# ASSESSMENT OF ULTRAFINE PARTICLES ON AIRCRAFT CABIN AT DIFFERENT PHASES OF FLIGHT

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## ABSTRACT

Indoor air quality contributes to one's comfort, wellbeing and work productivity depending on whether it is contaminated or not. Aircraft cabin environment is a type of indoor environment, which is different in terms of its need for pressurization, high occupant density and movement restriction thereby posing danger to both passengers and crew. The present study was aimed at studying the cabin air quality by ascertaining ultrafine particles on aircraft cabin at different phases of flight. Air samples were collected from 100 flights of 5 different aircraft types (B757 cargo, BAe 146, BAe 757, Airbus 319 and Airbus 320) at the 10 different phases of flights from engine start to landing and taxi-in. Mean, median and quartile values of ultrafine particle concentrations were calculated for the 10 phases of flight for individual aircraft types. The result revealed that, phases of flight where the aircraft were on ground had the higher mean values for all aircraft than other flight phases when the aircraft is in air thereby suggesting different particle sources for ground and air. Also Boeing 757 passenger aircraft recorded the highest particle concentration compared to the other 4 aircraft types. This also occurred while aircraft were on the ground, prior to the engines being started. Ultrafine particle concentration in both ground and air phases seem to be comparable with those in other indoor environments, suggesting fewer particle sources within the cabin itself and also effectiveness of the aircraft air conditioning system in removing or minimizing ultrafine particles.

**Keywords**: Indoor pollutants, Aircraft, Phases of flight.

## INTRODUCTION

Indoor environment represents an important microenvironment in which people spend most of their time each day (Haliosand Helmis, 2010). However, occupants of this highly complex environment may be exposed to a vast number of contaminants which could be in the form of gases and particles (Arvanitis *et. al.,* 2010, Oberdorster *et. al.,* 2005). As such, indoor air quality is the totality of attributes of indoor air that affect one's health and wellbeing. Exposure to poor indoor air quality can result to adverse health effects such as headaches, fatigue, and shortness of breath, sinus congestion, cough, sneezing, skin irritation, and dizziness, nausea, and eye, nose and throat irritation with some individuals being more sensitive to indoor air than others (Hudda *et. al*., 2018, 2014; Geiser *et. al*. 2005). Susceptible groups include people who suffer from allergies, respiratory disease, those with decreased immunity, and those that suffer eye problems (Oberdorster *et. al*., 2005). It has also been related to Sick Building Syndrome, reduced productivity in offices and impaired learning in schools (Apte and Erdmuann, 2002).

The aircraft cabin is a similar environment like other indoor environments, such as homes, offices and schools, in the sense that its occupants are exposed to a mixture of outside and recirculated air (Hudda *et. al*., 2018). However, the cabin environment is different in many aspects like high occupant density, the restriction of occupants to move at will, and the need for pressurization (IEH, 2011). Low air pressure and low humidity are some of the environmental factors that people encounter in a flight. Similarly, exposure to air pollutants like ozone, carbon monoxide (CO), various organic chemicals, allergens, irritants and biological agents are some of the pressing factors. Such exposures normally occur when the plane moves from taxiing and take - off through cruising to landing (NRC, 2002). Consequently, precautionary measures are taken by equipping the planes with environmental control system which helps in maintaining safer, healthier and comfortable environment for both the passengers and the crew (Keuken *et. al*., 2015).

Indoor sources of contaminants inside the cabin are associated with the passengers and crew in the form of bio effluents, viruses, bacteria, allergens, and spores; these contaminants are shed from clothing or skin or expelled from oral, nasal, or rectal orifices, dust, and pesticides (Geiser *et. al*., 2005; Oberdorster *et. al*., 2005). The present study was aimed at assessing ultrafine particles on aircraft cabin at different phases of flight.

## MATERIALS AND METHODS

### Sampling Instruments/Strategy

A total of 981 samples were collected from pumped sorbent tube samples and analysed. Sampling was carried out according to the Institute of Environmental Health (IEH, 2011) where three different instruments, including photo ionisation detector, p-trak (condensation particle counter) and air sampling pump, were used for the sampling. Boeing 757, Airbus A320/1, BAe 146, Airbus A319 passenger aircraft and Boeing 757 cargo aircraft were the aircraft types investigated in the study. The photo ionisation devices were placed in a cup holder, in the webbing behind the Captain's, First Officer's seat and held with elastic cords and string carried for the purpose. The pumps were kept in an open flight bag on the floor, and held in place by their integral clips, while the P-trak instrument was placed on the floor.

**Data Collation**

Five minutes (5 minutes) concentration of the ultrafine particles data collected was calculated for all the phases of flights of the 100 flight samples. Also times are recorded on a log sheet which was used to match up with the times in the ultrafine data file. The ultrafine particle analysis was carried out using a filled "sampling record" sheet as a guide to identifying the timing of the samples and a data file containing the particle data collected. The sampling record sheet contains all details about the flight type and number, duration of flight and also the time at which each flight phase begins and ends. Since the particle counter used was logged at an interval of one second, every five minutes mean contains up to 300 data.

**Phases of Flight**

The mean (±standard deviation) of the ultrafine concentration of each phase of flight individually from immediate to taxi -in for each of the 5 aircraft types were determined. Each of the phases contains about 20 data from the 20 sectors of each flight type. This analysis was used to look at the relationship between the concentration levels of ultrafine particle at phases of flight for individual aircraft types.

**Aircraft Types**

The concentration of the ultrafine particles between different aircraft types was analysed by comparing the data of each of the 10 phases of flights for the 5 aircraft types. The mean, median, standard deviation, percentiles, maximum and minimum values were calculated.

**RESULTS**

The results are presented in mean and standard deviation values for each aircraft type and its phases of flight. For Boeing 757 cargo, the highest mean concentration value and standard deviation was recorded at the first three phases with immediate phase having the highest values of 38898 particle/$cm^{-3}$. Decrease in concentration value was noticed from taxi-out to pre landing phase from where a slight increase occurred at taxi-in phase. The start off descent phase recorded the lowest mean and standard deviation value of 80 (±45) particle/$cm^{-3}$, respectively (Figure 1).

Results of the Boeing 757 passenger, shows the immediate phase and engine on phase as having the highest mean and standard deviation value of 5795 particle/$cm^{-3}$ and 115822 for immediate phase while 26545 particle/$cm^{-3}$ and 58249 for engine on phase, respectively. The concentration levels were low from taxi -out to taxi -in phase, with cruise phase having the lowest value of 116 (±70) particle/$cm^{-3}$ as mean (±standard deviation) (Figure 2).

Results of the Airbus A320/1 flight shows that, the mean counts were high at the first 4 phases from (immediate to take off), with immediate phase recording the highest mean and standard deviation values of 26,846 particle/cm$^{-3}$ (±20,429). The counts were then low for the next 5 phases from during climb to pre landing, with cruise phase recording the lowest count of 55 particle/cm$^{-3}$. A high increase in the mean count was recorded at the taxi–in phase (20,755 particle/cm$^{-3}$) (Figure 3).

The result of BAe 146 indicated that, the mean concentration values were higher at the first 4 phases of the flight immediate to take– off, with immediate phase recording the highest values of 32191 particle/cm$^{-3}$. It was low for the next 4 phases with a slight rise from the pre – landing to taxi –in phase. Top -of -climb phase recorded the lowest mean count of 99particle/cm$^{-3}$ (Figure 4).

The result of BAe 146 indicated that, the mean concentration values were higher at the first 4 phases of the flight immediate to take - off, with immediate phase recording the highest values of 32191 particle/cm$^{-3}$. It was low for the next 4 phases with a slight rise from the pre– landing to taxi –in phase. Top –of–climb phase recorded the lowest mean count of 99 particle/cm$^{-3}$ (Figure 5).

## DISCUSSION

Overall, the immediate phases were shown to have the highest particle count where the lowest maximum concentration was recorded from cruise phase with a value of 157 particle/cm$^{-3}$. The general pattern for all the phases of flight seems to be the same across all the aircraft types, with all the aircraft having higher concentration value at their initial (Immediate to take –off) and last phases (Taxi –in) and lower concentration at the middle phases from during climb to pre – landing phases. This analysis was done for the five different aircraft types. Higher values were mostly recorded at the first four phases of flight for the 5 air craft types, with the immediate phase recording the highest mean concentration values at all flights. For all the 5 aircraft types, the immediate phase mean concentrations values recorded are 38898, 57951, 26846, 32191 and 37442 particles/cm$^{-3}$, respectively. The lowest particle counts were recorded at the 5$^{th}$ to 9$^{th}$ phases (During climb to pre – landing phases), with Cruise phase recording the lowest count of 55 pp/cc. There was a slight increase in concentration values between pre – landing phase and taxi –in phase for Boeing 757 cargo and passenger, BAe 146 Airbus A319, while Airbus A320/1 Taxi - in phase recorded a peak increase from 3327particle/cm$^{-3}$ at Pre landing to 20755particle/cm$^{-3}$. Results of the five aircraft types showed negative standard deviation in some of the phases, which suggests that the data are right skewed and the methodology used may not have been the best way of testing it. This was more vividly captured by Hudda *et. al*. (2018) where box and whiskers plot with error bars of quartiles rather than standard deviation were used in a study of aviation – related impacts on ultrafine particle number concentration.

The result further shows that most of the concentration levels were peak at the initial phases (Immediate to Take – off) and the last phase (Taxi – in) which coincidentally occurred at phases when the aircraft is on ground. Activities that occur at these first three phases (Immediate, Engine On and Taxi – out) and 10th phase (Taxi – in) include engine start and taxiing when door has been shut with all passengers seated, and engine off and disembarking in case of Taxi – in Phase. It seems probable that such peak level of particle count at this phases (ground) may be from incomplete combustion, the outside air (dust from passengers during boarding and smoke from own engine) or from other aircrafts. Other potential sources at the ground phases are vehicles used for maintenance, loading and unloading of luggage to and from aircrafts, and also from cooking or food preparation in the aircraft. According to NRC (2002), particle concentrations are higher during boarding and disembarking. This theory coincides with the concentration values of this study during Immediate and Taxi – in phases where boarding and disembarking takes place. However, for the other 5 phases (During Climb, Top – of – Climb, Cruise, Start – of – Descent and Pre – landing) which recorded lower levels of concentration, which also occurred at air phases when the aircraft climbs above 20,000ft to when it comes down to 2,500 feet, the potential sources of ultrafine particles at these air phases could be from contaminated re-circulated air, from passenger's activities such as sneezing, coughing, spitting, groaning, etc. Similarly, it could also be the result of food preparation since cooking has been proved as a source of ultrafine particles in several studies of other indoor environments like homes, with concentration levels exceeding 100,000 particles/cm$^{-3}$. (Hudda *et. al*., 2018; Wallace and Ott, 2011). Also lower concentrations recorded at the air phase when compared to the ground phase could be related to fewer or smaller sources combined with effective filtration of recirculated air by the aircraft air conditioning system.

## CONCLUSION AND RECOMMENDATIONS

It can be concluded that, phases where the aircraft are on ground (Immediate, Engine-on, Taxi out and Taxi in) had higher concentration values than airborne phases (During Climb, Top of Climb, Cruise, Start of Descent and Pre Landing). However, the difference in concentration level at the two different phases (ground and air) and the existence of two apparently distinct statistical distributions suggests different sources of the ultrafine particles for the ground and air phases. This difference in concentration between the ground and air phases may also be suggestive of fewer sources of ultrafine particle in the airborne phases than the ground phases or that, the aircraft air conditioning systems are effective towards removing or minimizing particles within the cabin itself.

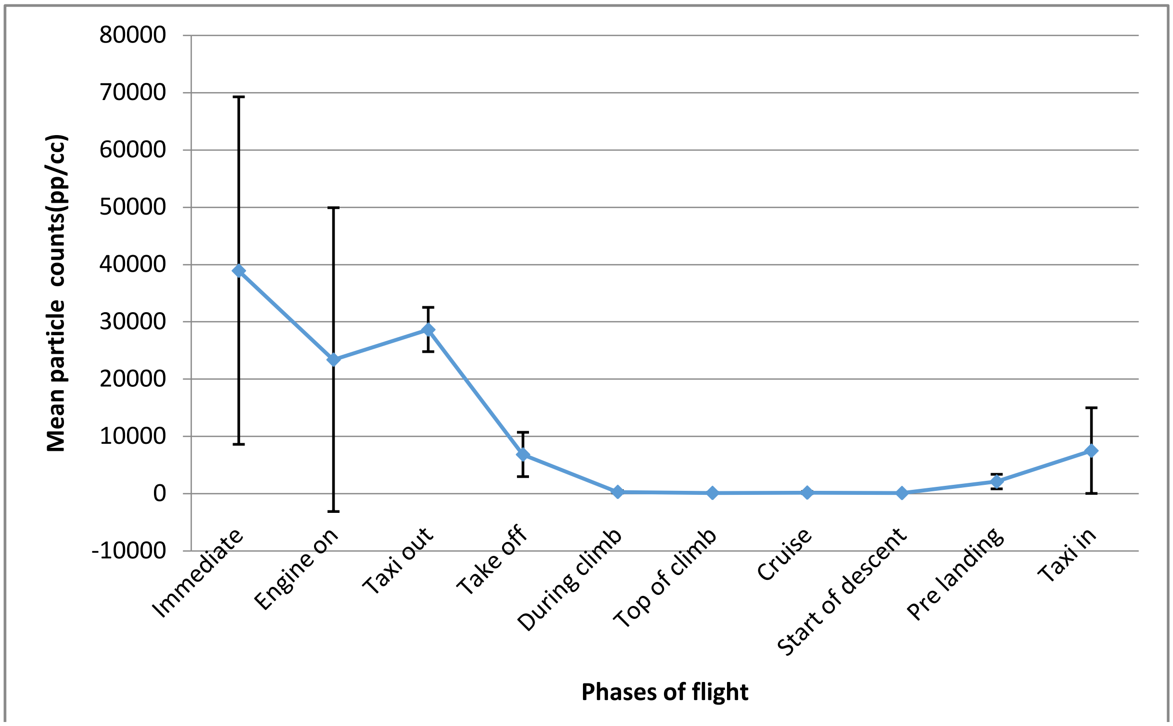


Figure1: Mean Particles Concentration in Boeing 757 Cargo

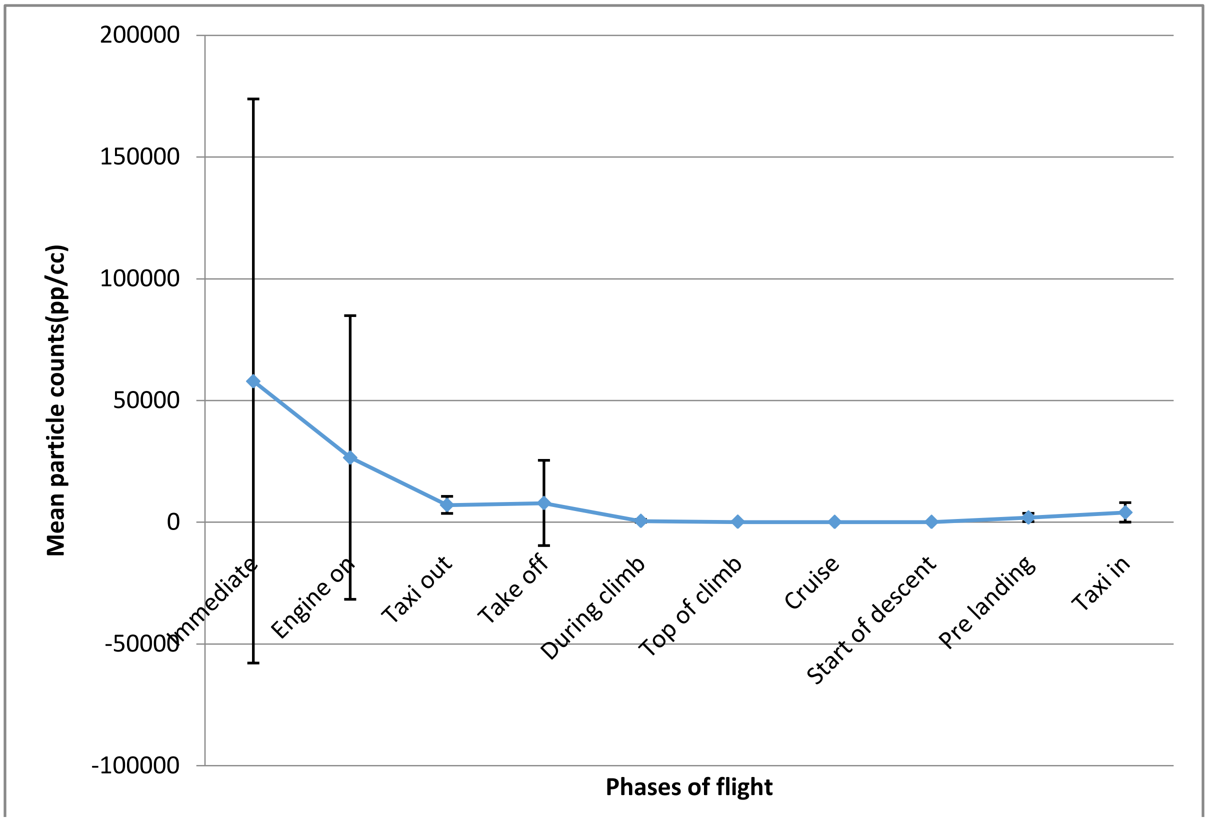


Figure 2: Mean Particle Concentration in Boeing 757 passenger

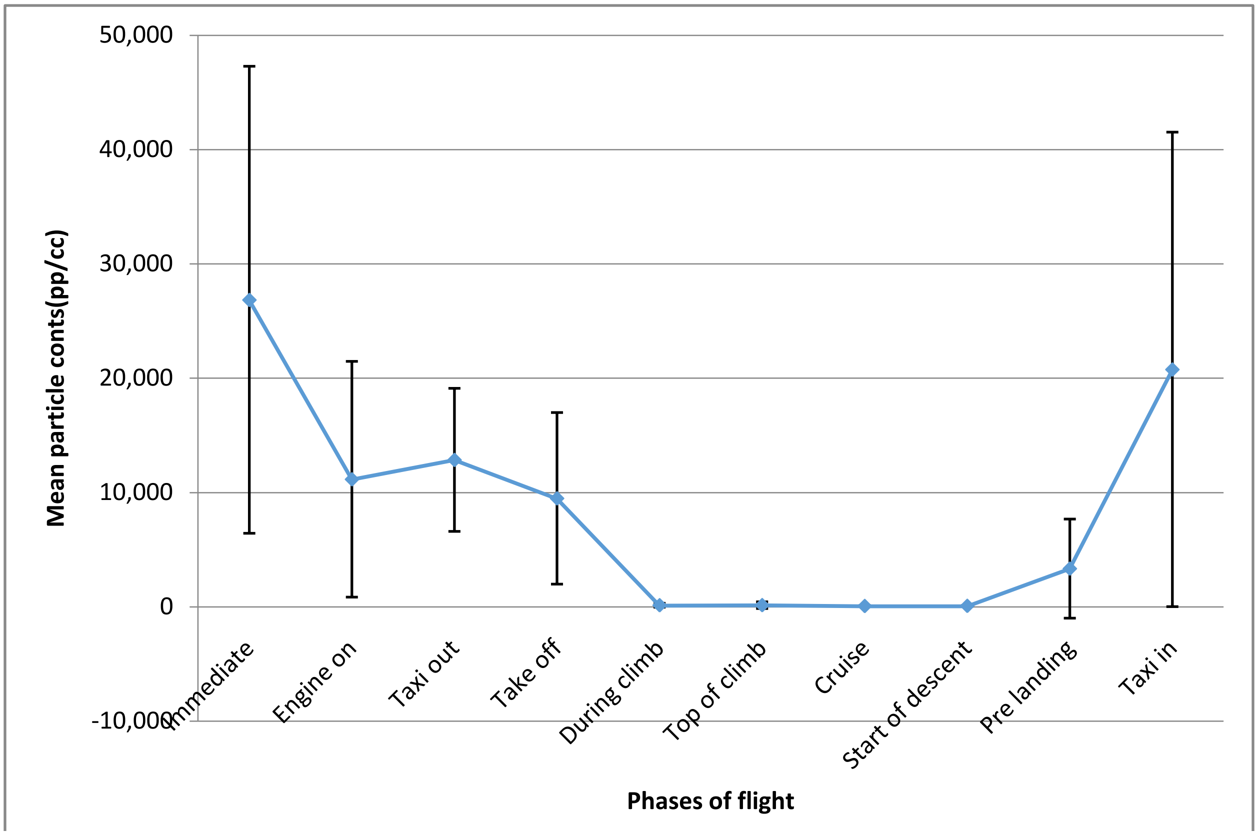


Figure 3**:** Mean Particle Concentration in Boeing Airbus A320/1

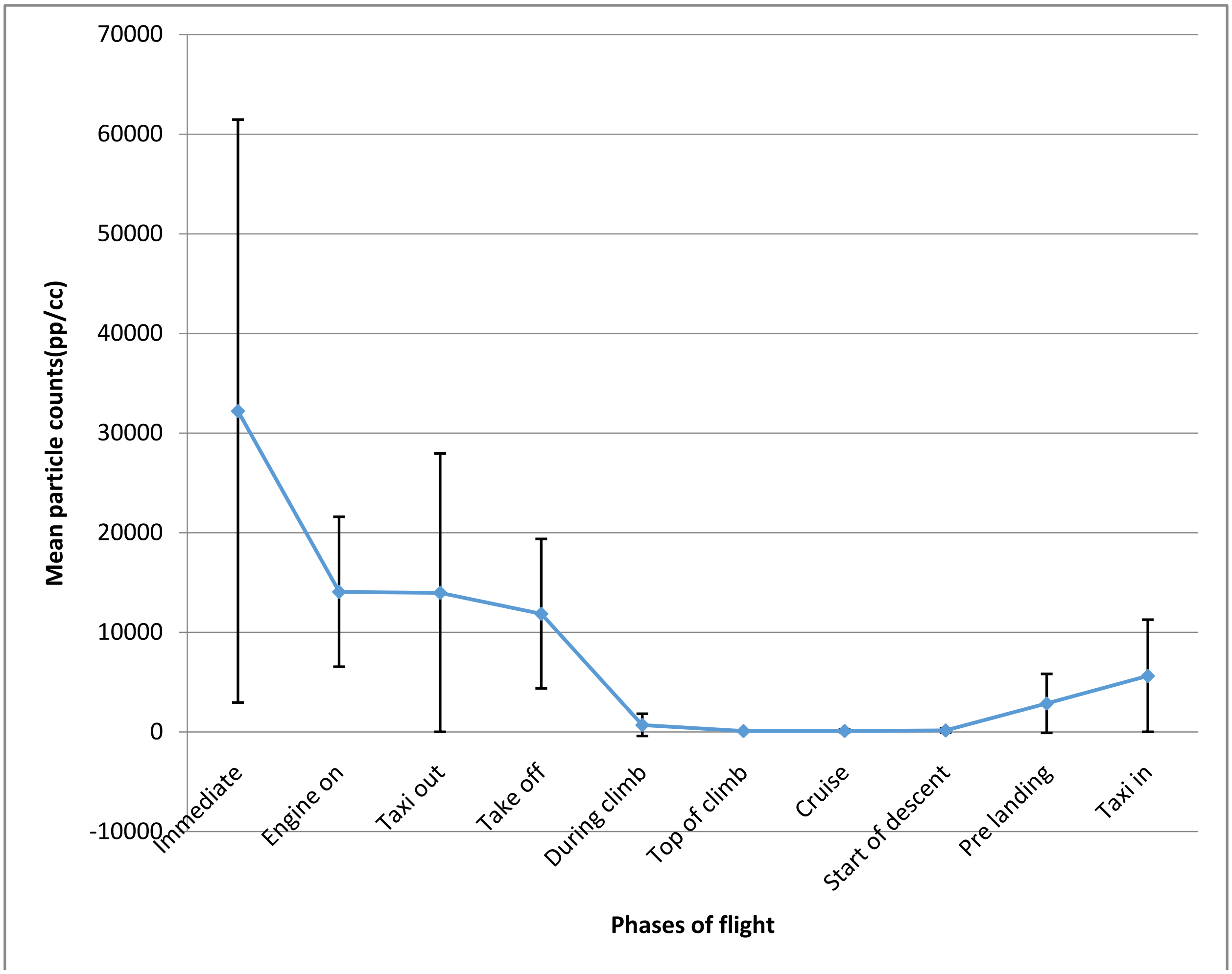


Figure 4: Mean Particle Concentration in Boeing BAe 146

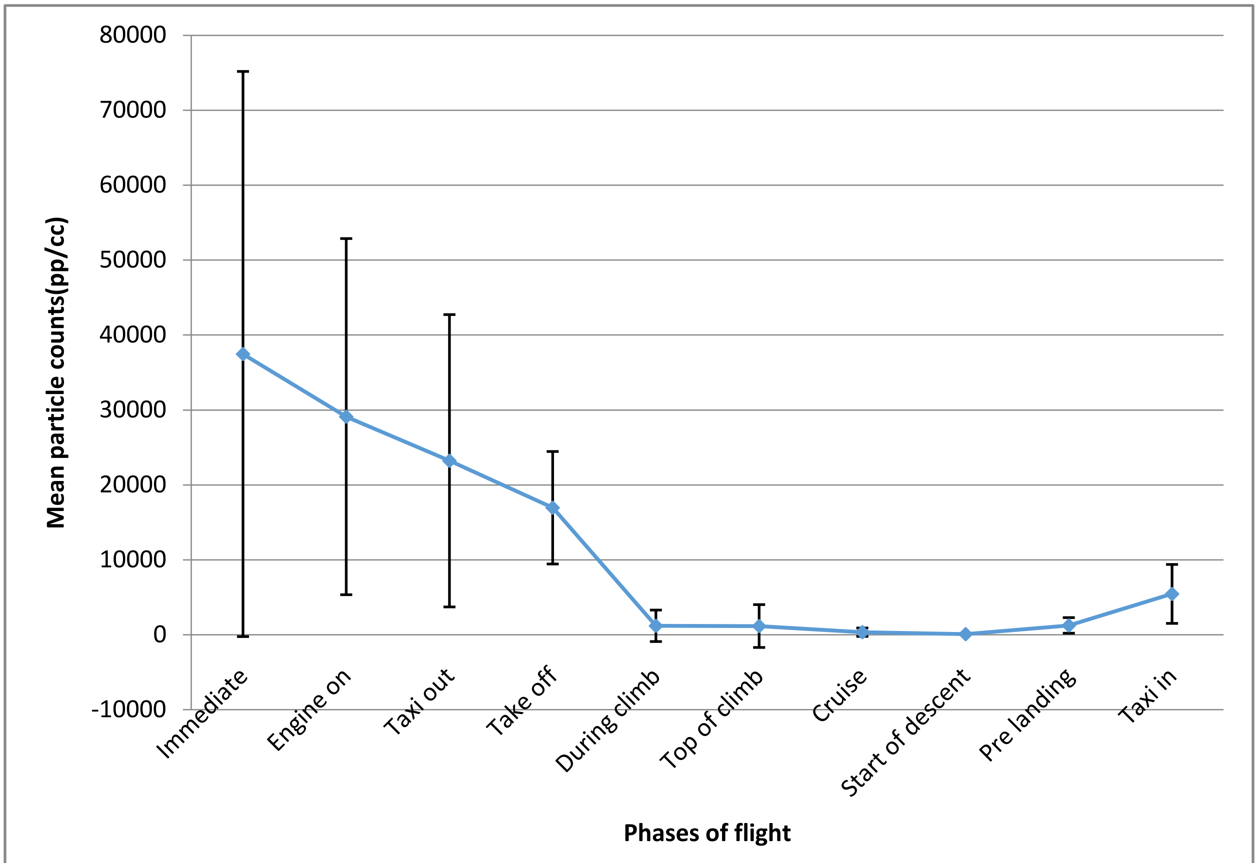


Figure 5: Mean Particle Concentration in Boeing Flight Part 5 Airbus A319

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