22.3	1160	2485	1735	313%

* calculations based on information from <http://www.seatguru.com/>

** does not include suites (mini-cabins that include flat bed, work station, and TV)

Comments by atmosfair and TRX Travel Analytics:

Both atmosfair and TRX Travel Analytics comment on seat configuration. Please see their appendices for more details.

Calculator Profiles for Seat Class

Atmosfair

Atmosfair's calculator offers three seat options: economy, business, and first class. Atmosfair's emissions calculator assumes an average number of seats for a particular aircraft (calculated with data from the main German airlines in 2002). For airlines that are not representative of flights with German airlines, but also operate to and from Germany, an average is used based on manufacturers' standard seating configurations according to *Jane's 1990-2003: All the World's Aircraft* and *JP Airline-Fleets International 2007* (Atmosfair, 2007). The seat pitch and widths of equipment from various carriers is calculated from data available online at www.SeatGuru.com. Atmosfair then applies the following multipliers:

- Economy Class = 0.8
- Business Class = 1.5
- First Class = 2

If a customer does not indicate seat class, a factor of 1 is used, representing the average space requirements of a passenger in a generic three class flight (Atmosfair, 2007).

TRX Travel Analytics

TRX Travel Analytics uses the OAG Schedules database to determine the number of seats on a flight, and the OAG Fleet database to determine the distribution of seats among the various cabins (OAG Back Aviation Solutions, 2007). The seat pitch and widths of equipment from various carriers is calculated from data available online at www.SeatGuru.com. TRX Travel Analytics breaks seat class down into four types. If there are multiple seating configurations for an aircraft, TRX Travel Analytics uses an average - weighted by the number of aircraft - of the different configurations. When no specific data for a flight is available, average values based on the class of equipment are used.

Where equipment class is unknown, overall averages for cabins of narrow-bodied jets are used:

- Economy Class = 1.00
- Premium Economy Class = 1.13
- Business Class = 2.04
- First Class = 2.69

Virgin Atlantic

Virgin bases its calculations on weight rather than seat space, arguing that seat classes other than economy include a higher baggage limit¹⁹ and involve larger seats that weigh more and include more sophisticated (and therefore heavier) entertainment systems. Virgin uses the number of seats in each seat class for a given route and multiplies it by seat weight, then adds that total to the 100kg (220 lbs) standard amount for each passenger's weight plus luggage. The authors were unable to obtain details on how Virgin Atlantic calculates seat class emissions or to find out why Virgin Atlantic chose to distinguish seat class by weight.

3. Calculator Comparison & Conclusions

This last chapter examines and compares the three calculators. Table 4 summarizes the different parameters that each calculator is based on. Table 5 summarizes the input and output parameters of each calculator. The input parameters refer to the variables that a user can enter into an emissions calculator. The output parameters refer to the information that is conveyed to the user once the emissions have been calculated.

Three travel routes are then used to compare emissions calculation results for the three calculators and the UK's Department for Environment, Food and Rural Affairs (DEFRA) multiplier for air travel emissions calculations. The DEFRA multiplier was included in the comparison because it is widely used by government agencies and private entities to calculate air travel emissions. DEFRA recommends the following multipliers for calculating emissions from air travel:

- 0.11 kg of CO₂ per person kilometer for long haul flights. This factor refers to a 5,000 km / 3,106 mile journey on a typical 450 seat capacity aircraft with a 70% occupancy rate.
- 0.15 kg of CO₂ per person kilometer for short haul flights. This factor refers to a 500 km / 310 mile journey on a typical 128 seat capacity aircraft with a 65% occupancy rate.

(DEFRA, 2005)

The last section includes the authors' comments and opinions of each of the evaluated calculators and concludes with final remarks about the issues and the quality of air travel emissions calculators in general.

¹⁹ As mentioned above, despite the higher baggage limit in upper class, it is unclear if upper-class passengers bring more luggage on board. Anecdotal evidence would suggest the opposite.

3.1 Input and Output Parameters of Offset Calculators

Table 4: Emissions Calculator Parameters

	atmosfair	TRX Travel Analytics	Virgin Atlantic	DEFRA
Non-CO₂ multiplier (RFI)²⁰	Yes: 1-3 for long haul ²¹ ; no multiplier for distances less than 500 km	Optional: 1 or 2.7	No	No
Aircraft model	Optional: Fuel burn rate data for 47 aircraft available.	Yes: Fuel burn rate data for 180 aircraft available. Data updated yearly.	Use of fuel consumption data of Virgin Atlantic fleet; unclear what data is used for non-Virgin Atlantic flights.	No
Routing and delays	Yes: adds 1kg of extra fuel per passenger for holding delays and 2.5 kg for taxiing, in addition adds 50 km to each trip for rerouting.	Yes: multiplier of 1.07 for US domestic flights; 1.10 for intra- European flights; Other short haul flights: 1.085. Long haul flights: decreases multiplier by 0.01 for every 1,000 miles, from 1.07 to 1.01	Not applicable since calculations are based on actual fuel use data.	No
	atmosfair	TRX Travel Analytics	Virgin Atlantic	DEFRA
Cargo	Yes: 2% marginal fuel increase due to cargo subtracted	Yes: emissions assigned weight, flight specific data when available. Otherwise averages of narrow-body jets: 1.7% cargo; wide-body jets: 19.9% cargo.	Yes: emissions assigned weigh, exact calculations unknown	No
Seat Class	Optional: 3 classes calculated by space. Multipliers of: Economy = 0.8 Business = 1.5 First = 2.0 If no class is specified, multiplier =1	Yes: up to 4 classes calculated by space, flight specific data when available. Otherwise multipliers of: Economy = 1.00 Premium Econ Class = 1.13 Business = 2.04 First = 2.69	Yes: calculated by weight, 4 classes, exact calculations unknown	No
Occupancy Rate	Yes: averages used: Germany 60%, EU 62%, intercontinental traffic 75%, charter flights 80%	Yes: Airline specific data when available, otherwise averages used: US 75.93%, non-US 67.35%	No	Yes: Averages of 70% for long haul; 65% for short haul

²⁰ Radiative Forcing Index (RFI) is usually referred to as the multiplier that includes non-CO₂ warming effects. See second paper in this series (forthcoming, summer 2008). Strictly speaking, the RFI multiplier does not deliver CO₂ equivalent emissions, since it does not have Global Warming Potential. Atmosfair, for example, labels the emissions as “CO₂ emissions that would have a similar warming effect as the total aircraft emissions” (Brockhagen, e-mail April 6, 2008)

²¹ Atmosfair applies a multiplier of 3 for emissions above 9000 m altitude and a multiplier of 1 for all emissions below 9000m altitude. The factor is adjusted according to the actual altitude. Hence, the “average RFI” for a flight depends on the aircraft type and the flown distance, and varies from 1 -3 (Brockhagen, personal communication).

Table 5: Emissions Calculator Input and Output Parameters

	atmosfair	TRX Travel Analytics	Virgin Atlantic	DEFRA
Inputs into calculator	<ul style="list-style-type: none"> • City pair • Seat class (optional) • Aircraft type (optional) • Scheduled or charter flight (optional) • Stop over (optional) • Round trip or one way • Number of trips • Number of travelers 	<ul style="list-style-type: none"> • City pair (for existing destinations; each stopover has to be calculated separately) • Airline (optional) • Multiplier for non-CO₂ impacts (2.7 or 1) • Round trip or one way • Price per ton of offset 	<ul style="list-style-type: none"> • City pair • Seat class • Round trip or one way • Number of travelers 	<ul style="list-style-type: none"> • Distance
Calculator Outputs	<ul style="list-style-type: none"> • Distance • Seat class, if specified • CO₂e (including multiplier) • Comparisons of emissions with other activities such as driving for a year, yearly emissions of average Indian. • Cost to offset through Atmosfair 	<ul style="list-style-type: none"> • Distance • All seat classes • CO₂e emissions (multiplier optional) • Flight schedule • Carrier airline • Operator airline • Equipment Code (aircraft type) • Cost to offset (based on chosen price) 	<ul style="list-style-type: none"> • Distance • Seat class • CO₂ • Cost to offset through myclimate 	<ul style="list-style-type: none"> • CO₂

3.2 Air Travel Examples²²

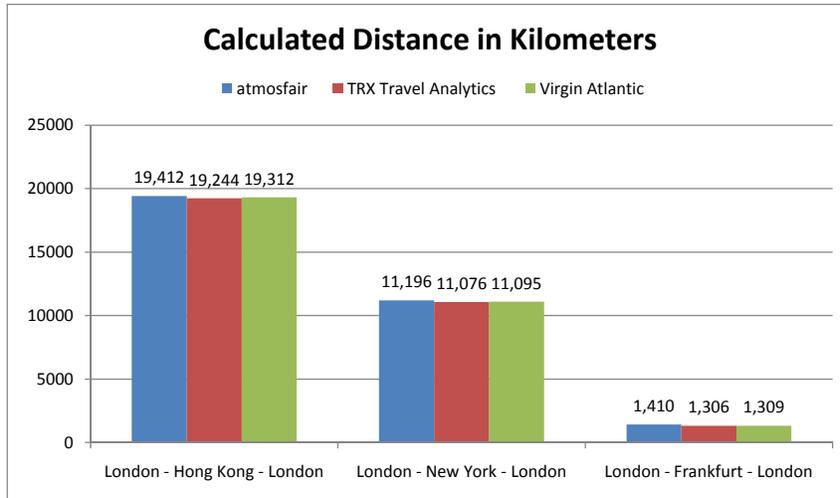
The following analysis focuses on CO₂ emissions calculations only. In other words, non-CO₂ effects (often referred to as *Radiative Forcing Index* (RFI) or *multiplier*), which are discussed in the second paper of this series, are not included. The discussion about the use of a multiplier is important. Our choice to remove it from this analysis does not imply that non-CO₂ warming effects from air travel should be ignored. Rather, it was removed to enable a comparison of how the parameters examined in this paper influence the results. Of the calculators discussed here, only the Atmosfair calculator automatically includes a multiplier. This multiplier has been removed from the examples below²³. TRX Travel Analytics offers an optional multiplier of 2.7, whereas Virgin Atlantic and DEFRA do not include a multiplier.

²² All examples were calculated on 2/21/2008, except for Atmosfair (see footnote 23).

²³ Atmosfair applies the multiplier to the emissions above 9 km altitude. Depending on the aircraft type, this multiplier is hence only applied to about 50% of the emissions for a flight of 500 km, and to about 90% for a flight of 10.000 km. For this reason, Atmosfair provided us with the numbers for the three examples used in these graphs (Brockhagen, personal communication).

Graph 1: Calculated Distance

Graph 1 shows that the calculated distances of three trips are very similar for all three calculators.

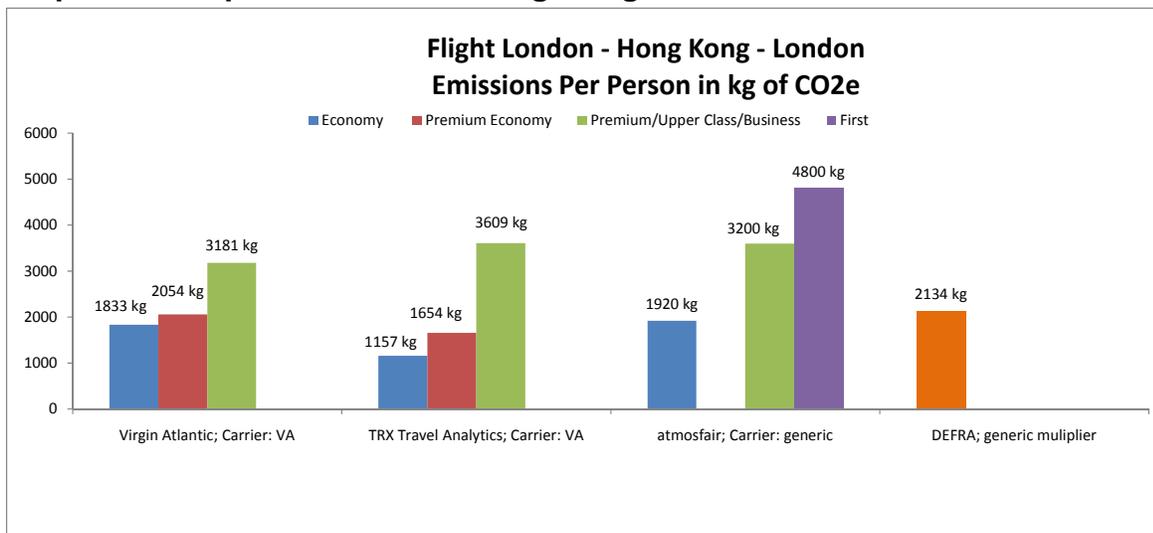


Flight Example 1: London – Hong Kong – London

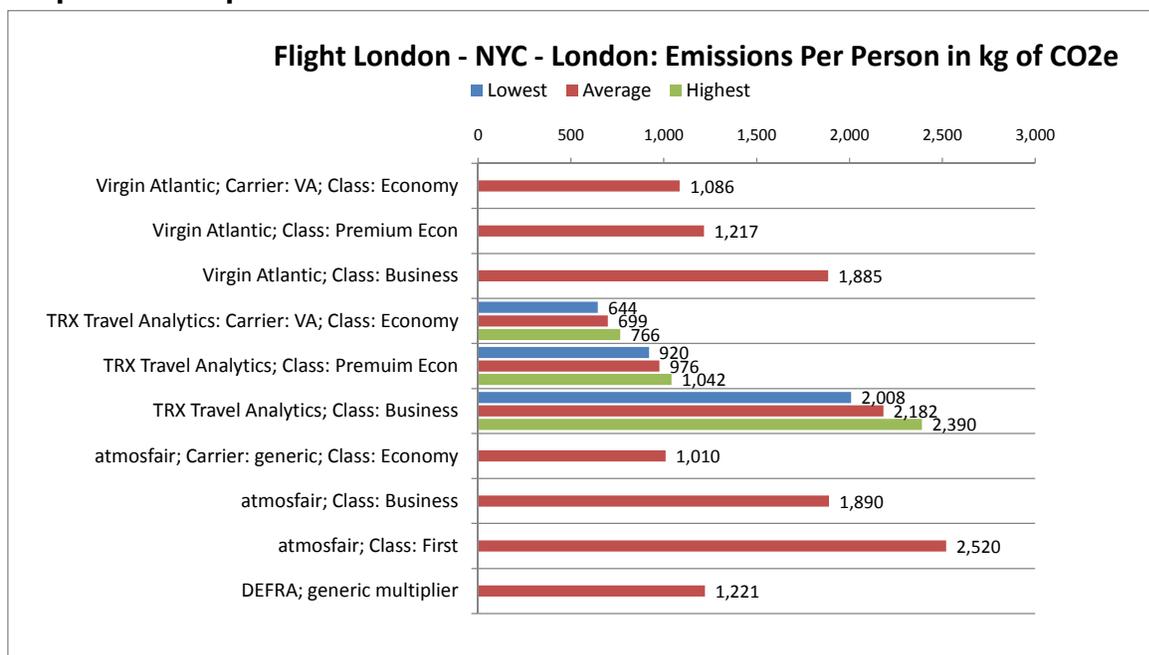
Flight Example 2: London – NYC – London

For the first two examples, it was assumed that the Virgin Atlantic calculations for this trip are based on Virgin Atlantic's fuel consumption data. To allow for comparisons, Virgin Atlantic flights were also used for the TRX Travel Analytics calculations. For Atmosfair, a generic carrier was chosen because Atmosfair does not allow for a particular airline carrier to be selected, and the type of aircraft for these Virgin Atlantic flights was unknown. DEFRA does not distinguish between seat classes.

Graph 2: Example 1: London – Hong Kong - London



Graph 3: Example 2: London – New York – London



Graph 3 shows emission averages from each the calculators in red. Virgin Atlantic uses two aircraft models on that route that have different emissions associated with them (see section on Aircraft Model). In its calculator, Virgin averages the emissions of these two aircraft models. TRX Travel Analytics, on the other hand, calculates the emissions for each of the two aircraft models. The blue bar shows the emissions of the more efficient model. The green bar shows the emissions of the less efficient model.

Discussion

The results vary considerably from calculator to calculator:

- In the first example, the results for an economy seat vary by a factor of 1.7; TRX Travel Analytics calculates 1157 kg, whereas Atmosfair calculates 1920 kg.
- In the second example, the results for an economy seat also vary by a factor of 1.7; TRX Travel Analytics calculates 644 kg, whereas Virgin Atlantic calculates 1086 kg.

Seat class calculated by space requirement has a disproportionate impact on emissions:

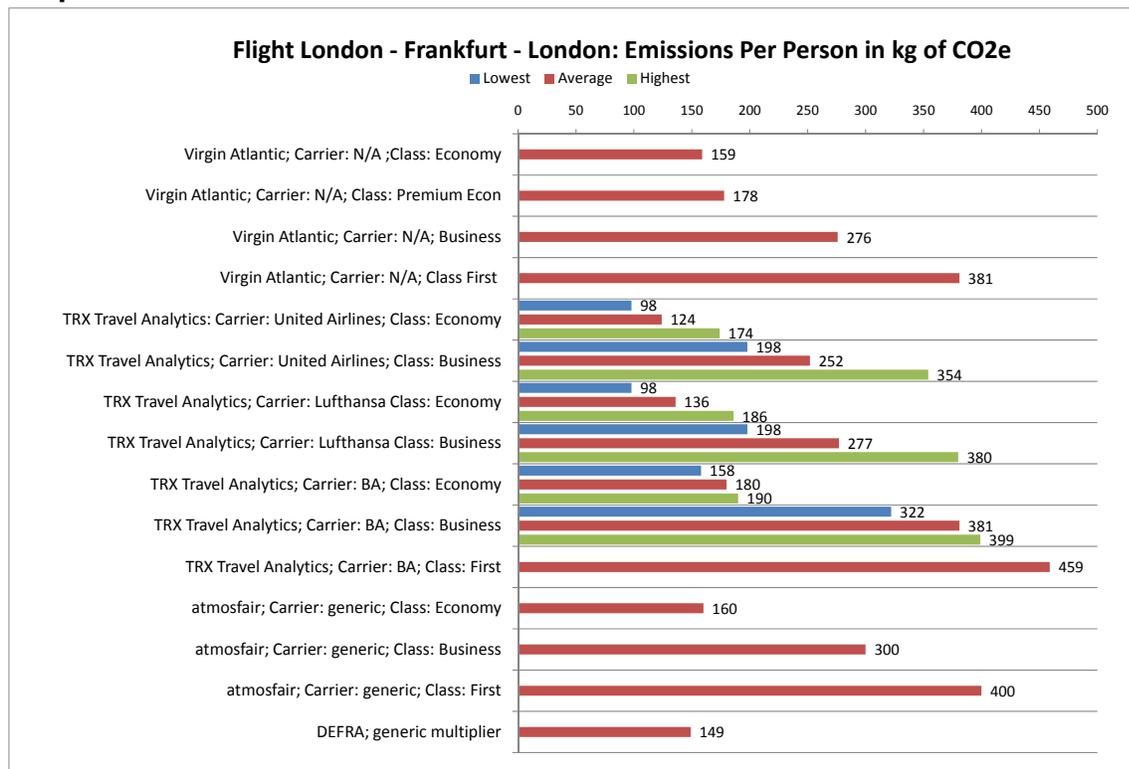
- In both examples TRX Travel Analytics has the largest spread between seat classes (over 300%). The highest emissions (3609 kg/2390 kg TRX Travel Analytics, business class) are over three times as high as the lowest emissions (1157kg/644 kg TRX Travel Analytics, economy class).
- Virgin Atlantic’s results for a business class traveler are only 1.7 times larger than for an economy traveler. This can probably be explained by the fact that Virgin Atlantic bases its seat class distinctions on weight. The difference between economy and upper classes in both examples is therefore less pronounced than if the emissions were assigned by space requirement.

Both atmosfair and TRX Travel Analytics have commented on this example, please see Appendix 2 for their discussion.

Example 3: London – Frankfurt – London

In this example, the TRX Travel Analytics calculator was used to compare emissions from the three different carriers that service this route (British Airlines, Lufthansa, and United Airlines). Because these carriers use different aircraft models and engine types, the emissions of the flights vary. The blue bars show the emissions of the most efficient aircraft model for each carrier, while the green bars show the emissions of the least efficient aircraft model for each carrier. The other calculators were also used: the red bars show averages.

Graph 4: London – Frankfurt – London



Discussion:

The results show significant differences between the aircrafts. According to the TRX Travel Analytics calculator, the emissions for the least efficient economy seat (190 kg, BA) are 194% higher than the most efficient economy seat (98 kg, UA). The emissions for the least efficient business seat (399 kg, BA) are 202% higher than the most efficient business seat (198 kg, UA).

3.2 Comments on the Evaluated Calculators

Atmosfair

Atmosfair developed one of the first air travel emissions calculators for offsets and provides in-depth background information. It also includes valuable information about other activities and their associated GHG emissions, which helps consumers put their air travel emissions in perspective. Although the authors approve of the transparency and level of detail included in the calculator, they conclude that the Atmosfair calculator could be improved in several ways:

- Atmosfair accounts for non-passenger cargo by subtracting the marginal increase in fuel use. It would be more correct to assume that cargo would be transported by air anyway and therefore emissions should be allocated proportionally to the weight of cargo and passengers with luggage.
- Atmosfair reports that it has updated its calculator twice since 2005. But many of Atmosfair's data sources seem to be a few years old and do not seem to be updated regularly. It is unclear how much this affects the accuracy of the calculations, but it certainly would be better if data sources were updated more frequently.

TRX Travel Analytics

TRX Travel Analytics developed its calculator in 2006. The website provides in-depth information about the data sources and metrics used for the calculator. For this and the following reasons, the authors rated the quality of the TRX Travel Analytics calculator as high. It is the best of the three evaluated calculators and is likely the best currently available air travel CO₂ emissions calculator:

- The calculator is based on extensive data sets and accounts for the largest number of parameters.
- Data sets are updated regularly.
- Because the calculator distinguishes between different carriers, it enables travelers to choose the most efficient carrier ahead of time.

Both atmosfair and TRX travel analytics have commented extensively on this paper. Most relevant to the author is the discussion elaborated on p. 7:

**Point of Discussion 1:
Does increased specificity lead to increased accuracy?**

For details, please see, p. 7 and both appendices.

Virgin Atlantic

Virgin Atlantic is in the unique position of having access to actual fuel use, cargo, occupancy rate, etc. data. Virgin Atlantic is therefore in a great position to develop an accurate calculator. Yet the authors conclude that the Virgin Atlantic calculator could be improved in several ways:

- Virgin Atlantic calculates seat class emissions by weight. Allocation by space requirement would be a more accurate measure.
- Virgin Atlantic does not account for occupancy rates. This is a shortcoming of the calculator.
- Virgin Atlantic's calculator claims that it is based on actual company fuel use data. Yet the calculator also calculates non-Virgin Atlantic routes. It is unclear on what data Virgin Atlantic bases these calculations.
- Not much detail is available on the data and the underlying metrics that have been applied to develop the calculator. This makes it difficult to determine its accuracy.

3.3 Conclusions

The impact of air travel on climate change is often a topic of debate. There are several reasons why it is important that air travel calculators are as accurate as possible:

GHG emissions calculations and offsetting are complex and require well-educated policy makers and an informed general public. Having calculators that give widely disparate results is confusing to the public and can impact willingness to reduce or offset emissions. Perhaps even more significantly, inaccurate emissions estimates from air travel could potentially lead to poorly designed policies. There has been much criticism of carbon offsetting and the associated carbon calculators. If public confidence in climate mitigation policies in general and offsetting in particular is to be strengthened, accurate information needs to be available for all sectors of the economy, including air travel.

It is disproportionately the wealthy that travel by air. Since the impacts of climate change will be felt disproportionately by the poor, this raises equity concerns. To set policies that address climate and equity concerns,²⁴ it is necessary to know the full extent of climate impacts from aviation.

On an individual level, travelers who strive to minimize and/or offset their impacts need to be able to accurately calculate their emissions. For example, knowing how much greater the emissions from an upper-class seat are, a traveler might choose an economy seat instead.

This paper examined the aircraft parameters that are needed to calculate CO₂ emissions on a per person basis. Three air travel emissions calculators were analyzed in-depth. The travel example analysis revealed that results vary considerably among these calculators. It was impossible to pinpoint why the results varied so widely, yet the authors identified several areas where calculators could be improved.

The TRX Travel Analytics calculator was judged to be the best calculator currently available and known to the authors. Yet even the best calculators cannot be 100% accurate given the scientific uncertainties, lack of data availability, and unpredictability inherent in air travel. For example, as with cars, aircraft can be flown more or less efficiently. The slope an aircraft takes for its climb and landing approach affects its efficiency. Only if actual fuel use data is available can such behavioral strategies be quantified; otherwise calculators are unable to capture these effects.

Calculators should include disclosure statements about the precision of the calculations and the underlying assumptions and lists the data sources. In order to improve and maximize accuracy, calculators need to be updated regularly to keep up with the dynamics of the air travel industry and to integrate new research results and updated data sets.

Transparent and easy-to-use calculators that rely on the most current data are important tools that enable travelers to identify and compare their air travel emissions to other activities that contribute to their GHG footprint. They not only help consumers and companies to calculate how many carbon offsets they would have to purchase to compensate for their emissions, but more importantly can inform choices that reduce travel footprints, such as combining trips, avoiding upper-class seats, and opting for alternatives to travel such as video conferencing.

This paper is the first in a series of two reports which examine the key factors that must be taken into account when calculating per capita air travel emissions for the purpose of carbon offsetting. The second paper will focus on how to account for non-CO₂ emissions from air travel (i.e. RFI multipliers).

²⁴ For an in-depth analysis of a potential climate and equity framework, see the *Greenhouse Development Rights Framework* (Baer et al 2007)

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Appendix A

Commentary by Dietrich Brockhagen (atmosfair)

May 20, 2008

This commentary has been written by Dietrich Brockhagen, atmosfair, on the emissions calculator paper written by Anja Kollmuss. It aims to show important points that are lacking in the current version of the emissions calculator paper.

1. The factors considered in the calculator paper are not complete. Important factors are missing. This commentary compiles quantitative information for these factors, showing that they may be in fact more important than those factors discussed in the paper.

2. There is pseudo accuracy, when important factors are addressed in detail and other equally or even more important factors are treated inadequately or are not covered at all. The claim of the paper that a calculator is the more accurate, the more detailed the data input is, can therefore not be sustained, if at the same time important factors are missing.

3. As a result, airline specific emissions calculation is not possible with any of the current calculators. Any choice of an environmentally concerned passenger based on the TRX calculator may reward an airline which actually performs worse than the TRX top performer.

The sources referred in this paper are:

1. Corinair Data files
2. Mapping table of QinetiQ between representative and actual aircraft
3. AERO2K report, explaining i.a. the representative aircraft concept.
4. Jet_engines_specifications
5. Lufthansa presentation, showing numbers on fuel efficiency and maintenance
6. Tankering study of the Oeko-Institute

1. Aircraft type, missing data

Both TRX and atmosfair use similar data (atmosfair from QinetiQ and DLR, TRX from Corinair). Both are in so far similar that they are used in climate models to create a fuel use 3D - grid for air traffic. The idea is to reduce the over 300 aircraft type world fleet to less than 50 aircraft, the so called representative aircraft (see e.g. the IPCC 1999 report, or the AERO2K project of the EU), in order to get complexity to a level that corresponds reasonably to the needs of the climate model. E.g. the A340-200 -300 and -600 are all represented by one aircraft a "A340". Others like the A340-500 are not even part of this. The representative aircraft have been chosen by their statistical weights (see attached AERO2K report and the Excel table, providing the QinetiQ mapping between 47 representative and 300 normal planes)).

This approach is good enough for a fuel data base for a climate model (because if coupled with international flight plans, you get a full 3D fuel inventory). However, it is too rough to allow for an airline comparison. The difference between the specific types of an aircraft like the A340 is however enormous: e.g. the A340-500 is the record holding long distance aircraft, flying up to 16.600 km non-stop (e.g. Singapore Airlines). This comes at the trade-off that fuel capacity had to be increased by 50% compared to the A340-300 and only about 180 passengers can be transported, compared to the normal >300 passengers. In order to shorten travel time, Rolls Royce Trent Turbofans engines are used, providing more thrust. Fuel consumption per passenger is increased because of the additional fuel weight to carry, fewer passengers and the higher speed.

Every aircraft type has its own optimisation philosophy (optimised in the first place e.g. for a certain distance, or passenger capacity, or speed, or fuel consumption). Because of burdensome technical approval procedures, it is common industry practice to derive different plane models from one basis version. This means that the body and wings are shortened or lengthened and engine types and fuel capacity are adapted. However, fuel economy differs much between the different aircraft models. E.g. within the most popular Boeing 737 family, there are more than 20 models (737-100, 200, 300, 400, 500, 600, 700, 800, 900) and variants (e.g. winglets). For a german documentation on the B737 family, see <http://www.airliners.de/industrie/flugzeuglexikon/description.php?aircraftid=36&manufacturerid=2> However, all these different models are presented by only 2 generic aircraft in Corinair (used by TRX) and 6 generic aircraft by QinetiQ / DLR (used by atmosfair). The difference in specific fuel consumption is shown in the table below:

Aircraft	Used by Atmosfair	Used by TRX
B737-100	-	X
B737-200	4,45 l / 100 Pkm	-
B737-300	3,64 l / 100 Pkm	-
B737-400	3,30 l / 100 Pkm	X
B737-500	4,50 l / 100 Pkm	-
B737-600	4,02 l / 100 Pkm	-
B737-800	3,27 l / 100 Pkm	-
B737-900	-	-

Source: atmosfair, derived from QinetiQ/DLR, assuming standard seating (Jane`s), 80% load factor, on a 4000 kilometre flight.

The B737 is the most built aircraft of the world. Note that the difference between the best and worst fuel efficiency is almost 40%! While the B737-100 to 500 series are old (all had their first flights before 1990), today many fleets, especially the budget airlines, predominantly use the B737 -600 to 900 (so called “Next Generation”), e.g. Easy Jet (100%) and Air Berlin (80%), which are almost a new construction and much more fuel efficient than the “old” ones. In summer 1999 the last B737-500 was delivered, since then only B737-Next Generation (600-900) were delivered (see Boeing Website). This indicates that the differences shown in the above table are relevant in reality, since the TRX calculator only applies the old B737 models as representative aircraft, whereas some airlines have predominantly Next Generation.

Similar results can be obtained for e.g. the B747 family (-100, -200, -400), or the different Airbus families. This is why atmosfair does not claim to have exact data for those 300 aircraft types (see attached AERO2K report) that are covered by its representative aircraft.

In the paper, in example 1, the TRX calculator shows that the flight from London to HongKong would be a A340-600 for Virgin. However, for this aircraft, TRX does not have data, but only for a A340. However, the A340-600 is the longest plane in the world and differs much from the “representative” A340.

Conclusion: By just using those less than 50 representative aircraft, neither TRX nor atmosfair are capable of calculating an airline specific fuel consumption, because neither has data for the exact type of aircraft used. This result also contrasts the claimed accuracy e.g. with regard to seating classes: If you do not know the exact plane type, how can you then use an exact seating?

2. Accuracy, missing information for ranking airlines

The report seems to take the assumption that the more input data are fed to the calculator, the more precise the result will be. But this is not necessarily true. This is because there are factors, which are not captured by any calculator, but which may be decisive when it comes to the comparison of different airlines:

The following table shows such factors and how much they come into play. These are all factors which are not considered by TRX and neither by atmosfair.

Parameter	Description	Margin of uncertainty (difference best to worst)
Engine type	Difference between different engines possible at one plane	15%
Aircraft type	Difference between real plane and representative plane (see section above)	40%
Maintenance	Of engine (7%) and body (2%)	9%
Tankering practice	Airline practice to refuel where it is cheapest, carrying a fuel penalty due to increased weight	10%

As for engines, data bases of engines show that the engines used to power common airplane have a specific fuel consumption that differs by up to about 15%. E.g. the Boeing 747 can be powered by four:

- PW 4056
- PW 4062
- RB.211 – 5246
- JT9D-7a
- CF6 80 C2B1F

These are engines from 4 different manufacturers (Rolly Royce, Pratt&Whitney, General Electric). Specific fuel consumption differs from 0,316 to 0,364 lb/(lb hr). All engine combinations are commonly used in practice (see e.g. “Jane`s aircraft of the world”). Same can be seen for the B757 or the Airbuses (see attached excel files on jet_engines).

Maintenance is clearly a factor of distinction between the airlines (see Lufthansa presentation).

Tankering is a daily industry practice for flights between countries with different fuel prices. Depending on the aircraft, instead of refuelling after each landing, you can connect several destinations without refuelling at all. The increased weight implies a fuel penalty that can amount to up to about 10% (see tankering paper of Öko-Institute). One could suppose that all airline tend to do tankering and therefore differences between airlines would be small. However, the potential for tankering depends also on the aircraft used and therefore differences may be large.

None of these factors is captured by atmosfair or TRX. The combined difference may thus account for up to about 50% difference or more between the airlines, even if all other factors would be perfectly known by the calculators. This clearly exceeds the differences between the top ten of the TRX airline ranking and therefore shows, that such a ranking cannot be sustained without these factors.

Of course, one could argue that the more input a calculator has, the more precise the result will be anyway. However, this is not the case here: How can you know that e.g. the less favourable seating of airline A will not be entirely offset by choosing a better plane, engine and maintaining it better as compared to airline B? The TRX calculator only sees the seating, but the seating will be wrong in many cases, because it refers to the wrong plane (representative aircraft instead of true aircraft) and furthermore the calculator is blind to the other factors, which may be more important, even if the seating were to be correct.

All factors are common in industry practice, as has been shown by the supporting materials and numbers provided here. Though we do not know the exact weight of these factors, the above information and

numbers shows that they are significant. Without knowing the exact number on the magnitude of the effects per airline we cannot just hope that they will cancel each other out and the airline result will be precise. Even if all factors were much smaller and less frequent than shown here, they would impede an airline ranking, given the small differences between the airlines in the TRX ranking.

Conclusion: We face a situation here, where a calculator sometimes may have accurate data for one important factor (seating), which may however be entirely offset by 4 other important factors, not known to the calculator. Therefore, the methodology and data do not allow for an airline ranking.

3. Applying the RFI correctly

There is one important factor not addressed in the paper: Flight altitude. Only above a certain threshold altitude RFI effects can occur, below, emissions are not impacting the atmosphere other than emissions from any other transport activity. E.g. contrails need supersaturated air with respect to ice in order to form, NOx needs a certain range of background concentration and long residence times (thus no washout through rain, tropospheric - stratospheric exchange etc.) in order to form relevant volumes of ozone. These conditions are mostly given in altitudes 9-13 kilometres around the tropopause (upper troposphere and lower stratosphere).

On a short distance flight, depending on the aircraft, only 50% of the emissions could occur in these critical altitudes. Sometimes it can be 0%, depending just on the aircraft type and the distance.

TRX applies the RFI as lump sum factor to all emissions irrespective of the altitude, atmosphere differentiates. Let us discuss three examples:

a) A short distance flight, which does not reach critical altitudes. CO₂ emissions: 100. Assumed RFI 2.7.
Result atmosphere, emissions: 100
Result TRX, emissions: 270
Difference: 170%

b) Short distance flight of 500 kilometres, where 50% of emissions are emitted above critical altitudes. CO₂ emissions. 100. RFI: 2.7
Result atmosphere, emissions: $(50 + 50 * 2,7) = 185$
Result TRX, emissions: 270
Difference: 30%

c) Long distance flights, 95% of emissions are emitted above critical altitudes. CO₂ emissions. 100. RFI: 2.7
Result atmosphere, emissions: $(5 + 95 * 2,7) = 261$
Result TRX, emissions: 270
Difference: 3%

As we have seen, the differences can be anywhere between a few percent and more than 100 %.

While the other factors not known such as engine type or aircraft type have errors, which from the outset have no clear direction (towards more or less than true fuel consumption), this error systematically overestimates the emissions.

Hence, by ignoring this differentiation, all accuracy gained by differentiated seat classes etc. is in jeopardy. If an environmentally concerned passenger uses the TRX calculator and sets the RFI to 2,7 he would get a picture about the climate impact of the flight, which can be more wrong than any accuracy gained through the rest of the calculator.

4. More factors to be considered for airline ranking

On top of the factors discussed above (aircraft type, maintenance, engines, tankering), there are more, which currently impede a well based airline ranking:

1. **Load factor:** The load factor would need to be determined for a given city pair. This data is however not available, but only on a per airline level, which may however be different from the load factor at the route under consideration. Load factors depend directly on the airline policy with regard to pricing, routing, season, events in the destinations (trade fares) etc. However, one airline may have a higher average load factor on one route, but another airline may have a higher load factor on the same route at a different daytime or season. But even if we average all flights on a certain route: My airline of choice may only achieve the desired high load factor on some intercontinental flights, but perform badly on my actual hub to spoke flight, whereas a competitor airline may perform vice versa. Therefore, even average load factors for every single airline, as published by AEA or ICAO and used by TRX do not allow for a green-ranking of the airlines. Only if broken down to the routes, a comparison would be somewhat tangible, but still limited. However, since route specific load factors is sensitive information, they are not published, and where they are, they cannot be verified by third parties.
2. **Seating configuration:** Airlines often have different seating configurations for a certain aircraft type, depending on where it is used. Even within one specific plane, configuration may change on a daily basis (i.a. adding or replacing some seats), depending on demand. Whereas the seating configuration of the airlines (amount of business, economy and first class seats) is precisely published (e.g. Bucher, Switzerland), data on the space distribution for these service classes are not. However, the space distribution is crucial when it comes to calculate CO₂ emissions. Available data (e.g. Seat Guru, used by TRX) captures neither of these issues (different seating at the same aircraft type of one airline and changing configuration on demand level).
3. **Operation:** Airlines have different ways to operate their planes, which also affects fuel consumption. Important parameters are the slope of the climb out phase and of the landing approach, or the overall speed of the flight.

Appendix B

Commentary by Thomas Tomoski (TRX Travel Analytics)

May 29, 2008

This addendum was written by Thomas K. Tomosky, Ph.D., Application Manager for TRX Travel Analytics. This set of comments incorporates my feedback on a number of issues raised about TRX's approach to calculating airline emissions.

1. Issues regarding Virgin Atlantic LHR-HKG

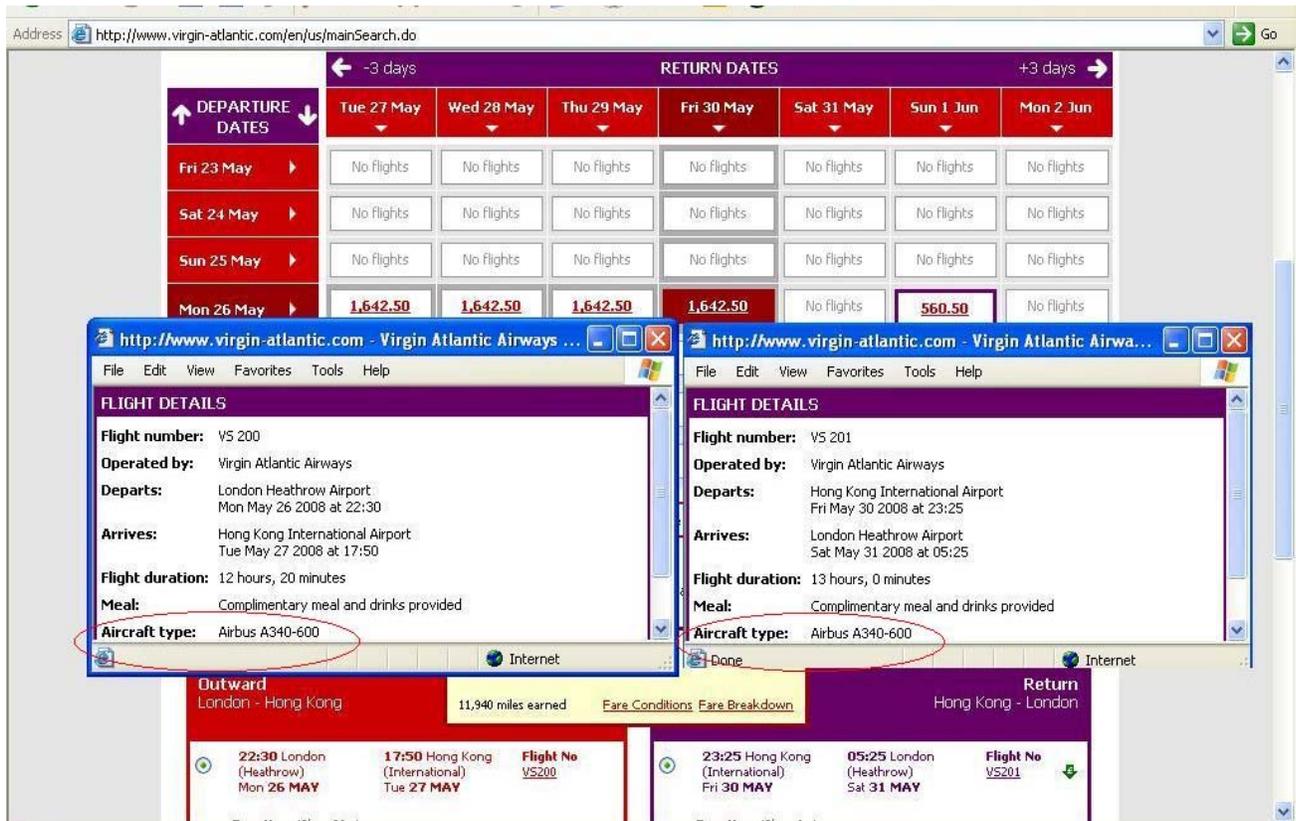
Atmosfair claims that the TRX calculator lists an A-340-600 for the Virgin Atlantic flight London- Hong Kong. This claim is incorrect:

A. We get our data from the airlines themselves

Airlines report their forward schedules to a third-party, OAG (Official Airline Guide) Back Aviation. OAG then consolidates each airline's schedules and makes the global schedules available to the aviation industry. We use what the airlines themselves report to OAG as their forward schedules. In this case, Virgin Atlantic reported to OAG that it had scheduled an A340-600 (346) for this route, so this is what our web site displayed. Why Atmosfair refers to an A340-300 is unknown to us.

B. Virgin Atlantic uses an A346 for LHR-HKG

We visited the Virgin Atlantic website and looked at the available options for a LHR-HKG flight leaving May 26 and returning May 30. See the image below. For both the Outward and Return flights, the A340-600 is displayed, which is presumably what Virgin reported to OAG and is exactly what we have on our web site.



C. Seating configuration for A346

Atmosfair claims that the seating configuration for the A346 is unknown. Perhaps Atmosfair is unaware that in addition to their forward schedules, most airlines also report to OAG their seating configurations for their fleet of aircraft. OAG consolidates this data and sells the resulting Fleet database to the aviation industry. Virgin Atlantic may or may not have the seating configuration for the 346 on their web site (we didn't check) but Virgin certainly has reported to OAG that there are 2 seating configurations for the 346. This is the data we use. The configurations are as follows:

First Class: 0
Business Class: 45
Premium Economy Class: 38
Economy Class: 225
Total: 308
Aircraft Count: 18

First Class: 0
Business Class: 45
Premium Economy Class: 28
Economy Class: 233
Total: 306
Aircraft Count: 1

We use the average seating configuration weighted by the number of aircraft using that configuration. In this case, it would be very close to the 308-seat count configuration.

D. Fuel burn rates

It is true that we use fuel burn rates for the generic A340 for the A360, since the specific A360 fuel burn rates are not publicly available. We have long maintained that we are willing to use, and can easily incorporate, the best data available. We will be investigating QinetiQ to see if they truly have better data than the fuel burn rates from EMEP/CORINAIR Emission Inventory Guidebook –2006. If anyone knows of trusted, publicly available fuel burn rates for specific aircraft type, please let me know.

2. Issues regarding estimates of inaccuracy.

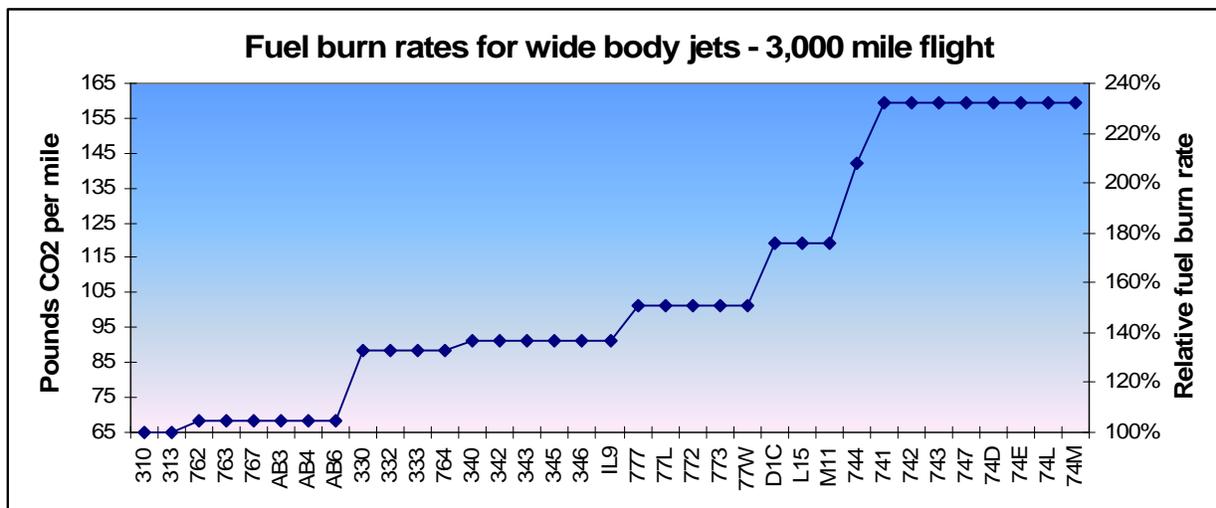
We would be happy to calculate estimates of inaccuracy IF the underlying data were known to us, or to anyone else. It is true that differences exist in the fuel burn rates of different members of the A340s. It is harder to quantify those differences, since that data is not publicly available, as far as we know. Atmosfair cannot claim to have good estimates of inaccuracy when all the underlying data is not known. We simply do not know what the differences are. Because of that, we feel it is not justified to claim that using aircraft specific data leads to "pseudo-accuracy"

Atmosfair seems to be taking the position that the data may be too fuzzy to make a legitimate comparison between the emissions of different aircraft types. We would be very interested to see specific data to prove this assertion.

To determine if our data can be used to distinguish between different aircraft, we undertook a careful analysis of the data we have been using - both from OAG and from EMEP/Corinair.

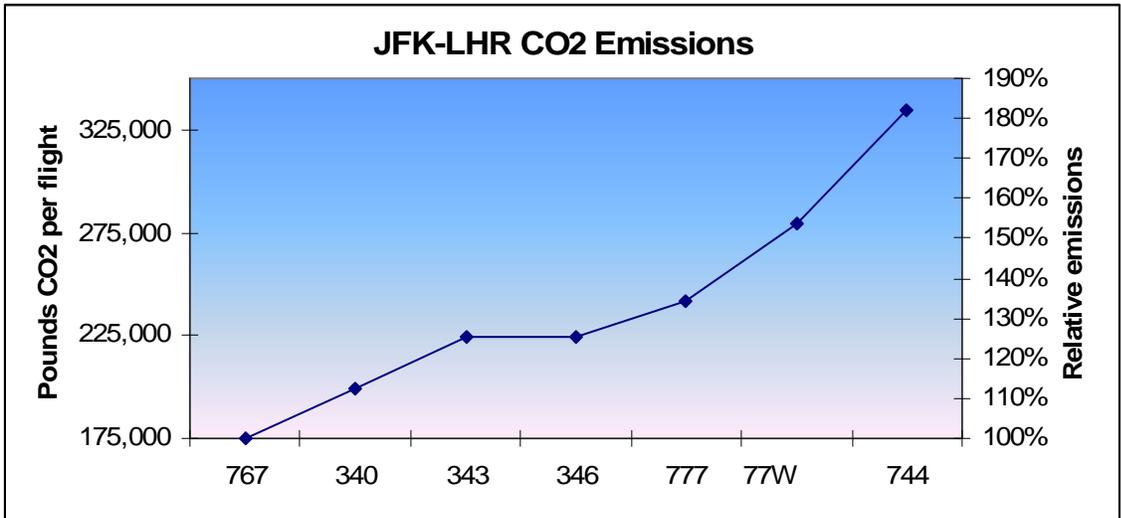
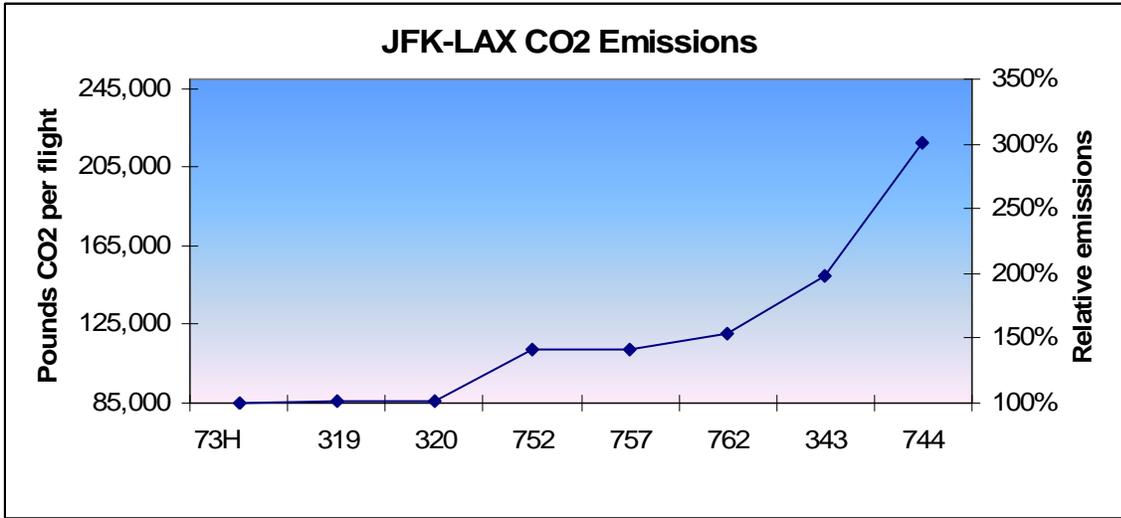
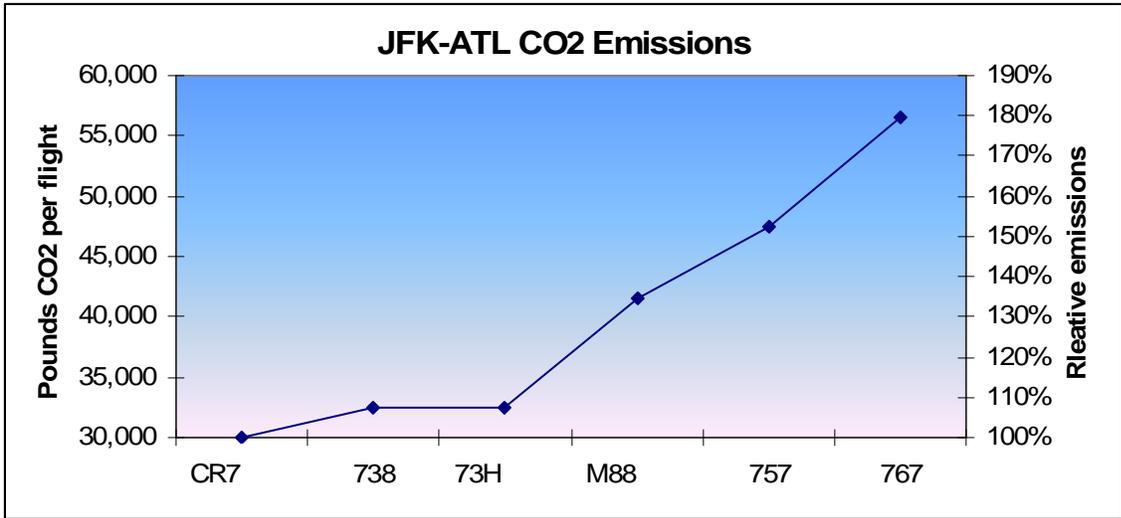
A. Fuel burn rates for wide body jets

We first examined the fuel burn rates for wide body jets for a typical 3,000 mile flight. On the right hand Y-axis, we normalized the emissions based on the lowest pounds CO₂ per mile for the A310. As you can see, there is a wide range of fuel burn rates. We would admit that one could not realistically distinguish between an A310 and a B762, for example, but there are HUGE differences between other jets. In fact, most members of the 74x series have fuel burn rates 2.3 times that of most of the 76x series. **Our preliminary research indicates fuel burn rates within members of a family are much less than the variations between families.** So, even if there is some uncertainty in the fuel burn rates of some jets, we should be easily able to distinguish a number of wide body jets from each other. A quick glance at the data for other equipments types (narrow body, regional jets, and turboprops) also shows significant variances.



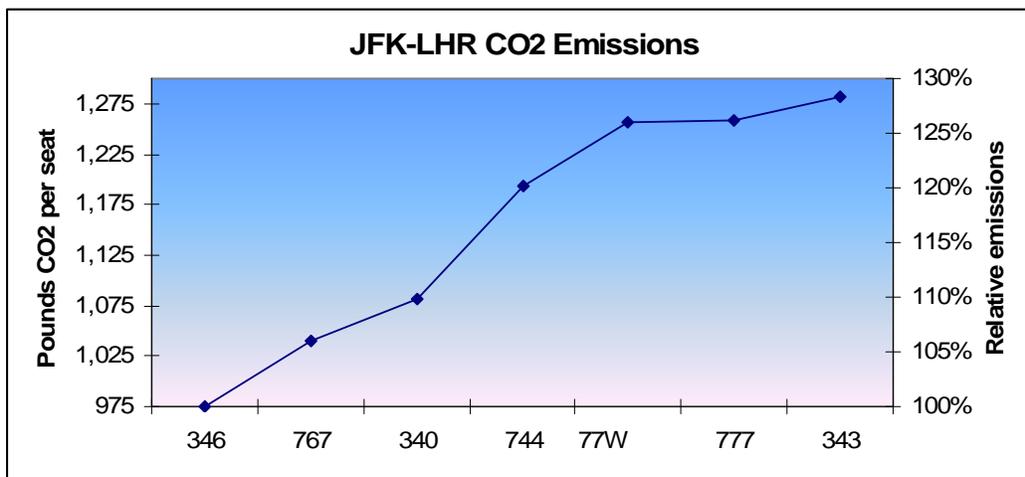
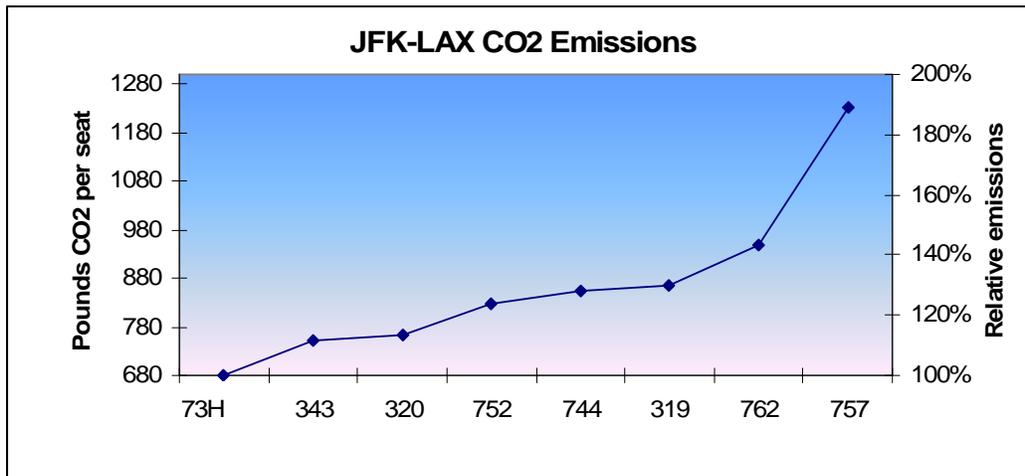
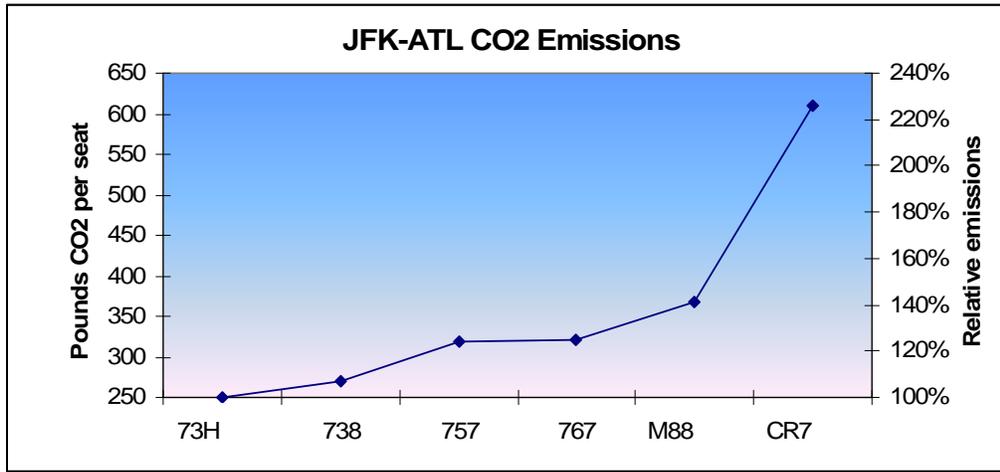
B. Pounds of CO₂ per flight

We then examined the pounds of CO₂ per flight for 3 different flight ranges: JFK-ATL (758 statute miles), JFK-LAX (2,467 statute miles), and JFK-LHR (3,441 statute miles). The aircraft used are those specified by OAG for these city pairs for scheduled passenger flights. In these flights there is a mixture of regional, narrow body and wide body jets. You will see below that emissions can vary from 1.8 times, 3.0 times, and 1.8 times respectively for these city pairs. Again, even if there is some uncertainty about an individual jet's fuel burn rates, there is a wide enough disparity between jets to make it worthwhile to try to use the best data available, since there are major differences between jets.



C. Pounds of CO2 per seat

To analyze the effects of a different number of seats per jet, a final analysis looked at the pounds of CO2 per seat. To keep this analysis simple, we used the same city pairs above and we did not break out the seats by cabin. Once again, you will see that there are large differences in the pounds of CO2 emitted per passenger: 2.3 times, 1.9 times, and 1.3 times. Here are the results:



Although there may be some uncertainty or fuzziness regarding the fuel burn rates of each and every aircraft we evaluate, there are certainly large differences when we look at all commercial aircraft

used for scheduled passenger flights. These differences are not in the 10-20-30% range, but typically in the 150-200-300% range. This fact encourages us to continue to use the best available data and to have confidence in results when comparing emissions from different aircraft.

We believe we have demonstrated here that the differences in CO₂ emissions between aircraft are so large that, even if there are some uncertainties in fuel burn rates for specific aircraft, that the use of the most up-to-date, publicly available data is clearly warranted. As better, more specific data is made publicly available, we will incorporate it into our model.

3. Other issues

A. Use of engine and maintenance data

We are committed to using the best available data in our model. To date, we have not found a publicly available source of comprehensive data on engine fuel burn rates. We are exploring an alternative source of credible data that may provide a defensible fact base. Meanwhile, we trust that the fuel burn rates established by the EMEP/CORINAIR Emission Inventory Guidebook –2006 take into account the variety of engine types typically used by these aircraft in the stages (distance buckets) that are reported by the Guidebook.

Atmosfair provides margins of uncertainty for different parameters: 15% uncertainty for engine type, 40% uncertainty for aircraft type, 9% uncertainty for maintenance, and 10% uncertainty for tankering practice. We would very much welcome a further discussion and more data analysis to show the sources of these estimates. We agree that all these factors ideally should be taken into account but we are not aware of any currently available robust data sets on these topics.

B. Use of altitude data

Altitude does not affect CO₂ emissions, since CO₂ emissions are a direct function of fuel consumption. Altitude data would be of use in determining non-CO₂ emissions, however, our model does not claim to calculate non-CO₂ emissions. We believe that the science associated with RFI factors related to aviation emissions is still under development. Our model currently allows the user to turn on or off an RFI factor of 2.7. We intend to modify this so that the user may use any RFI factor that they wish, including the choice of ignoring any RFI factor.

C. Seating Configurations

Atmosfair claims that TRX Travel Analytics does not know the exact plane type that was used for a given carrier-city pair. Atmosfair seems concerned about the potential differences between what type of an aircraft a carrier schedules for a given city pair (which we clearly do know from buying the OAG Worldwide Schedules database), versus what type of aircraft was actually flown. Again, our position is to use the best available data. We know of no data source that reports the actual equipment used. Further, we do know that airlines have a very strong preference for using the same equipment type for any Irregular Operations for three good reasons:

- 1) the flight crew assigned to the original equipment may not be certified to operate a different type of aircraft,
- 2) the flight schedules are optimized for many factors, including fuel usage. Changing the equipment type will likely sub-optimize the operating costs of the flight, and
- 3) by using the same type of aircraft the airline avoids having to re-assign all the passengers to a new seating configuration. Therefore, we confidently assert that the scheduled aircraft type very closely matches the actual type of aircraft used.

Atmosfair also asserts that our calculator will have the wrong seating for a plane because we are referring to a representative aircraft and not a true aircraft. We purchase 2 databases from OAG - one is the Schedules database and one is the Fleet database. The Schedules database tells us which aircraft are used for which flights by each carrier, and the Fleet database tells us the seating configuration of each aircraft within each carrier's fleet. In case of multiple seating configurations (e.g., British Airways having some 767-300s with 189 seats and other 767-300s with 240 seats), we use an average of the different configurations, weighted by the number of aircraft in the carrier's fleet using each configuration. **Consequently, we obtain the most likely seating configuration used by the carrier on any flight for a given aircraft type.** We welcome any advice that would lead us to making a more accurate calculation about seating configurations – we are simply not interested in ignoring good and important data.

Atmosfair states that TRX Travel Analytics has the wrong seating configurations since SeatGuru does not capture relevant information. As stated above, we use the Schedule and Fleet databases from OAG to determine the number of seats on a particular aircraft and the distribution of those seats in different configurations. We only use SeatGuru data to determine the seat footprint (seat pitch x width).