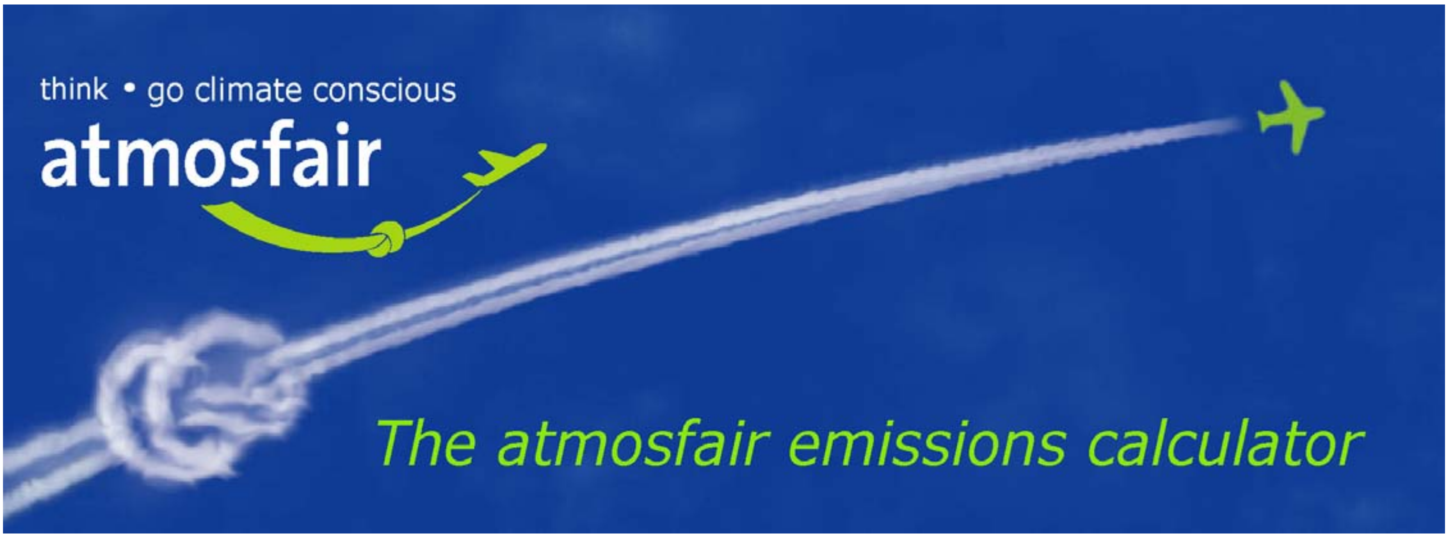

This text documents the details of the atmosfair Emissions Calculator program.

1. *Principles*
2. *What factors determine how climate-damaging my flight is and how are they captured by the Emissions Calculator?*
3. *On what data sources is the Emissions Calculator based?*
4. *How accurate are the methods and results?*
5. *Overview: aircraft types, seating, engines and standard distances*
6. *References*

1. *Principles*

The Emissions Calculator has been designed in accordance with the following principles:

Data independence:
The data sources come from independent scientific research projects.

Appropriate accuracy:
The accuracy of the calculations is appropriate to atmosfair's goal. Important factors for the equivalent climate impact of a flight are simulated by the Emissions Calculator. Where the user is unable to provide the factors requested, average values are used. This also applies to external factors, such as for example the state of the atmosphere at the time of the flight.

Testing:
The Emissions Calculator's methodology and the data on which it is based have been checked by Germany's Federal Environmental Agency.

2. What factors determine how climate-damaging my flight is and how are they captured by the Emissions Calculator?

2.1 The different pollutants

Summary: Aircraft engines emit a range of pollutants which raise the temperature of the atmosphere directly or indirectly. Carbon dioxide (CO_2) is the easiest to describe in terms of its production and effect. It is produced during the combustion of kerosene in direct proportion to the consumption of kerosene. CO_2 is used as the basis for calculating climate damage. The various other pollutants and their effects can be summarised via an internationally recognised calculation method so that its warming effect can be converted into CO_2 equivalents. The Emissions Calculator first calculates the fuel consumption per passenger and, based on this, then determines the amount of CO_2 whose warming effect is comparable to that of all pollutants emitted by the flight together (effective CO_2 emissions). This is the amount of CO_2 output by the Calculator which is saved by atmosfair in climate protection projects.

Aircraft engines emit a range of pollutants which increase the atmospheric temperature. The most important are carbon dioxide (CO_2), nitrogen oxides (NOx) and various particles of soot or sulphur. The climate impact of these pollutants has been described in detail by the IPCC, the United Nations Intergovernmental Panel on Climate Change (IPCC 1999). The impact of these pollutants on the climate varies:

Carbon dioxide (CO_2)
is always generated during the combustion of fossil fuels (coal, gas, oil). The amount of carbon dioxide emitted is a direct function of fuel consumption: 3.16 kilograms CO_2 are produced per kilogram of kerosene on combustion in the aircraft engine with ambient air. Carbon dioxide is a greenhouse gas which, simplified somewhat, remains in the atmosphere for approx. 100 years after its emission. As a result is can spread over the entire globe, driving global warming throughout the world. CO_2 is regarded as a leading gas in climate science in climate science and is used as a reference variable for comparisons between the effectiveness of different greenhouse gases.

Nitrogen oxides (NOx ⇨ ozone)
Nitrogen oxides are produced in the aircraft engine at high temperatures and pressures by the reaction between oxygen and atmospheric nitrogen. Its production depends greatly on the engine load. It is estimated that approx. 8-15 grams nitrogen oxides are produced per kilogram kerosene consumed in passenger jet engines when cruising. Nitrogen oxides have two main impacts on the climate: firstly, they reduce the lifetime of the greenhouse gas methane, an effect that reduces global warming. Secondly, at cruising altitudes of about 10 kilometres they form the powerful greenhouse gas ozone which spreads out along the major air corridors, for example over the

North Atlantic, where several hundred aircraft fly daily from Europe to the US and back.

Particles (condensation trails and ice clouds):
Particles in the engines' exhaust plume are produced by condensation from gaseous pollutants and consequent processes. Water, soot and sulphur are important starting materials for this. Ambient air saturated with moisture can condense on particles, resulting in condensation trails and high, hazy ice clouds (cirrus clouds). These clouds act like a glass roof over the earth and thus contribute to climate warming. The formation of these clouds depends less on the number of emitted particles than on the fact that the ambient atmosphere is sufficiently humid.

Further pollutants:
In addition to these pollutants there are others which are not discussed here because of their lesser importance than those mentioned above. More information on these substances can be found in IPCC 1999.

Calculating the impact of the pollutants using the RFI:
The climatic impacts of the different pollutants can be converted to those of carbon dioxide. This is done using the "Radiative Forcing Index" (RFI, see IPCC 1999). The result is a quantity of CO_2 that would have to be emitted to cause the same warming effect, when averaged globally, as the various pollutants together. The RFI is a constant numerical factor (approx. 2-4, best estimate 2.7, see IPCC 1999). This means that at present the total climate impact of all the different pollutants from a flight can be approximately expressed by taking the emitted volume of CO_2 times three and converting it in this way to effective CO_2 emissions. Since the carbon dioxide is a direct function of kerosene consumption (see above), all the Emissions Calculator needs is to calculate the kerosene consumption per passenger on a flight. The CO_2 and the effective CO_2 emissions are then calculated by simple multiplication by the above-specified factors (3.15 kg CO_2 per kilogram kerosene and the RFI factor). The Emissions Calculator therefore does not calculate the emissions of nitrogen oxides and particles and their impacts individually, but instead draws the impacts of these pollutants together via the CO_2 and RFI. This is adequately accurate in light of the various uncertainties still existing. Calculating the nitrogen oxides and particles and their impact separately would only give a pretence of accuracy which does not exist in reality (see also para. 4).

2.2 Flight altitude and state of the ambient air

Summary: The equivalent climate impact of the emissions and their effects depends on the flight altitude and the state of the atmosphere at the time when the aircraft flies through it and emits the pollutants. This is adequately addressed in that the Emissions Calculator treats the emissions at high cruising altitudes in excess of approx. 9 kilometres above sea level (this is usually the case for flight distances of greater than approx. 400–500 km) as more harmful than those of short-haul flights.

The equivalent climate impact of the nitrogen oxides and particles (see 2.1) is a function of the flight altitude and the state of the atmosphere at the time the aircraft flies through it and the pollutants are emitted.

Nitrogen oxides, ozone:
The generation of the greenhouse gas ozone from nitrogen oxides under the effect of insolation is a result of similar chemical smog reactions to the formation of nitrogen oxides from automotive emissions in cities during the summer months. At high flight altitudes above approx. 9 kilometres, however, the smog reaction is more effective than at ground level. The existing concentration of nitrogen oxides is crucial in this context: if there are few nitrogen oxides available, ozone is quickly formed; if, on the other hand, there is a very high concentration, further nitrogen oxides can even result in ozone being broken down again. It is therefore important to know whether a flight operates on a route which is frequently or rarely flown and whether the aircraft climbs to the critical heights.

Particles, ice clouds:
Long-lasting condensation trails and high hazy clouds of ice can only form if the air through which the aircraft is flying is sufficiently humid. Near the equator this is generally only the case at very high altitudes of about 12-16 kilometres above sea level. Since even modern civil jets rarely fly at such altitudes, the formation of condensation trails and ice clouds here is rarer than at more moderate latitudes and in the polar regions of the earth where these clouds can form at depths of as low as 5 kilometres. The humidity in the air is also generally a function of the season, as a result of which this too influences the likelihood of such aircraft-generated clouds being formed.

The Emissions Calculator cannot address these effects in detail since this would require an enormous amount of data which would be out of all proportion to the accuracy thus achieved. Furthermore, neither the passenger nor the airline can influence the present state of the atmosphere on the route and at the time of a flight. It would therefore not be justified for some passengers to have to pay a higher surcharge than others. Consequently the Emissions Calculator only takes account of the most important systematic parameter, the flight altitude: for all emissions produced at a cruising altitude under standard conditions above 9 kilometres an RFI factor (see 2.1) of 3 is used in the calculation, meaning that average values are applied to simulate the impact of condensation trails, ice clouds and ozone from aviation-related nitrogen oxides. This is normally the case if flights are over a distance of 400 to 500 km or further. In the case of shorter and thus usually lower flights the effects of ozone and condensation trails or ice clouds are ignored, with the result that only the pure carbon dioxide emissions are effectively taken into account here.

An RFI of 3 is applied in the Emissions Calculator rather than the IPCC's best estimate of 2.7. The reason for this is that the value of 2.7 is an average for all flights, i.e. also including short-haul flights which do not reach the necessary altitude for the increased climate impact. If, as in the atmosfair Emissions Calculator, the short-haul flights are calculated without an RFI factor but the emissions above 9 km with an RFI factor, there is a higher RFI value for the latter. This is easily within the RFI range of 2 to 4 indicated by the IPCC.

2.3 Aircraft: aircraft type, seating, seat occupancy rate and transported cargo

Summary: The aircraft type, the number of seats on board, their seat occupancy rate and the transported cargo have a direct impact on the fuel consumption per passenger. The most important factors among these are seating and seat occupancy rate. The Emissions Calculator takes these factors into account by using the average figures for German airlines and aircraft manufacturers' standard configurations with regard to seating. As far as the seat occupancy rate is concerned, a distinction is drawn between the scheduled and charter market segments which have different average seat occupancy rates. In the case of scheduled flights these figures are also differentiated by flight region.

2.3.1 Aircraft type

Fuel consumption depends on the aircraft type. A distinction is generally made between propeller-engined aircraft, which are generally used for short-haul flights, and jets, which operate on both short- and long-haul routes. Today's aircraft fleets in the industrialised countries are dominated by the various aircraft types of the two major manufacturers Boeing and Airbus. Since fuel consumption is an important criterion for the two manufacturers, modern (comparable) jets have similar fuel consumptions per passenger. However, because of jets' long service lives (approx. 30 years) many airlines are still using relatively old aircraft today which often have a significantly higher fuel consumption.

The Emissions Calculator has a database of detailed consumption figures of 20 aircraft types currently including their distance dependence, and these figures permit a largely realistic calculation of fuel consumption. These aircraft types come from different aviation engineering generations and cover an estimated 80% of the total worldwide air traffic. Propeller-engined aircraft are not yet included in the database since no data is yet available for these.

However, new aircraft types are constantly being launched. The Emissions Calculator does not take account of these since their fuel consumption first has to be determined in scientific studies. The Emissions Calculator will therefore never include the most up-to-date aircraft in the fleets, but this is not crucial as long as the Calculator is regularly updated. If the customer enters the option "Aircraft type unknown", the Emissions Calculator also operates with virtual "hybrid aircraft". These are virtual aircraft composed mathematically of defined proportions of real aircraft which are operated particularly frequently in the flight region requested by the customer. So the system takes into account, for example, that different airlines and thus also different aircraft are used on flights to Eastern Europe than for domestic German flights or flights to Africa.

In specific terms, air traffic is divided into six regions for "hybrid aircraft": internal, Eastern, Southern and Western Europe, intercontinental and all other flights. Countries have been assigned as follows:

- Internal: flights within Germany.
- EU West: flights from Germany to an airport in the EU + Scandinavian countries + Switzerland, but excluding Italy, Spain and Greece, or back.
- EU East: flights from Germany to an airport in Eastern Europe, including Serbia and Croatia, or back.
- EU South: flights from Germany to an airport in Italy, Albania, Greece, Spain, or back.
- Intercontinental: flights from Germany to an airport which is not in any of the other regions (incl. South America, USA, Africa, Middle East, Asia, Oceania), or back.
- Other: flights which do not touch Germany.

Within these regions a distinction is still made between different distance classes. A hybrid aircraft in the EU West region over a distance of 500 kilometres is thus made up of different real aircraft than in the case of a flight to the same region over 2,000 kilometres since different aircraft are actually used here.

2.3.2 Number of seats

A further important factor in fuel consumption is the number of seats on board. Today's jets are fitted out with seating by the manufacturer in accordance with the airline's specification. The seating can turn out very differently: the seats in Business class are larger and heavier than the Economy seats which generally constitute the major proportion of the seating in a jet. But the airlines also differ in the number of seats which fit in a row. Each airline attempts to configure the seating of its aircraft such that it best meets its customer profile in terms of willingness to pay and comfort requirement.

Since the weight of a jet is determined to a very large extent by the airframe and fuel carried, whether there are many or few passengers on board has little impact on total fuel consumption. Calculations for an Airbus A310, for example, show that the total fuel consumption on a flight of 2,000 kilometres only increases by about 10% if the payload is increased from 60% to 100% (DLR 2000). Aircraft therefore use less fuel per passenger, the more passengers there are on board.

The Emissions Calculator assumes an average number of seats on board a particular aircraft configuration (see Table 3). The figures quoted were determined as follows: the average weighted with the number of aircraft was determined for all the aircraft of a type operated by the main German airlines (Aero Lloyd, Hapag Lloyd, Air Berlin, DBA, Eurowings, Germania, Hamburg international, LTU, Lufthansa, Thomas Cook), based on the year 2002. This average is representative of flights with German airlines. Since, however, other airlines also operate to and from Germany, this "German" average was then averaged again using the manufacturers' standard seating configurations (Janes 1990–2003).

2.3.3 Flight class

There is only a limited area for seating in the body of an aircraft. But there is an almost direct correlation between seating and fuel consumption because the aircraft's fuel consumption changes only slightly depending on whether there are many or few seats. Since, however, Business seats require more space than Economy seats, Business seats take space away from Economy seats where there is a fixed total space available. In an extreme case a Business seat can require more space than two Economy seats. Measured against the total number of seats available in the aircraft, therefore, the impact of Economy passengers on fuel consumption is below average and Business passengers above average. The deciding factor determining how marked this effect is is the ratio of Business to Economy seats and the space requirement of a Business seat compared with an Economy seat. These vary from airline to airline and from aircraft type to aircraft type.

The Emissions Calculator is based on a simple estimate which uses the seating plans of various airlines. It calculates that 20% of the seats are Business Class and these require 1.4-times as much space as the Economy seats. For fuel consumption this means that Economy passengers consume 10% less than the average for all seats, while Business passengers consume 40% more. In individual cases the outcome of this effect can be twice as pronounced.

2.3.4 Seat occupancy rate

The ratio of passengers on board to available seats is termed the seat occupancy rate. As shown above, the seat occupancy rate of passengers on board has a direct impact on fuel consumption per passenger. The seat occupancy rate achieved by the airlines depends on various factors, including ticket prices, the flight type and the flight region. The flight type is generally a distinction between charter and scheduled flights. Charter flights have a higher seat occupancy rate because they are usually chartered long before the flight by travel companies, with the result that the seats are often almost fully occupied. Scheduled flights, on the other hand, generally operate in accordance with a flight schedule. It is therefore possible for some aircraft to take off with few passengers on board if there is no demand at the particular time on the route in question.

The Emissions Calculator addresses these different seat occupancy rates by applying a common average of 80% for charter flights (Öko-Institut 2004). For scheduled flights the seat occupancy rates are also differentiated according to the flight region: for Germany 60%, EU 62%, intercontinental traffic 75% (AEA 2002). If the flight type is not known, an average of 75% is applied.

2.3.5 Transported cargo

Most airlines transport both passengers and cargo in passenger aircraft in order to make the most effective use of their aircraft. The additional cargo carried is generally handled flexibly, taking account of the seat occupancy rate by passengers.

The DLR emissions profiles, which are used to calculate the fuel consumption of the individual aircraft types, do not distinguish between the type of load (DLR 2000). Since, however, additional cargo is generally carried, the fuel consumption per passenger would turn out to be too high if the total fuel consumption were simply divided by the number of passengers. A certain proportion of the fuel must therefore be deducted to allow for the additional cargo. It can be calculated from information on the total cargo and passenger figures in Germany from the Arbeitsgemeinschaft Deutscher Verkehrsflughäfen [ADV – German Airports Association] that the ratio of cargo tonnes to passenger tonnes is around 16% in total (ADV 2003), where a total weight of 100 kg per passenger including baggage is assumed. It is known that approximately half of the cargo is additional cargo (Pompl 2002). The additional cargo proportion is therefore around 8%. In light of the weak correlation discussed above between payload and total fuel consumption this means that a proportion of almost 2% of the fuel consumption can be attributed to the additional cargo. The Emissions Calculator deducts 2% at the end from the consumption results without cargo to correct the systemic error for the additional cargo.

2.3.6 Aircraft engine

Different engines have different emissions figures, and even the same engines on different aircraft types can have quite different emissions figures if they are operated under different load conditions. Most aircraft types can be purchased with different engines from just a few major manufacturers.

Their fuel consumption is very similar for most engines within a class. However, the individual pollutant emissions can vary greatly depending on the manufacturer, e.g. for the nitrogen oxides that contribute to the formation of the greenhouse gas ozone.

The Emissions Calculator uses DLR databases (DLR 2000) in which a frequently used engine is assigned to particular aircraft. Other engines are not taken into consideration in the calculation. This would involve a substantial increase in data which cannot be justified by the insignificant improvement in the accuracy of results.

2.4 Flight distance and the ratio of take-off, cruising and landing of the aircraft

Aircraft fuel consumption is highly dependent on the distance covered. In principle, the absolute consumption is higher in total, the greater the flight distance. On short-haul flights, however, the relative consumption per 100 kilometres covered is higher than on medium-haul flights. The reason for this is that the take-off and initial climb require a great deal of energy and play a greater role on short-haul flights. Long-haul flights also consume more fuel per 100 kilometres than medium-haul flights because for a large part of the flight the aircraft also has to carry the fuel which is only used at the end of the flight.

The Emissions Calculator calculates the distance of a flight as a great circle route (shortest distance between two points on the earth and adds surcharges for detours, holding patterns etc., see para. 2.5) between the departure and destination airports and takes detailed account of the dependence of consumption on the climb, cruise and descent phases of a particular aircraft type.

Correlation between fuel consumption and distance
Fig. 1 below shows as an example the calculated fuel consumption of a fully occupied Airbus A340 with 271 seats as a function of the distance covered. The fuel consumption is given in litres kerosene per passenger per 100 kilometres. It is clearly apparent that consumption per 100 kilometres is at its lowest on medium-haul flights of around 2,000 kilometres in length, reaching figures of approx. 3.7 litres kerosene per passenger per 100 kilometres. On short- and long-haul flights, on the other hand, consumption is higher. The consumption figures can deviate widely from this example for other aircraft types, but the fundamental dependence of the consumption on the distance is characteristic of most modern jet aircraft.

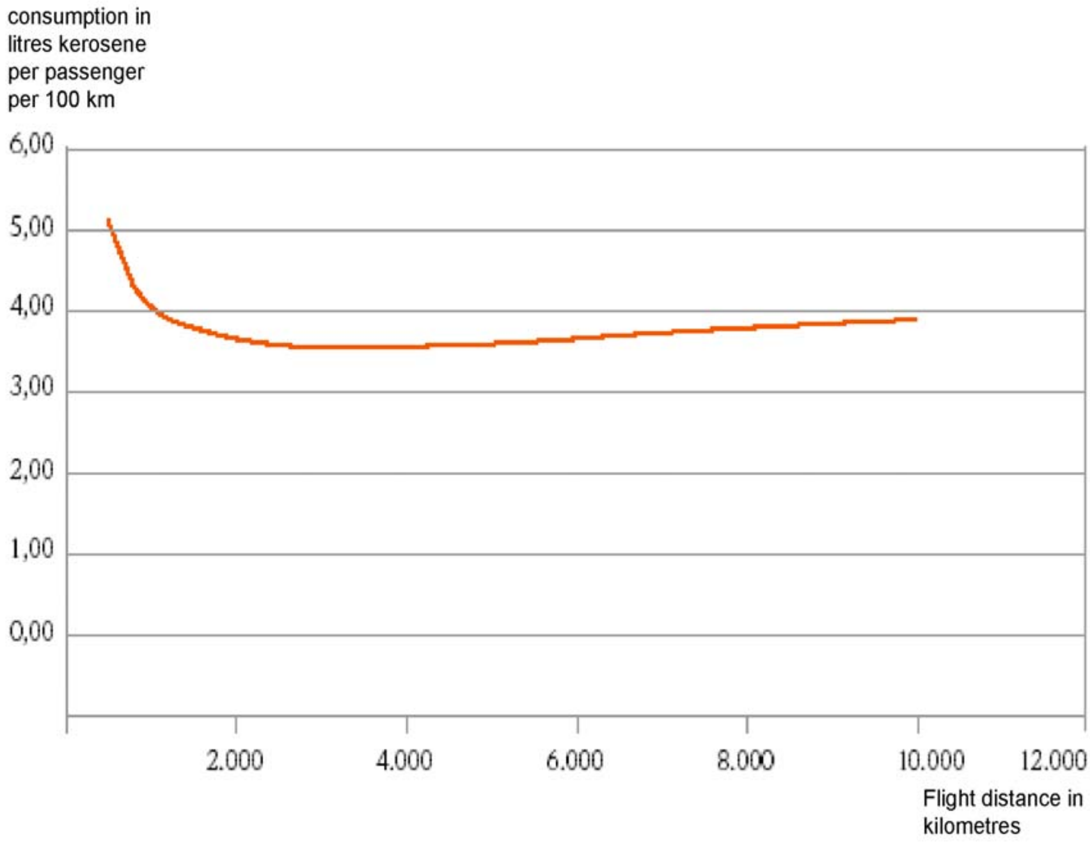

Fig. 1: Fuel consumption of a fully occupied Airbus A340 with 271 seats as a function of flight distance. Source: DLR 2000

2.4.2 Taking account of the distance in the Emissions Calculator

There are two stages to the Emissions Calculator: in the first stage it calculates the flight's great circle distance (shortest distance between two points on the earth) from the geographic coordinates of the departure and destination airports. To this are added default values for detours, holding patterns etc. (see para. 2.5). In the second stage the Emissions Calculator calculates the fuel consumption of a particular aircraft as a function of the distance. Here the Calculator operates on the basis of altitude profiles. These indicate the flight altitude of a flight in comparison with the
distance covered. Fig. 2 shows examples of typical simplified altitude profiles. It is apparent that each flight consists of three phases:

1. Climb phase, in which the aircraft climbs to its cruising altitude after take-off. This phase can be between about 50 kilometres and about 300 kilometres long.
2. Cruise phase, in which the aircraft covers a certain distance at a constant altitude. This phase can vary from one hundred to several thousand kilometres, depending on the total distance. The flight altitude of this phase varies: on short-haul flights it is in the range from about 5 to 7 kilometres, on long-haul flights it is frequently approx. 10.5 kilometres to about 13 kilometres.
3. Descent phase, in which the aircraft descends from its cruising altitude again until landing. It is often as long as or slightly longer than the climb phase.

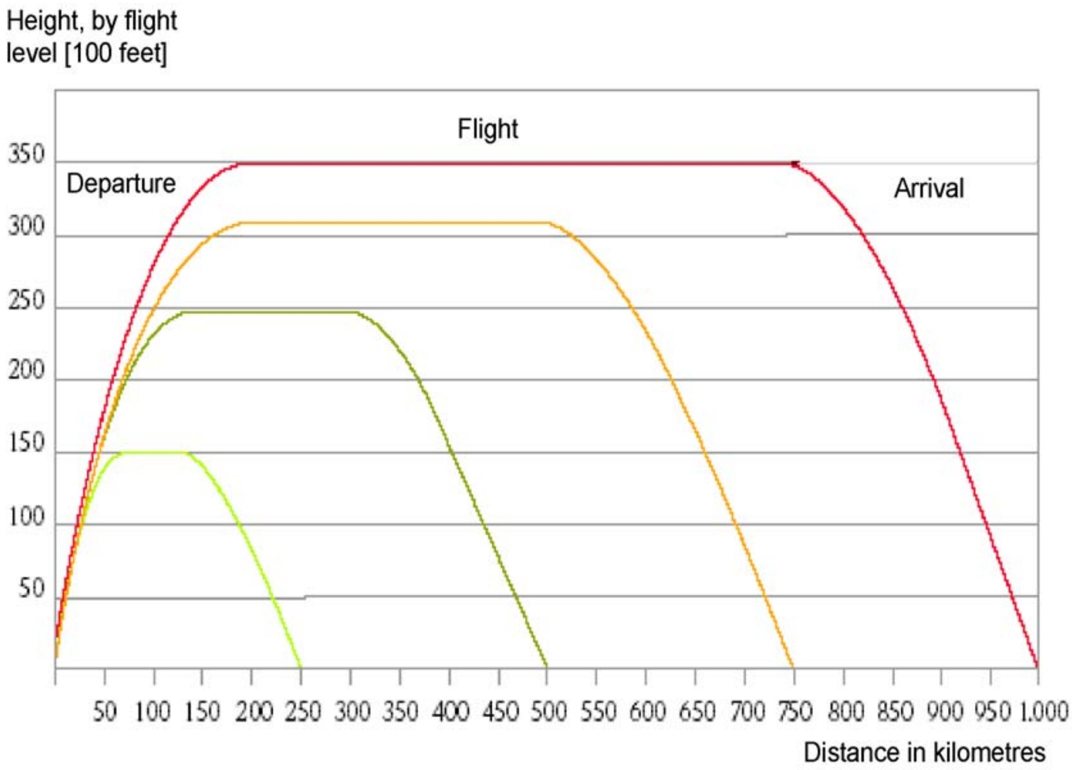

Fig. 2: Altitude profile of flights of different distance. On flights of 1,000 kilometres and more in length aircraft frequently climb to flight level 350 (approx. 10.7 kilometres altitude), on flights of 250 kilometres in length to flight level 150 (approx. 4.5 kilometres altitude). Further altitude profiles for flights up to 10,000 kilometres in length are not shown in the figure. Source: DLR 2000

The Emissions Calculator has stored these standardised altitude profiles and the associated fuel consumptions during the three flight phases for the commonest aircraft types (DLR 2000). 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 kilometres (provided the aircraft has this range).

In order to calculate the fuel consumption over a specified actual distance for a customer's particular flight, the Emissions Calculator takes the consumptions during the climb and descent phases of the profile which is closest to the total distance of the customer's flight and extends or shortens the cruising phase as appropriate. As there are up to 8 different standard profiles available per aircraft type, this method reasonably simulates the actual flights within the realm of the technically feasible.

Example: a customer flies in a Boeing 737-400 from Frankfurt to Barcelona (distance approx. 1,140 kilometres). For this the Emissions Calculator uses the altitude profile of the B 737-400 for a 1,000-kilometre flight and takes the fuel consumption figures for the climb and descent phases directly from this. Since, however, the standard profile is 140 kilometres shorter than the actual flight, the Calculator artificially extends the cruising phase of the profile by 140 kilometres. The cruising phase fuel consumption is correspondingly extrapolated. Finally, the fuel consumptions of the three phases are added to obtain the total fuel consumption for the flight to Barcelona.

2.4.3 Discussion of the method used

The method used here represents a refinement of an existing method. The basic method was developed in 2000 in a study for the German Federal Environmental Agency by the German Technical Inspectorate (TÜV) and the German Aerospace Center (DLR) to calculate a German aviation emissions register (TÜV 2000). It was further differentiated for the Emissions Calculator by incorporating the separate capture and interpolation of climb, cruising and descent phases. As a result of this interpolation discontinuity can occur at limits of distance categories (if, for example, a 5,499-kilometres flight is calculated using the 4,000-kilometre profile, and 5,501-kilometre flight is calculated using the 7,000-kilometre profile). Such discontinuity cannot be avoided in simple calculation programs and can be ignored in light of the overall uncertainties.

2.5 Wind, detours, holding patterns and taxiing at the airport

Headwind, detours from the great circle distance as the shortest connection between two points, holding patterns in the vicinity of the airport and taxiing to and from the runway consume fuel. The Emissions Calculator does not take explicit account of the effect of wind since it assumes that this effect is cancelled out in the course of a return flight. The other factors are taken into account by means of standard fixed corrections which have mostly been derived from aviation studies in Germany.

2.5.1 Wind

The aircraft is always exposed to the prevailing wind conditions en route from the departure to the destination airport. In our region (Europe) the characteristic feature is the West Wind Drift. The headwind on westward flights therefore increases fuel consumption on average per 100 kilometres and the tailwind reduces it on eastward flights.

The Emissions Calculator assumes that most flights are undertaken in pairs, i.e. there is a corresponding return flight for each outward flight. Thus the effects of a headwind or tailwind on fuel consumption cancel each other out on average, and no further allowance is therefore made for them.

2.5.2 Detours

The kilometres flown by an aircraft en route from the departure to the destination airport in addition to the great circle distance (which corresponds to the shortest connection between two points on the earth) are deemed detours. These do not include the holding patterns which are counted separately (see below). Detours are captured statistically. Fig. 3 shows the detours on flights in Germany, in the form of the detour factor (quotient of actual flight distance including detour divided by great circle distance) as a function of the great circle distance. If the detour is expressed in absolute terms, it is in the region of 50 kilometres for almost all flight distances. Similar studies of long-haul flights come to the same results.

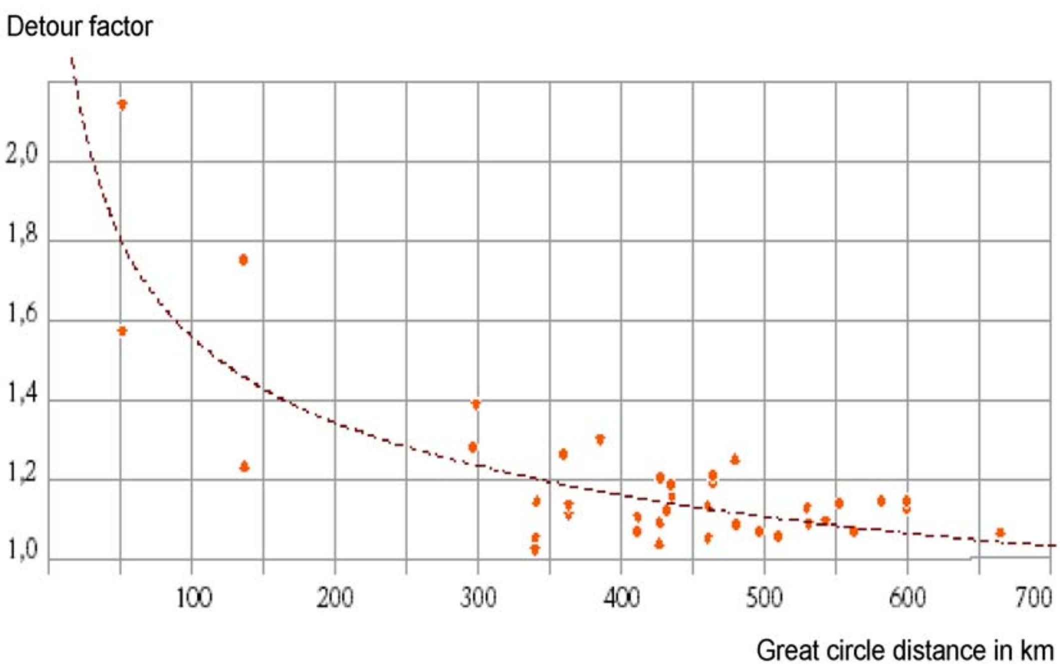

Fig. 3: Correlation between detour factor and great circle distance

The Emissions Calculator takes account of this empirical result by adding the approximately constant detour as a fixed figure to all flights. This seems adequately precise in view of the low significance of this factor.

2.5.3 Holding patterns

Aircraft fly in holding patterns at the destination airport if the landing runways are not yet free. The Lufthansa Environmental Report shows that almost 1 kilogram fuel is consumed per passenger on average (Lufthansa 2002). Since further details were not available, the Emissions Calculator uses this these factor here as a fixed surcharge for all flights, even if they do not touch Germany. While this is undoubtedly inexact, it seems appropriate, given the low overall significance of this effect.

2.5.4 Taxiing before take-off and after landing

Before taking off, aircraft have to taxi from the terminal to the runway and use up fuel which is not included in the flight profiles. The same applies to taxiing to the terminal after landing. In Germany an aircraft spends on average almost 15 minutes per flight taxiing on the ground. The engines are running at low power during this time. A study of the fuel consumption for taxiing at domestic German airports concludes that approx. 2.5 kilograms kerosene were consumed per passenger for the two taxiing processes together (Brockhagen 1995). This quantity is also assumed by the Emissions Calculator as a fixed surcharge for all other flights from and to as well as outside Germany. While this is undoubtedly inexact, it seems appropriate, given the low overall significance of this effect.

3. On what data sources is the Emissions Calculator based?

The specifications of the clients, Germany's Federal Ministry for the Environment and Germanwatch, were complied with in designing the Emissions Calculator, i.e. only independent scientific data sources were to be used for the Emissions Calculator. All the main sources for the Emissions Calculator are therefore the results of independent scientific studies commissioned by the German Federal Environmental Agency, the United Nations or the EU. Further data is derived from the published specialist literature or relevant directories. Only in two cases were figures from aerospace industry publications used because they were the only ones available. These relate to the fuel consumption in holding patterns and the seat occupancy rate of aircraft on scheduled flights in different regions. In terms of their weight these are small (holding patterns) or consistent with the known degrees of magnitude (seat occupancy rate), as a result of which their use is uncontroversial.

3.1 DLR database

The German Aerospace Center (DLR) conducted emissions calculations for the commonest jet aircraft types in a research project for the German Federal Environmental Agency (UBA). The results are summarised in a database containing the consumption and emissions data as a function of altitude and distance (DLR 2000). The aircraft type/engine combinations are shown in Table 3 together with the standard distances. This database is at the heart of all the Emissions Calculator's calculations.

3.2 UBA study

A study into polluter-related pollution reduction in the aviation sector was conducted between 1996 and 2000 on behalf of the UBA. This study recorded in detail the air traffic from, to, in and over Germany in 1995 (TÜV 2000). Air traffic was broken down into five regions: domestic German, Eastern, Southern and Western Europe and intercontinental. Within these regions the aircraft types in operation were recorded and broken down by different distance classes. This is the data from which the Emissions Calculator constructs the "hybrid aircraft" if the customer does not know the aircraft on which he flew or is to fly.

3.3 IPCC

The United Nations Intergovernmental Panel on Climate Change (IPCC) is the world's ultimate scientific authority on climate change. Its reports always formed the basis for the international climate negotiations of the member states of the United Nations (see www.ipcc.ch). The IPCC published a special report on aviation in 1999 (*www.grida.no/climate/ipcc/aviation/index.htm*). This details all the fundamental effects of aviation on the climate in detail. The Radiative Forcing Index for determining the equivalent climate impact of non-CO_2 emissions (see para. 2.1), in particular, was derived from this report.

3.4 Specialist literature

A few constant factors such as the average taxiing time at German airports were taken from the published specialist literature (Brockhagen 1995).

3.5 Aircraft directories and fleet databases

The publishers Bucher and Jane publish annual directories containing a wealth of technical details on the equipment configurations of aircraft and fleets (Bucher, Jane). These were used as the basis for calculating the number of seats on board a particular aircraft type.

3.6 Aerospace industry publications

This includes Lufthansa's Environmental Report, which contains information on fuel consumption in holding patterns, and the annual report of the Association of European Airlines (AEA), which contains detailed information on the seat occupancy rates of the major European airlines in different flight regions.

Statistics from the ADV were used to address the extra consumption as a result of the additional cargo (ADV 2003).

3.7 Experts' estimates

For some data there was no up-to-date published literature. In these cases experts' estimates or unpublished research reports were used, both from the German Aerospace Center. This applies to the detours flown for different flight distances.

3.8 Overview of data sources

Table 1 summarises the data sources for the Emissions Calculator's individual parameters.

Parameter in the Emissions Calculator	*Data source*
Pollutants, climate impact, RFI	*IPCC 1999*
Fuel consumption, aircraft types, engines, transported cargo	*DLR 2000*
Standard distances, flight altitude, flight profile	*DLR 2000*
Hybrid aircraft, composition	*TÜV 2000*
Number of seats on board an aircraft	*Bucher 2003, Jane's 2003*
Seat occupancy rate	*Ökoinstitut 2004, AEA 2002*
Detours DLR, unpublished fuel consumption in holding patterns	*Lufthansa 2002*
Fuel consumption, taxiing to and from runway	*Brockhagen 1995*
Additional cargo	*DLR 2000 and ADV 2003*

Table 1: Data sources for the atmosfair emissions calculator

4. How accurate are the methods and results?

The Emissions Calculator is based on methods and data sources which permit the equivalent climate impact of a flight to be calculated with an appropriate degree of accuracy. The Calculator works with different levels of accuracy depending on the customer's input. The central factors for the equivalent climate impact of a flight are captured and simulated by the Emissions Calculator. The data sources and methods are of high quality and represent the scientific state of the art.

4.1 Uncertainty factors

A compromise between accuracy and data volume was struck when designing the Emissions Calculator. The most important factors are simulated, if at all possible, without giving an exaggerated impression of accuracy. Table 2 lists the main uncertainty factors which play a role in the accuracy of the result in the chain from the passenger via the aircraft type and the airline to the equivalent climate impact of the emissions.

Table 2: Overview of the uncertainty factors in the Emissions Calculator

Field	*Factors*	*Estimated uncertainty*	*How addressed in Emissions Calculator*
Aircraft	*Aircraft type*	*Moderate (approx. 25%)*	*Detailed*
	Seating	*Moderate (approx. 25%)*	*Average*
	Seat occupancy rate	*Moderate (approx. 25%)*	*Detailed*
	Engine type	*Moderate (approx. 10%)*	*As standard*
	Condition of aircraft and engines	*Low (<5%)*	*Not addressed*
Flight	*Specific fuel consumption as a function of flight distance*	*High (50%)*	*Detailed*
	Detours	*Low (<5%)*	*Fixed surcharge*
	Holding patterns	*Low (<5%)*	*Fixed surcharge*
	Weather (wind, temperature etc.)	*Low (<10%)*	*Average*
Emissions	*Current state of atmosphere (temperature, humidity etc.)*	*High (approx. 100%)*	*Average*
Climate impact	*Scientific knowledge level to IPCC 1999*	*Moderate (approx. 30%)*	*Average*

The uncertainty factors have different weightings. The factors with low weighting were adequately addressed by inclusion as a fixed surcharge. Allowances for external factors, such as the present state of the atmosphere at the time of the flight, were made by using averages. Averages were also used to deal with those uncertainties which result from different equipment configurations for aircraft of the same type. The Emissions Calculator takes detailed account of those factors which would, if fixed surcharges were used, have a highly uncertain impact on the result, particularly the aircraft type, the seat occupancy rate and the dependence of the specific fuel consumption on the flight distance.

The only important factor which is not taken into account is the respective airline. This would have a direct impact on emissions in that the airline itself determines the number of seats on board a particular aircraft type directly and spends more or less on maintaining the airframe and engines. While the latter factor has only a slight impact and was therefore not taken into account, it could be desirable in the long term to simulate the former factor in the Emissions Calculator too. However, this could only be achieved at the cost of a huge increase in the amount of data gathered since the seating can change and even within an airline there are often the same aircraft types with different seating configurations. At present this seems to be out of proportion to the targeted result.

4.2 Data quality

At the heart of the data sources used is the database containing the fuel consumption profiles of individual aircraft over different basic distances. This data is provided by the German Aerospace Center (DLR 2000). The quality of this data is high, and it was used as the starting point for emissions registers in the IPCC report commissioned by the United Nations.

4.3 Methodological quality

The emissions calculations are based on the method of distance- and altitude-dependent fuel consumption (see para. 2.4). This method is a refinement of an existing method. The basic method was developed in 2000 in a study for the German Federal Environmental Agency by TÜV and the DLR to calculate a German aviation emissions register. It was further differentiated for the Emissions Calculator by incorporating the separate capture and interpolation of climb, cruising and descent phases.

4.4 No spurious accuracy

Table 2 also shows that it is impossible to give a fixed figure of X or Y% for the overall accuracy of the Emissions Calculator. On an individual flight the seat occupancy rate or the atmospheric properties, for example, can vary greatly in the case from the averages used. This would mean that the climate impact of this one flight would differ very greatly from the calculated average. These inaccuracies are, however, specified by the system, and it would not be sensible to want to eradicate them, even if the ability to do so were available. Ultimately neither an airline nor a customer can do anything if the general weather situation at the time of his flight is such that harmful condensation trails form at the specified flight altitude. In future it may be feasible and desirable to fly above or below these critical atmospheric layers by specifically varying the altitude. Until such time there is no point in including this factor in the calculation.

It is also true with reference to the seat occupancy rate on a particular flight that a customer may by chance fly on an aircraft where every seat is occupied and he therefore consumes less fuel in relative terms than in an empty aircraft. Since this result is purely fortuitous for him, however, the system would give the customer the pretence of accuracy if this actual factor were to be included when ultimately it is a matter of chance.

4.5 Three different accuracy levels

The Emissions Calculator operates at three different accuracy levels. Which of these applies depends, firstly, on whether the customer knows the aircraft type and, secondly, whether or not the flight touches Germany.

If the customer knows the aircraft type and inputs it from the input screen, the emissions are calculated directly via the aircraft type. This means that in this case the Emissions Calculator can deliver accurate data, irrespective of a customer's destination.

If the customer does not know the aircraft type, the first step is to determine the flight region (e.g. EU West or Germany). Then a "hybrid aircraft" is used as a function of the distance to calculate the emissions (see para. 2.3.1). The composition of this hybrid aircraft is based on empirical flights to and from Germany.

If the customer does not know the aircraft and he enters a flight which does not touch Germany (e.g. from New York to Rio de Janeiro), the Emissions Calculator works on the basis of aircraft types which are most commonly used worldwide on particular routes. This means that accuracy is reduced by comparison with the first two accuracy levels.

The seat occupancy rates are also captured more accurately at levels 1 and 2 because regionally-dependent figures are available here for scheduled flights.

5. Overview: aircraft types, seating, engines and standard distances

Tables 3 and 4 show the aircraft types used by the Emissions Calculator with the assumed standard engines, the assumed seating and the possible standard distances which form the basis for interpolation to the exact flight distance (see para. 2.4).

Table 3 shows the figures for the individual aircraft types captured, while Table 4 shows the "hybrid aircraft" which the Emissions Calculator uses if the customer does not know the aircraft type.

Aircraft type	*Code*	*Engines*	*Seats*	*Standard distance [km]**
Airbus A300	*EA30*	*CF6-80C2B1F*	*271*	*250, 500, 750, 1,000, 2,000, 4,000, 7,000*
Airbus A310	*EA31*	*CF6-80C2A2*	*228*	*250, 500, 750, 1,000, 2,000, 4,000, 7,000*
Airbus A320	*EA32*	*CFM56-5A1*	*150*	*250, 500, 750, 1,000, 2,000, 4,000*
Airbus A330	*EA33*	*PW4168*	*340*	*250, 500, 750, 1,000, 2,000, 4,000, 7,000*
Airbus A340	*EA34*	*CFM56-5C2*	*271*	*500, 750, 1,000, 2,000, 4,000, 7,000, 1,0000*
Boeing 737-300	*B73S*	*CFM56-3-B1*	*126*	*250, 500, 750, 1,000, 2,000, 4,000*
Boeing 737-400	*B73F*	*CFM56-3C-1*	*157*	*250, 500, 750, 1,000, 2,000, 4,000*
Boeing 737-500	*B73V*	*CFM56-3B-1*	*106*	*250, 500, 750, 1,000, 2,000, 4,000*
Boeing 747-200	*B747*	*CF6-50E2*	*421*	*500, 750, 1,000, 2,000, 4,000, 7,000, 10,000*
Boeing 747-400	*B74F*	*CF6-80C2B1F*	*403*	*750, 1,000, 2,000, 4,000, 7,000, 10,000*
Boeing 757	*B757*	*RB211-535E4*	*243*	*250, 500, 750, 1,000, 2,000, 4,000, 7,000*
Boeing 767	*B767*	*PW4060*	*268*	*500, 750, 1,000, 2,000, 4,000, 7,000, 10,000*
DC-9	*DC9*	*JT8D-11*	*105*	*250, 500, 750, 1,000, 2,000, 4,000*
DC-10	*DC10*	*CF6-50C2*	*270*	*500, 750, 1,000, 2,000, 4,000, 7,000, 10,000*
Lockheed Tri-Star	*L101*	*RB211-524B*	*256*	*750, 1,000, 2,000, 4,000, 7,000*
MD-11	*MD11*	*PW4460*	*298*	*500, 750, 1,000, 2,000, 4,000, 7,000, 10,000*
MD-82	*MD82*	*JT8D-217*	*142*	*250, 500, 750, 1,000, 2,000, 4,000*
TU-154M	*TU54*	*NK-8-2U*	*166*	*250, 500, 750, 1,000, 2,000, 4,000*
Fokker 100	*FK10*	*TAY620-15*	*112*	*250, 500, 750, 1,000, 2,000*
BAe 146	*BA46*	*ALF 502R-5*	*86*	*250, 500, 750, 1,000, 2,000, 4,000*

Table 3: Aircraft types, assumed engines, seating and standard distances of the stored fuel consumption and altitude profiles

** The standard distances are the basis for interpolation to actual flight distances, see para. 2.4*

Table 4: Hybrid aircraft and their composition from actual aircraft types as a function of flight region and distance

Region	Hybrid aircraft composed of (code, see Table 3)	Seats	Standard distance [km]
Germany	B73F, EA32, EA31, B757	176	250
Germany	B73S, EA32, B73V, B37F	128	500
Germany	B73S, EA32, B73V, B37F	128	750
Germany	B73V, MD82, B757, B73S	137	1,000
EU East	B73F, EA32, EA31, B757	176	250
EU East	B73S, EA32, B73V, B37F	128	500
EU East	B73S, EA32, B73V, B37F	128	750
EU East	B73S, B73V	117	1,000
EU East	B73S, TU54, EA32	148	2,000
EU East	EA31, TU54	178	4,000
EU South	B73F, EA32, EA31, B757	176	250
EU South	B73S, EA32, B73V, B37F	128	500
EU South	B73S, EA32, B73V, B37F	128	750
EU South	B73S, BA46	115	1,000
EU South	B73F, B73S, MD82, EA32, B757	164	2,000
EU South	EA31, B757, EA30	230	4,000
EU West	B73F, EA32, EA31, B757	176	250
EU West	B73S, EA32, B73V, B37F	128	500
EU West	EA32, FK10, B73S, BA46	123	750
EU West	B73V, MD82, B757, B73S	137	1,000
EU West	EA32, BA46	119	2,000
EU West	EA31, B757, EA30	230	4,000
International	B73F, EA32, EA31, B757	176	250
International	B73S, EA32, B73V, B37F	128	500
International	B73V, MD82, B757, B73S	137	1,000
International	EA32, BA46	119	2,000
International	EA31, B757, EA30	230	4,000
International	B767, B747, EA310, DC10	333	7,000
International	B767, B74F, EA34, MD11	331	10,000
Other	B73F, EA32, EA31, B757	176	250
Other	B73S, EA32, B73V, B37F	128	500
Other	EA32, FK10, B73S, BA46	123	750
Other	B73V, MD82, B757, B73S	137	1,000
Other	EA32, BA46	119	2,000
Other	EA31, B757, EA30	230	4,000
Other	B767, B747, EA310, DC10	333	7,000
Other	B767, B74F, EA34, MD11	331	10,000

The standard distances are the basis for interpolation to actual flight distances, see para. 2.4

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