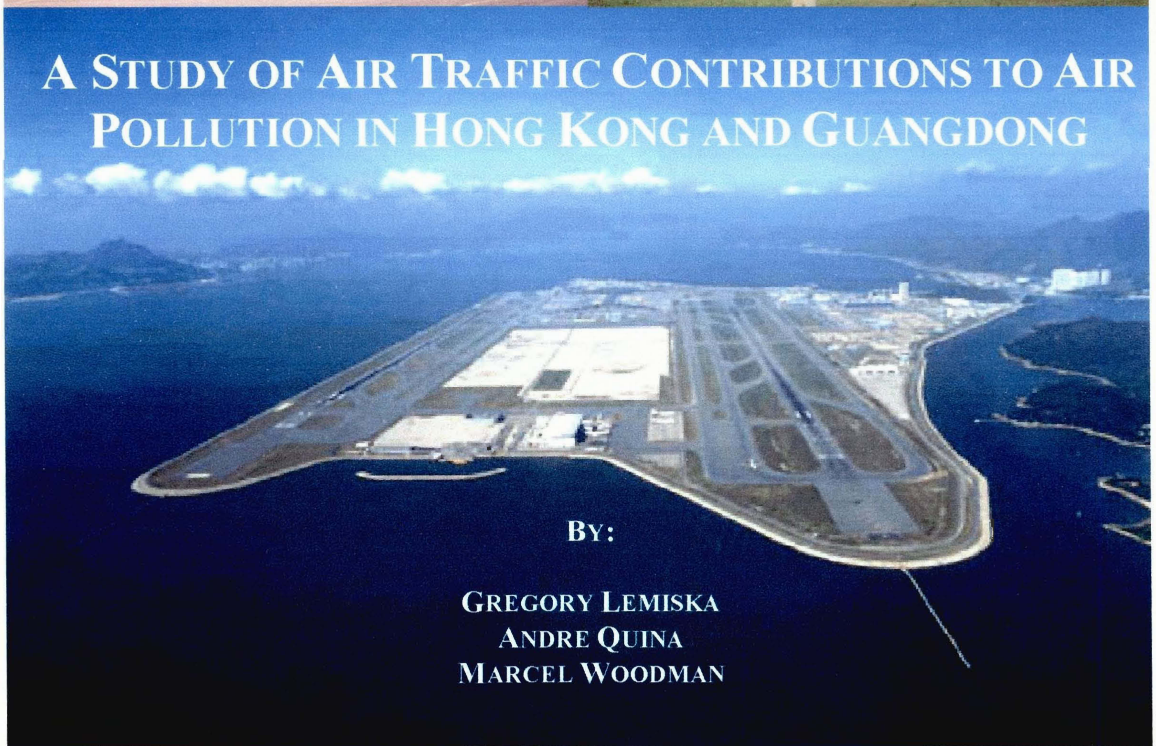


A Study of Air Traffic Contributions to Air Pollution in Hong Kong and Guangdong

By:

Gregory Lemiska
Andre Quina
Marcel Woodman

WPI Worcester Polytechnic Institute

Civic Exchange 思匯

A Study of Air Traffic Contributions to Air Pollution in Hong Kong and Guangdong

An Interactive Qualifying Project Report
Submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
In partial fulfillment of the requirements for the
Degree of Bachelor of Science

Sponsoring Agency: The Civic Exchange, Hong Kong
On-Site Liaison: Ms. Christine Loh, Chief Executive Officer, The Civic Exchange

Submitted by:

Gregory Lemiska

Andre Quina

Marcel Woodman

Approved by:

Professor Yi Hua Ma, Advisor

Professor Creighton Peet, Co-advisor

4 March 2002

Abstract

Sponsored by the Civic Exchange, the objective of this study was to determine the levels of air pollution contributed by air traffic in Hong Kong through the calculation of an in depth pollution inventory. In addition, the effects of and possible solutions to the air traffic pollution problem were identified by analyzing air traffic statistics, general pollution studies, and data from on-site interviews. The results helped create an understanding of the nature of aircraft pollution's effects on Hong Kong's ecology, economy, and health.

Acknowledgements

We would like to thank all the people who have helped make this study possible. From the Civic Exchange, we would like to thank Ms. Christine Loh, Chief Executive Officer and the project's Liaison, for helping us obtain interviews and for providing guidance. We would also like to thank Ms. Ester Lam of the Civic Exchange, for all the chocolate, medicine, and shopping tips along with helping us out with everything to do with the project. From Worcester Polytechnic Institute we would like to thank our two project advisors, Y. H. Ma, Professor of Chemical Engineering, and Creighton Peet, Adjunct Assistant Professor, for all their help and support.

We would also like to thank the large number of people who provided us with both time and information through personal interviews. We would like to thank Professor Moira Chan-Yeung, Chair Professor of Respiratory Medicine at the University of Hong Kong, and Mr. Benson Yeung, Senior Environmental Protection Officer, and Mr. Charles C. K. Wu, Environmental Protection Officer, from the Hong Kong Environmental Protection Department, for providing us information concerning the health effects of air pollution.

We would also like to thank Professor Alexis K H Lau, Associate Director of the Center for Costal and Atmospheric Research and Adjunct Associate Professor of the Department of Mathematics at the Hong Kong University of Science and Technology, Dr. Christopher Chung, Senior Environmental Protection Officer, and Mr. Hin-chung Lau, Environmental Protection Officer, from the Hong Kong Environmental Protection Department, and Mr. Wing-mo Leung, Senior Scientific Officer, and Mr. Kim-po Wong, Chief Experimental Officer, from the Hong Kong Observatory for providing us with wind pattern information and other data concerning the weather around Hong Kong and the Pearl River Delta.

Finally, we would like to thank Mr. Jeffery Law, Senior Operations Officer of the Technical Administration Section, from the Civil Aviation Department, Mr. Francis Ng, Assistant General Manager – Airfield, Ms. Yuyu Tse, Environmental Scientist, and Mr. Tommy Wan, Environmental Scientist, from the Hong Kong Airport Authority, and Mr. Savio Chan, Reliability Engineer, from Cathay Pacific Airways for providing us with information concerning aircraft and airport policies.

Executive Summary

As a leading research foundation in Hong Kong, our sponsor, the Hong Kong Civic Exchange, is concerned with the current environmental situation of Hong Kong. Numerous studies have been done concerning different sources of pollution in Hong Kong, but the impact and contribution of air traffic to air pollution has thus far been neglected. This study is an inquiry into the correlation between the current levels of air pollution and air traffic in Hong Kong and Southern China. Furthermore, this study attempts to identify possible ramifications of air traffic emissions as well as suggest possible recommendations in an attempt to assist in improving the situation. The primary goal is to calculate an emissions inventory for the Hong Kong International Airport (HKIA) and other airports in the area, and to use these data in understanding the contribution of aircraft to the effects of air pollution in Hong Kong and nearby Guangdong. The tasks involved in accomplishing this goal included: acquiring general and air traffic specific air pollution data for Hong Kong, determining aircraft and airport statistics within the Hong Kong area, calculating the contribution of air traffic to air pollution from the collected figures, acquiring data concerning the health and environmental effects of air pollution on the affected areas, and correlating the pollution data with the suspected harmful effects.

Once these data were collected, they were analyzed to determine the levels of NO_X, CO, SO_2, O_3, and particulate matter that were resultant from aircraft. These figures were calculated using a combination of the Hong Kong EPD and the United States FAA standards for emissions sourcing. This combination provided a means of producing the most accurate results with the data that could be obtained. Some of the conclusions that were drawn are:

- HKIA air traffic is expected to increase by 29% over the next 10 years.
- The time-in-modes for the HKIA are slightly higher than the international standard (except in the case of the idle/taxi mode) because of Hong Kong's higher than normal mixing height and longer runways.
- The practice of reduced thrust take-off, limited reverse thrust, and us e of ground power supplies at HKIA can help reduce airplane emissions, while reduced engine taxiing was not implemented for safety and cost reasons.
- Aircraft pollution is not currently a major contributor to Hong Kong's overall air pollution problem, but with increased pressure on reducing vehicle emissions and factory emissions as has been the case in recent years, it will soon become more significant.
- SO_2 emissions have decreased significantly over the last few years, while NO_X, CO and VOCs have stayed approximately the same.
- The local wind patterns around Hong Kong cause the air pollution to become trapped over the islands during the day and allow them to blow away during the night.
- Because of the predominant southerly winds during the summer, pollution from the Pearl River Delta gets blown into the Hong Kong region, accounting for much of the haze and other pollution problems during that time period.
- The presence of the Nan Ling Mountains blocks most of the air pollution from

the Beijing area from entering the Hong Kong/ Guangdong air shed.
- While a direct association has not been made, data have been presented that correlate health effects with air pollution increases.
- High levels of air pollutants, ozone in particular, cause adverse effects on plants.
- The economic costs of adverse health effects attributed to air pollution are between 14 and 17 billion Hong Kong Dollars.
- Acid rain is formed from NO_X and SO_2 emissions and can have devastating effects on structures, flora, and fauna.

Using recorded and estimated levels of air pollution, an association between health, environmental, and economic issues and ambient air pollution was estimated. Because of the continuous increase in the percentage of aircraft contribution to the ambient air pollution, it is believed that a reduction in aircraft emissions would be beneficial to the people of Hong Kong. Based on this conclusion, we suggest that further action be taken to understand better the contribution of aircraft to air pollution and recommend the following actions regarding the reduction of this contribution. The following preliminary recommendations have been made as a result of this study:

- Gather information on other airports in the Guangdong area before their size increases and the pollution generated from them is too large to conduct an accurate estimation.
- Communications among all airports and among all people who are modeling the pollution conditions around Hong Kong and China should be encouraged to increase accuracy in their predictions through frequent and open sharing of data and methods.
- Place taxes on aircraft fuel in order to decrease waste fuel. Higher taxes should be placed on low quality fuel to discourage its use.
- Adjust landing fees for aircraft coming into the airport based on emissions performance of the specific model of the aircraft.
- Subject the HKIA to the same reporting requirements as other polluters, including public notification of its effects.
- Increase the quality of ground power in the airport's apron so that a steady and reliable power source is available for convenient and efficient use by aircraft, thereby reducing the usage of Auxiliary Power Units (APUs)
- Calculate the emissions data for other air pollutant emitters in Hong Kong and Guangdong on a frequent basis in order to gain a more complete picture of the air pollution problem in Hong Kong.

Authorship

Chapter 1: Introduction

Marcel Woodman	30%
Gregory Lemiska	35%
Andre Quina	35%

Chapter 2: Literature Review

2.1 General Air Pollution

Marcel Woodman	90%
Gregory Lemiska	05%
Andre Quina	05%

2.2 Aviation Technology related to Air Pollution

Marcel Woodman	05%
Gregory Lemiska	90%
Andre Quina	05%

2.3 Air Pollution in Hong Kong

Marcel Woodman	10%
Gregory Lemiska	10%
Andre Quina	80%

2.4 Closing Points

Marcel Woodman	25%
Gregory Lemiska	25%
Andre Quina	50%

Chapter 3: Methodology

3.1 Overview

Marcel Woodman	30%
Gregory Lemiska	40%
Andre Quina	30%

3.2 On Site Interviews

Marcel Woodman	30%
Gregory Lemiska	30%
Andre Quina	40%

3.3 Data Collection

Marcel Woodman	40%
Gregory Lemiska	30%
Andre Quina	30%

3.4 Analysis

Marcel Woodman	30%
Gregory Lemiska	40%
Andre Quina	30%

Chapter 4: Results and Discussion

4.1 Aircraft Data

Marcel Woodman	20%
Gregory Lemiska	40%
Andre Quina	40%

4.2 Pollution Data

Marcel Woodman	350%
Gregory Lemiska	30%
Andre Quina	35%

4.3 Effects Of Air Pollution in Hong Kong

Marcel Woodman	50%
Gregory Lemiska	25%
Andre Quina	25%

4.4 Methods of Reducing Pollution in Hong Kong

Marcel Woodman	35%
Gregory Lemiska	30%
Andre Quina	35%

4.5 Closing Points

Marcel Woodman	30%
Gregory Lemiska	35%
Andre Quina	35%

Chapter 5: Conclusions and Recommendations

5.1 Conclusions

Marcel Woodman	50%
Gregory Lemiska	25%
Andre Quina	25%

5.2 Recommendations

Marcel Woodman	40%
Gregory Lemiska	30%
Andre Quina	30%

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1
Introduction

The human contribution to global air pollution dates as far back as the sixth century BC (Connor, 1994). The first known significant polluters were the ancient Greeks and Romans, who released lead into the atmosphere while extracting silver from lead ore. From these humble beginnings the saga of air pollution continued throughout the industrialization and technical advances of human civilization. As society has modernized, the levels of toxins released into the air have persistently increased. These increased levels of toxins in the environment reek havoc on the delicate balance of ecosystems globally. Furthermore, these pollutants can have devastating effects on the health and well being of humans. Currently, estimates indicate that air pollution has become such a problem that globally it accounts for more premature deaths than homicides or automobile accidents (Earth Justice, 2001). Although in the last half-century many have begun to realize the dire implications of airborne pollutants, and in fact numerous laws and regulations have been put into effect in order to curb the current crisis, the problem is still extremely significant.

There is ample room for improvement in the global air pollution situation, but as long as humanity desires the conveniences of modern society, there will always be some degree of air pollution (Hong Kong Department of the Environment, 2000). The key to minimizing the negative effects of modern society, as related to atmospheric pollution, is understanding the nature of the problem. Maintaining an awareness of the quantities and types of toxins released by given facets of technology provides a means for analyzing the resulting effects, as well as further allowing strategies for reduction and containment of the produced pollution. Studies into the causal aspects of air pollution have become increasingly common and are increasing the public's awareness. Unfortunately these investigations, as of yet, have not reached full coverage for all sources of air pollution in every part of the world.

Currently Hong Kong ranks as one of the cities with the worst air pollution in the world (Crystal, 2000). Numerous aspects concerning the sources of these extreme levels of pollution in this area have been studied, but the impact and contribution of air traffic to air pollution has thus far been neglected. The present study represents a groundbreaking inquiry into the correlation between the current levels of air pollution, and air traffic in Hong Kong and Southern China. Furthermore, this study assesses possible ramifications of the air traffic toxins released into the atmosphere as well as identifying possible recommendations in an attempt to assist in improving the situation.

As a leading research foundation in the area, the Hong Kong Civic Exchange has taken on the role of sponsor for this project. This agency represents an independent, non-profit, public policy think tank (Hong Kong Civic Exchange, 2001). Its goals are promoting civic education, public awareness and participation in governance by strengthening civic participation in public life. This organization frequently undertakes research and development in economic, social, and political policies, while simultaneously contributing to shape public policy by working to advance programs that are sustainable, resilient, non-violent, economically efficient, just, participatory, locally appropriate and spiritually rewarding. The features of this group provide for a natural integration of skills and experience across various disciplines including academia, business, politics, finance, technology and the non-profit sectors.

The Hong Kong Civic Exchange has identified the current environmental situation of Hong Kong and has assessed the current lack of coverage of research concerning the contributions of air traffic to the area's air pollution levels. As the team selected to carry out this research, we have identified the main goal of this study to be to determine the levels of air pollution contributed by air traffic in Hong Kong and nearby Guangdong and to identify any effects and possible solutions. This goal has been subdivided into numerous tasks required for the successful completion of the project. These tasks included: acquiring general and air traffic specific air pollution data for Hong Kong, determining aircraft and airport statistics within the Hong Kong area, calculating the contribution of air traffic to air pollution from the collected figures, acquiring data concerning the health and environmental effects of air pollution on the affected areas, and correlating the pollution data with the suspected harmful effects.

Once these data were collected, they were analyzed to determine the levels of NO_X, CO, SO_2, and particulate that were resultant from aircraft. These figures were calculated using a combination of the Hong Kong EPD and the United States FAA standards for emissions sourcing. This combination provided a means of producing the most accurate results with the data that could be obtained. Data that could not be acquired were estimated on a worst-case and best-case scenario to produce a possible range in which the pollution levels would fall. Using the levels of pollution, an association could be estimated between the health, environmental, and economic effects of ambient pollution and the possible effects of the aircraft pollution. Based on this extrapolation of possible effects and the emissions data, it became possible to make practical recommendations of methods to assist in reducing the levels of aircraft pollution and the effects of this pollution.

Chapter 2
Literature Review

2.1 General Air Pollution

2.1.1 Types

Air pollution consists of any of the following constituents: carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide ($N0_2$), VOC's (Volatile Organic Compounds), lead (Pb) and particulate matter. Ozone is also a pollutant and is often generated by the combination of sulfur dioxide with VOC's and nitrogen dioxide with VOC's. Controlling the amount of sulfur dioxide and nitrogen dioxide regulates the amount of ozone in the atmosphere. There are three main elements to any air pollution problem: a source, a receptor affected by the pollutants, and a mode of transportation for the contaminants (Burton, 1991). Modifying any one of these elements often leads to a dramatic change in any or all of them, possibly leaving one with a completely different problem to solve. In order to measure air pollution, a quantitative measurement scale is required, not only to determine concentrations, but also to determine just how much a particular source is contributing to the problem. As a direct result of these quantifications, air pollution is usually measured in parts per million (ppm) or parts per billion (ppb).

2.1.2 General Effects

In order to assess the risks of various types of air pollution, scientists have increased the concentrations of the chemicals by almost 1000 times the normal environmental doses in their studies (WRI, 1999). By studying the interactions of the chemicals, and the effects that they have upon rodents, they are able to determine which chemical combinations produce ill effects such as cancer. They then extrapolate these results to determine how these chemicals will affect people, plants, and animals in the environment. The Japanese National Institute for

Environmental Studies also uses a similar method to determine the health risks of various pollutants on humans because of the control they have over the rodents (JNIES, 2001). Scientists can control their eating habits, sleeping habits and air intake easily because of their size, making it simple for them to determine and regulate what is affecting the rodents. Recently, they have also begun using genetically altered animals to provide a greater amount of regulation over the test and control subjects.

2.1.2.1 Health

There are many different ways that pollution can affect a person's heath, with the effects ranging from a slight cough and bronchitis to heart disease and lung cancer (WRI, 1999). The most vulnerable groups include those with a weakened immune system, such as the elderly or infants, or those with asthma. Some effects, such as bronchitis and coughing, are short term and will decline if the pollution levels decrease, while others are permanent, and have no cure. In a worst-case scenario, death can result from over exposure to polluted air. It is estimated by the World Bank (2000) that particulate levels exceeding standards cause roughly 2 to 5 percent of all deaths in urban areas of the developing world. Each of the various constituents of air pollution has its own effects on the human body, and therefore affects health in different ways.

Kleinman (2000) states that ozone is a very energetic combination of oxygen that, when it comes in contact with a surface, releases its chemical energy. If this happens in the lungs, the energy causes damage to the airways. Acute health effects can occur following prolonged exposures at moderate physical exertion with concentrations of O_3 as low as 0.08 ppm (EPA, 1999). Groups at increased risk of experiencing such effects include active children and outdoor workers who regularly engage in outdoor activities and individuals with respiratory ailments (e.g., asthma, pneumonia). Examples of chronic effects of O_3 are;

inflammation of and structural damage to lung tissue, and accelerated decline in lung function.

Carbon monoxide (CO) is a common byproduct of combustion that results from the incomplete burning of fuels (EPA, 1999). CO reacts quickly with the hemoglobin in the blood, preventing the uptake and transportation of oxygen. It stays in the blood for a long period of time, and so if the levels of carbon monoxide in the system rise quickly, it will stay at those levels for several hours. Effects of CO include decreased physical endurance in healthy individuals. In elderly individuals high levels of CO can reduce quality of life because the individuals' systems cannot compensate for the lack of oxygen.

NO_2 causes respiratory problems when individuals are exposed to high levels of the pollutant for a short duration (less than three hours) (EPA, 1999). Asthmatics are especially sensitive and can be affected by even low amounts of NO_2. Studies (Kleinman, 2000) indicate a relationship between NO_2 exposures and increased rates of respiratory illness in young children, but results are not yet definitive. Animal studies (JNIES, 2001) have suggested that NO_2 impairs respiratory defense mechanisms and increases susceptibility to infection, and that chronic exposure to relatively low NO_2 pollution levels may cause structural changes in the lungs of animals. These studies suggest that chronic exposure to NO_2 could lead to adverse health effects in humans.

Particulate matter is a label applied to a variety of substances that form particles of varying sizes (EPA, 1999). Exposure to large particles, sized between 2.5 and 10 microns in diameter, is associated with aggravation of asthma and increased respiratory illness. Chronic health effects associated with long-term exposure to high concentrations of coarse particles have not been identified but are assumed. Small particles, sized less than 2.5 microns in diameter, are reported (EPA, 1999) to have effects including premature mortality, aggravation of respiratory and cardiovascular disease, changes in lung function and increased respiratory symptoms, changes to lung tissues and structure, and altered respiratory defense mechanisms. Sensitive sub-populations appear to be at greater risk to these effects. Individuals with respiratory and cardiovascular disease or asthma experience aggravation of symptoms, the elderly experience premature mortality and hospitalization, and children experience increased respiratory ailments and decreased lung function.

VOC's are typically noted by their reaction with NO_X in the atmosphere to form ozone. However, individual VOC's may have their own specific effects. For example, benzene, a common VOC released through the evaporation of fuel, is a carcinogen (EPA, 1999). Acute effects of specific VOC's in high concentration can include eye and respiratory tract irritation, headaches, dizziness, visual disorders, and memory impairment.

Kleinman (2000) also states that it has been shown that air pollution can have a larger effect on children than it does on adults. Children breathe larger amounts of air than adults when performing energetic tasks, often taking in 20 to 50 percent more air than adults performing comparable activity. Children also respond to the effects of air pollution differently. The outward symptoms such as coughing and headaches do not often appear. This, however, does not mean that children are not as sensitive to air pollution as adults. There are several studies, such as the Children's Health Study by McConnell, et. al. (1999) and the EPA's Children's Environmental Health Yearbook (1998), that show that children who have suffered losses in lung function often do not cough or even feel discomfort.

2.1.2.2 Environmental Effects

All forms of air pollution have negative effects on the surrounding ecology, but specific types can have individual impacts. Ground-level ozone has several negative effects on plant life (EPA, 1999). O_3 interferes with the production and storage of food, which negatively affects growth, reproduction and general plant health. This makes the plants more susceptible to disease, insect attacks, and harsh weather. Ground-level ozone can also kill or damage leaves, causing them to fall off the plants prematurely or to become spotted or brown. These effects significantly affect the appearance of natural areas. NO_X also plays a role in the formation of acid rain. Acid rain causes surface water acidification and damages trees at high elevations (for example, red spruce trees over 2,000 feet in elevation). NO_X itself is a brown gas that contributes significantly to levels of visible smog. The environmental effects of particles are reduced visibility and soiling. Particulate matter is the primary source of visible smog and haze. Soiling is the buildup of particles on objects at ground level. It is most obvious on buildings and vehicles. VOCs can cause a variety of environmental effects. The specific effect is dependent on the exact chemicals present. For example, VOCs that contain chlorine can contribute to the depletion of the ozone layer. At high levels, VOCs can adversely affect plants, but the principal environmental effect of VOCs is their contribution to the formation of ozone.

2.1.2.3 Structures

Air pollution also has its effect on buildings and other structures (WRI, 1999). Over long periods of time, acid rain will deteriorate the paint on surfaces, and even begin to eat away at the surface itself, as shown in Figure 2.1. Particulate matter may also cause problems for structures, much the same way that it has caused problems for this statue. Given more time, acid rain will eventually eat away all distinguishing features, and may even claim the important structural support of an object.

2.1.3 Sampling

Burton (1991) gives two different methods by which to gather data about air pollution: ambient sampling and source sampling. With ambient sampling, it is often hard to distinguish where the pollution originated, but it is easier to study the effects that the

Figure 2.1. The Effects of Air Pollution on Monuments (University of Colorado, 2001).

pollution is having on the local environment. Ambient sampling can aid in the establishment of a pollution alert network, monitor the effects of a particular pollutant, or predict the effect of a possible pollution source. Source Sampling provides a very clear view of where a particular constituent is being produced, but it provides very little data on how that individual pollutant is affecting the ecosystem. Because source samples from engine exhaust often have a higher temperature and contain more water vapor, it raises a different set of problems and objectives. Source samples are usually used to identify compliance with a regulation, obtain emissions data, and determine the need for maintenance.

2.1.4 Methods of Reduction

2.1.4.1 Cottrell Precipitator

Frederick Cottrell designed the Cottrell precipitator in 1907 as a way for Dupont to eliminate a problem in a process designed to manufacture sulfuric acid (Zumdahl, 1998). By passing gases through an electric charge, they would then pick up a charge themselves. They could then be attracted to an oppositely polarized electrode. After the pollutants have been collected on the electrode, they can easily be washed off. Because of the design of the device, it is best used in smokestacks and other areas where the pollution is concentrated.

2.1.4.2 Fuels

There are a number of different types of fuels that can be used for engines and also as heating oil (O'Rourke, personal interview, 2001 Nov. 23). Heating oil ranges from number 6 to number 2, with number 6 being the dirtiest and also with the most pollutants. At a meager 35 cents (US) a gallon, the sulfur content of number 6 fuels is around 2.2 percent. Number 6 fuels also contain more nitrogen and particulate matter, therefore making them greater pollutants. There are several different ways of reducing the pollution that comes from fuels. By using a lower number fuel, you end up releasing a lesser amount of pollutants into the air. There is also a process called stage 1 fuel recovery, which takes the built up fuel vapor from the underground tanks and when new fuel is put in, the vapor is pumped into the transportation tank to be taken back and recycled. In stage 2 fuel recovery, the same process is used, but it is applied to passenger vehicles.

2.1.4.3 Government Regulations

Government regulations can also have a large effect on the amount of air pollution. El-Fadel (2001) stated that without government restrictions on the amount of pollution that industries, automobiles, and other sources of pollution generated, there would be no incentive for these polluters to limit the levels of toxins they release into the atmosphere. However, by imposing fines to those who exceed their allotted pollution limits, it forces them to put money into research to reduce the amount of pollution generated.

2.1.4.3.1 Command and Control

The command and control strategy for air pollution control consists of emphasizing the meeting of objectives through setting standards for ambient air quality and emissions (El-Fadel, 2001). The main goal of this strategy is to provide relatively simple and enforceable regulatory standards. However, it also presents limitations concerning the ability to expand these practices and the cost efficiency of the implementation and upkeep. The command and control strategies tend to focus on short-term compliance solutions rather than long-term pollution reduction.

2.1.4.3.2 Market-based

Market-based strategies, sometimes called cap-and-trade systems, are a way of combining private costs with social costs to reduce overall air pollution (El-Fadel, 2001). The objective is to transfer social decisions to the private level, allowing private sectors more control over how they reduce pollution. There are two primary ways to implement this system, upstream and downstream. Upstream places control on the fuel producers, allowing for a more complete coverage of emissions, but because these systems cannot influence the buying patterns of consumers, the actual pollution patterns may vary significantly. With downstream systems, it places the control in the hands of the fuel consumers, allowing for more consistent results, but at a higher cost to the government.

2.1.4.3.3 Emission Tax

The earliest emission taxes were conceived to reduce pollution in the most efficient manner (El-Fadel, 2001). In order to reduce pollution, the individuals that produce it are required to pay a set amount dependent upon the type of contaminants and the amount. Pollution charges consist of two main components, a gravity component and an economic benefit. The economic benefit is used to counterbalance any benefit that would be gained from noncompliance with the regulations. The gravity component is the monetary compensation for the damage that has been done to the environment, and it is calculated from the amount and toxicity of the pollutant, length of violation, and the sensitivity of the environment (Figure 2.2). The gravity component can also be adjusted by the willingness to agree, the negligence of the violator, and the compliance history of the violator (USEPA, 1996). In general, emission taxes are adjusted such that an industry would find it better to control emissions than pay the taxes on them.

2.1.4.3.4 Trading Permits

Trading permits are also a popular method of trying to reduce pollution (El-Fadel, 2001). This approach introduces a flexible emission control system that can be swapped among different violators. All polluters are given a certain amount of pollution that they can release, which can be traded or saved for later use if they go under that limit. If they go over that limit, a heavy fine is incurred.

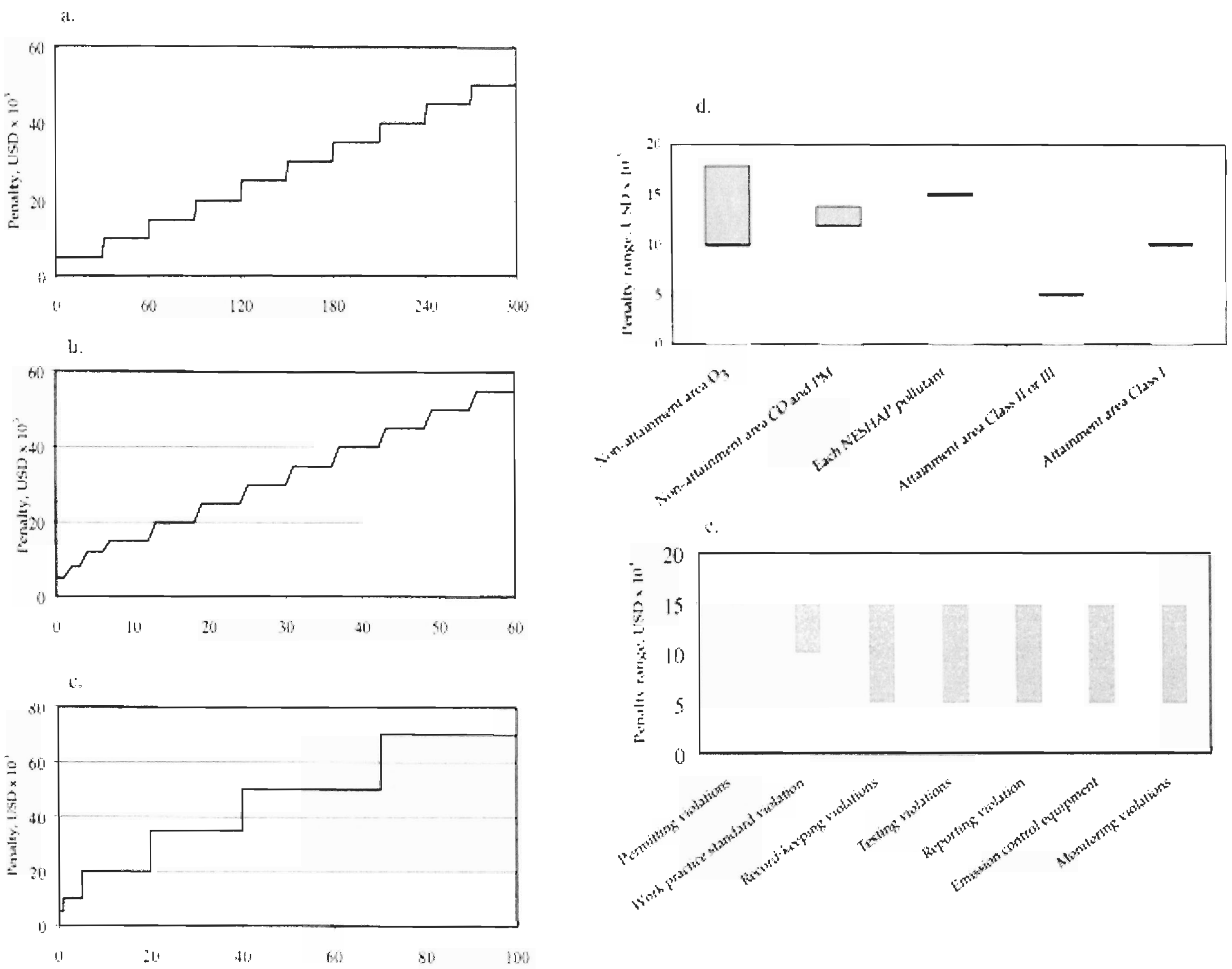


Figure 2.2. Selected Penalties to the Gravity Component (USEPA, 1996).

(a) Based on the violation level (b) Based on the violation length (in months) (c) Based on the violator size (in thousands of people) (d) Based on the sensitivity of the environment (e) Based on importance to regulatory scheme

2.1.4.4 International Regulations

El Fadel (2001) also stated that many of the international regulations are similar to national regulations, but applied on a much broader scale. An international organization is required to regulate policies such as international taxes and tradable quotas. International taxes hold each country responsible for what pollution they generate. These taxes are often passed down to the individual polluters in the appropriate system. Tradable quotas work almost exactly the same as trading permits, except the trading participants are allowed to exchange permits with others at any distance.

2.2 Aviation Technology related to Air Pollution

2.2.1 General

The burning of aircraft fuel produces several pollutants of both gaseous and particulate types. The United States EPA Evaluation of Air Pollutant Emissions from Subsonic Commercial Jet Aircraft (1999) describes the principal pollutants as being CO_2, H_2O, NO_X, CO, HC's, SO_2 and C. The amount of NO_X, CO and HC's emission depends on the operating conditions of the engines such as air speed and altitude. NO_X is created from the incomplete burning of fuel. Aircraft generally burn what is referred to as jet fuel, which typically consists of pure kerosene or a mixture of kerosene, gasoline, and fuel oils. Output of NO_X is low when engine power and combustion temperature are low, but it increases as the power increases and temperature rises, specifically when temperatures become high enough to force the oxidation of atmospheric nitrogen. CO_2 and H_2O are the products of the oxidation of fuel carbon and hydrogen through interaction with atmospheric oxygen. CO, C and hydrocarbons, or VOC's are the results of partially burned, or totally unburned fuel. SO_2 derives from oxidation of the trace sulfur found in jet fuel. The sulfur content for commercial jet fuel is generally around 0.3% of fuel weight, and the emissions are highest during take-off and climb-out when fuel consumption rates are high. Therefore, the overall amount of fuel burned, and thus pollutants emitted, depends on the type of aircraft, the type of engines in use, and the time spent in each operating mode.

Typical types of aircraft engines used for commercial flight include turbojet, turbofan and turboprop. Manufacturers such as General Electric, McDonnell Douglas and Lockheed

Martin produce each of these separate types of engines in a variety of forms. Engines generate different levels of individual pollutants depending on how they are running. An engine at idle speed produces high levels of SO_2, CO and hydrocarbons per gallon of fuel because it burns all of the fuel flowing to the burners, as the fuel is traveling at a slower speed. An engine operating at full throttle produces high levels of VOCs and particulate because the fuel is flowing much faster past the burners and is not completely burned (Figure 2.3).

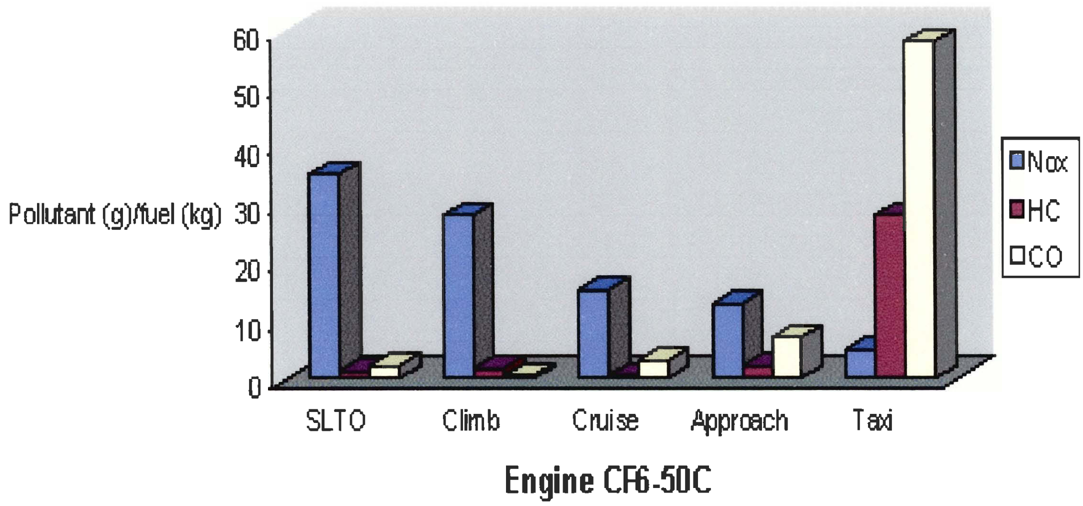


Figure 2.3. The Amount of Pollutant Per Kilogram of Fuel Produced by Aircraft Engines During Various Phases of Flight (Liu, 1998).

2.2.1.1 Landing and Take-Off (LTO)

The parts of any flight that are the most inefficient are during the landing and take off (LTO) cycle. The Swedish Civil Aviation Administration (2000) describes the LTO as being divided into four parts; approach, idle, takeoff and climb out. A LTO cycle begins as the aircraft descends below 3000 feet to approach and land at the airport. The second step in the landing portion of the cycle is the taxi to the gate and idle. The next three steps are the three operating modes in the takeoff portion of the cycle: taxi-out/idle (which is combined with the taxi in/idle portion), takeoff, and climb out to 3000 feet. These five LTO cycle operating modes are defined by the existence of standard power settings for a given aircraft, thus giving a means for estimating emissions. Table 2.1 shows average times and thrust percentages for most aircraft.

Table 2.1. Example of Typical LTO Thrust Percentages and Section Times (Swedish Civil Aviation Administration, 2001).

Mode	Time	Thrust
Take-Off	0.7 min	100%
Climb	2.2 min	85%
Approach	4 min	30%
Taxi	26 min	7%

The LTO is the most variable and inefficient part of an aircraft's movement. Every airport will have different average taxi times, which greatly affect the amount of pollution generated during a single LTO. Airports strive not only to reduce these times in order to serve passengers better, but also by reducing this time, the amount of emissions can be reduced due to fuel savings.

2.2.1.2 The Mixing Zone

The take off and landing cycling is the main concern for this study because it is during these phases of flight where the majority of pollution takes place and also because this pollution is emitted below 3000 feet. Liu (1998) states that this altitude is significant because the layer of the atmosphere below it is the mixing zone. The mixing zone is defined as the immediate layer of air above the earth where chemicals in the air will have a direct effect on things on the ground. This is because substances emitted in this zone can circulate to any altitude within it. The boundary above the mixing zone is created by a rapid variance in temperature versus altitude. This temperature barrier prevents the exchange of chemicals between the lower and upper parts of the atmosphere. The normal height of this barrier is 3000 feet, but it varies with wind patterns, latitude, temperature and topography.

2.2.1.2 In-flight Delay

The National Airspace System Architecture published by the FAA (2000) describes in-flight delays as major contributors to aircraft emissions because they are an unnecessary waste of fuel. Bad weather, high level of air traffic and many other factors can cause delays. To minimize weather related delays, airports use automated landing and take off systems that guide the plane for the pilot in low visibility situations. To avoid weather delays caused by severe weather, it is necessary to have good forecasting, and to be able to divert, or delay the start of flights before the aircraft are near their destinations. High amounts of traffic are a significant contributor to airborne delays, especially at major airports. Because FAA regulations limit the rate at which aircraft can land on a specific runway, dependent upon the setup of the runways at the given airport, airports often must have aircraft circle the airport while waiting for a turn to land. There are several ways to avoid/reduce these delays. The first lies with proper scheduling. When airlines schedule flights to and from airports, the airports must plan accordingly, and make adjustments to flight schedules so that there are no backups. Secondly, airports that experience large amounts of traffic related delays should consider adding runways.

2.2.1.3 Flight Paths

The Hong Kong Civil Aviation Department (HKCAD)(2001) says the flight paths for Hong Kong International Airport were developed in accordance with international standards and recommendations. The HKCAD also states that they were designed very particularly through several studies. Their development accounted for runway alignment, terrain, environment and obstacle clearances, location of navigation aids, aircraft operating criteria, noise considerations, airspace co-ordination with nearby airports and other concerns. Hong Kong is a relatively small island, but it is quite hilly. Because of the unusual elevation problems, it was impossible to avoid residential areas and remain in compliance with international safety requirements. Because of these safety constraints, the existing flight paths are as effective as possible and cannot be altered. (Hong Kong Civil Aviation Department, 1998)

Flight paths to date are generally not optimized for minimal fuel consumption due to safety concerns and navigation practices. The ideal route for any aircraft is a straight line from take off to landing, at the specific aircraft's optimum altitude. Aircraft must follow assigned routes that are designed with safety first. Currently there is research being done into the practicality and safety of a "free-flight" air traffic system. This system would allow aircraft to choose their own flight plan, with recommendations and advice from a central air traffic control center (FAA, 2000). The best flight paths are the ones that are the most direct and are suited specifically for the aircraft flying it. For example, a Boeing 777's ideal flight path is not the same as that of a Douglas DC-10. Variables that affect a flight path's efficiency are factors such as altitude, rate of climb, rate of descent, directness, avoidance of weather effects and other concerns. The problems involved in implementing a free flight system involve the prevention of collisions, heavy traffic, and delays. To solve these problems, the FAA is researching the practicality of what would essentially be a nation wide "control tower' that would keep track of all planes in the air at a central location, and inform pilots of pertinent information about their flight path, and what they need to do to avoid problems (FAA, 2000).

2.2.2 Noise Pollution

The landing and take off of airplanes is the noisiest part of airplane operation. Noise pollution varies directly with emissions, typically the more emissions being produced, the noisier the engine. Many cities have regulations concerning the amounts of noise a given aircraft can produce at specific altitude and distance from the airport from which it is landing/taking off. Often times these restrictions require aircraft to use inefficient flight paths, i.e., steep climb out angles that require large amounts of thrust. The Hong Kong Civil Aviation Department (October, 1998) describes the major effects of noise pollution as being noise disturbances including loss of sleep, and negative effects on wildlife populations. Noise pollution can be counteracted on the public's side with the use of noise proofing materials in the construction of homes.

2.2.3 Current Air Traffic Patterns

Traffic patterns are specific to every airport. They are determined by factors that include the layout of the particular airport, geography of the region, how busy the airport is, wind patterns, and population density. Hong Kong International Airport (HKIA) has two parallel runways which run northeast to southwest (HKCAD 2001). The two runways are normally operated in a segregated mode, i.e. the South Runway dedicated for departures and the North Runway for arrivals. There are some circumstances where the airport may be operated with a single runway. These occur in the event of runway blockage or maintenance periods at night. The direction from which aircraft land at HKIA mainly depends upon the wind direction. Aircraft generally land into the wind. When the wind is from the west or southwest, aircraft will approach HKIA from the northeast. When the wind is from the east or northeast, aircraft will approach HKIA from the southwest. Figure 2.4 and Figure 2.5 show the current departure and arrival flight paths for HKIA.

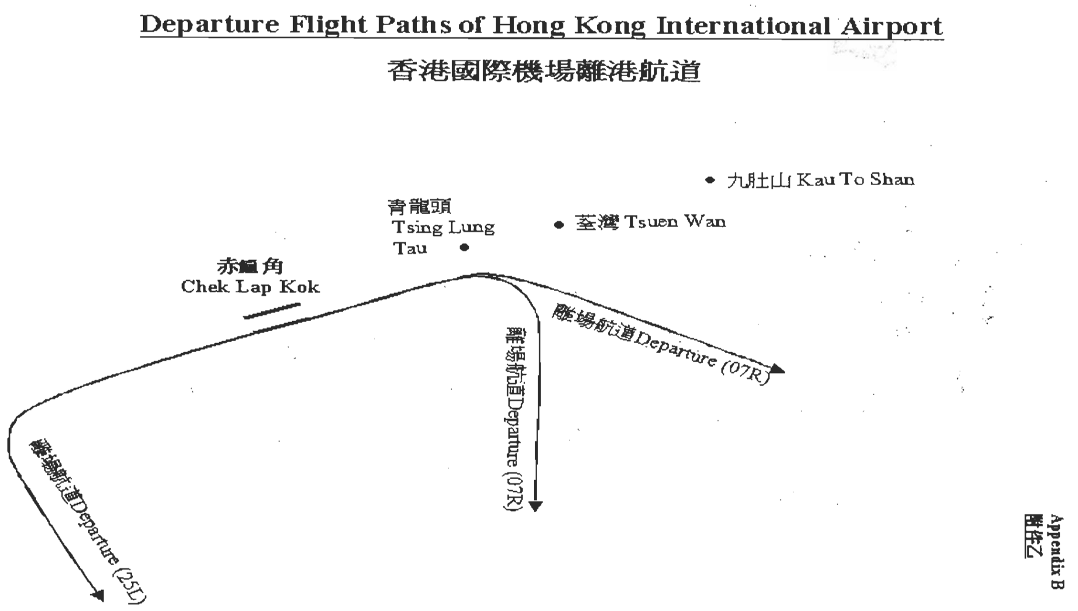


Figure 2.4. Departure Flight Paths from HKIA (Hong Kong Civil Aviation Department, 2001).

Figure 2.5. Arrival Flight Paths to HKIA (Hong Kong Civil Aviation Department, 2001).

2.2.3.1 Affected Areas

Flight paths affect the land around them based upon their proximity to that location. Generally, the amount of pollution varies directly with proximity to air traffic routes, that is to say, the closer the aircraft fly to a specific point, the more pollution is likely to be at that point. This is true for both forms of pollution, air and noise. A major player in where exactly chemical pollution will have the greatest effect is weather patterns. Areas down wind of flight paths are assumed to experience often greater chemical pollution effects than areas directly underneath flight paths. With noise pollution, however, wind does not play an important factor, and effects of noise pollution vary with distance regardless of wind conditions.

2.2.4 Airport Data

FAA reports contain vast amounts of data for all the international airports within the United States. These data include average unimpeded taxi times, pollution levels, traffic density, traffic totals, traffic make-up, and airport layout. Airport layout has a significant impact on the taxi times. Typically, airports with fewer runways have the lowest times. The problem with limited runways is that it reduces the number of aircraft that can land or take off within a given amount of time. This rate is strictly regulated by international organizations depending on the size, orientation and separation distances of runways. Dulles International Airport, located in Washington, DC has the most similar layout to that of HKIA, and thus it is expected that the two airports will have similar LTO times (see Appendix 8.8) HKIA's parallel runway configuration is very efficient because the terminal is placed in close proximity to them. Most landing aircraft land on the runway going towards the terminal and most departing aircraft leave moving away from the terminal. This greatly reduces aircraft taxi times because of the limited amount of distance to the terminal between the end of the landing part of the LTO and the beginning part of the LTO.

2.2.5 Aircraft Data

The FAA has an astounding amount of numerical data regarding all types of aircraft. These data include engine reference charts and emissions tables. From these tables it is possible to calculate average emissions per unit of time for the major air pollutants (refer to Appendix 8.7).

2.3 Air Pollution in Hong Kong

In the last century Hong Kong has become a major focal point for industry and commerce (McGeveran, 2001). Much of the success of this city can be attributed to its unique political and geographic situation. For more than a century, Hong Kong, as a colony of Great Britain, represented one of the few strong western gateways into the eastern world. Furthermore, Hong Kong provided a major harbor that quickly developed into one of the world's greatest international ports. These inimitable circumstances caused a commercial and developmental explosion in the city, engineering it into a juggernaut of industry, banking, and trade. Although these vast developmental strides for the city in the last century have generated innumerable benefits, they have come with a substantial environmental cost.

More than a century of rapid commercial and private development within the city has taken its toll. Currently Hong Kong ranks as one of the most polluted cities in the world, and of this pollution, the air pollution situation in Hong Kong is particularly dire (Crystal, 2000). This immense air pollution problem was most clearly illustrated in February of 1999 when foghorns had to be used to guide ships through the dense pollution in the harbor (see Appendix 8.4). In fact, according to the Hong Kong Citizen's party (1998) these levels of pollution have become so high that they are starting to affect public health significantly. The health implications of the current levels of pollution are staggering. In 1998, the Citizens Party estimated that about one in eight people in Hong Kong reported asthma symptoms. Furthermore, they stated that an average of seventy to ninety people died each year from asthma complications, nearly a third were younger than thirty. In addition to asthma related deaths, the World Wildlife Fund for Nature Hong Kong (2001) estimated that an additional 300 deaths were attributed to the many other respiratory diseases that have been prevalent in Hong Kong. The Citizen's party continued by identifying one of the most significant of these diseases as rhinitis, an inflammation inside the nose causing symptoms similar to hay fever (1998). They further stated that current health care statistics showed that nearly forty per cent of children in Hong Kong suffered from this disease, the highest rate in Asia.

These staggering health problems related to pollution in turn have an effect on the economy of Hong Kong. In a 1999 RTHK (Radio Television Hong Kong) letter to Hong Kong (see Appendix 8.4), Legislator Christine Loh of the Citizens Party indicated that,

> "Government studies confirm that the annual health costs associated with air pollution are equivalent to some half a percent of Hong Kong's GDP, that is, $5.5 billion at 1996 figures. Friends of the Earth suggested that if 10% of visitors get put off by air pollution here and don't come, then the loss in tourism revenue could be as high as $4.5 billion a year."

This suggests that air pollution's current damage to the economy, taking into account only tourism and health costs, could reach as high as one percent of the Hong Kong GDP. Furthermore, other economic consequences could result through the damage to buildings and monuments due to oxidation or acid rain.

2.3.1 The Air Pollution Index and Monitoring Stations

2.3.1.1 Air Pollution Index

The Air Pollution Index (API) in Hong Kong is a scale that indicates the relative levels of air pollution for a given day. The Air Pollution Index has provided a powerful tool for the general pubic and their understanding of the air pollution situation in Hong Kong since the system's establishment in June of 1995 (HK EPD, 2000). Loh (1998) provides a breakdown of the API by stating that any rating from 0 to 50 was considered "good", a rating from 51 to 100 was valued "moderate", a rating of 101 to 200 was deemed "unhealthy", and any API level beyond 200 is considered "very unhealthy" (for a more complete breakdown, see Table 2.2). Although the vague nature of the API provides that this scale is by no means a precise indicator of pollution, according to the Hong Kong Environmental Protection Department, it gives a simple way of describing air pollution levels to provide daily information about air pollution to the public and to enhance the awareness of the people of Hong Kong (HK EPD, 2000). The API forecast serves as an alert to the public prior to a serious air pollution episode. It helps the general public, especially susceptible groups such as those with heart or respiratory illnesses, the elderly, and children, to consider taking precautionary measures when necessary.

Table 2.2. API Breakdown and Description (HK EPD, 2000).

Air Quality Status	Air Pollution Level	API	Health Implications
Air quality significantly worse than both short-term and long-term AQOs.	Severe	201 to 500	People with existing heart or respiratory illnesses will experience significant aggravation of their symptoms and there will be also widespread symptoms in the healthy population. These include eye irritation, wheezing, coughing, phlegm and sore throat.
Air quality worse than both short-term and long-term AQOs.	Very High	101 to 200	People with existing heart or respiratory illnesses will notice mild aggravation of their health conditions. Generally healthy individuals may also notice some discomfort.
Air quality within the short-term AQOs but worse than the long-term.	High	51 to 100	Very few people, if any, may notice immediate health effects. Long-term effects may, however, be observed if you are exposed to such levels for a long time.
Air quality within all AQOs.	Medium	26 to 50	None expected for the general population.
Air quality well within all AQOs.	Low	0 to 25	None expected.

***AQO is Air Quality Objective**

2.3.1.2 Monitoring Stations

The Air Pollution Index, in addition to a large array of other air pollution statistics, has been made available through the numerous air quality monitoring stations that have been constructed all over Hong Kong since 1991 (HK ESD ASG, 2000). Currently there are fourteen monitoring stations that produce nearly continuous readings for Sulfur compounds, NO_X, VOCs, RSP, Ozone, and Hazardous Air Pollutants (HAPS) (see Figure 2.6). Each day the levels of these pollutants are measured and summarized by the Hong Kong Environmental Services Department in order to understand pollution trends and to make forecasts for the following day's API. This system exemplifies a large step forward for Hong Kong, but the air pollution figures produced are often misleading.

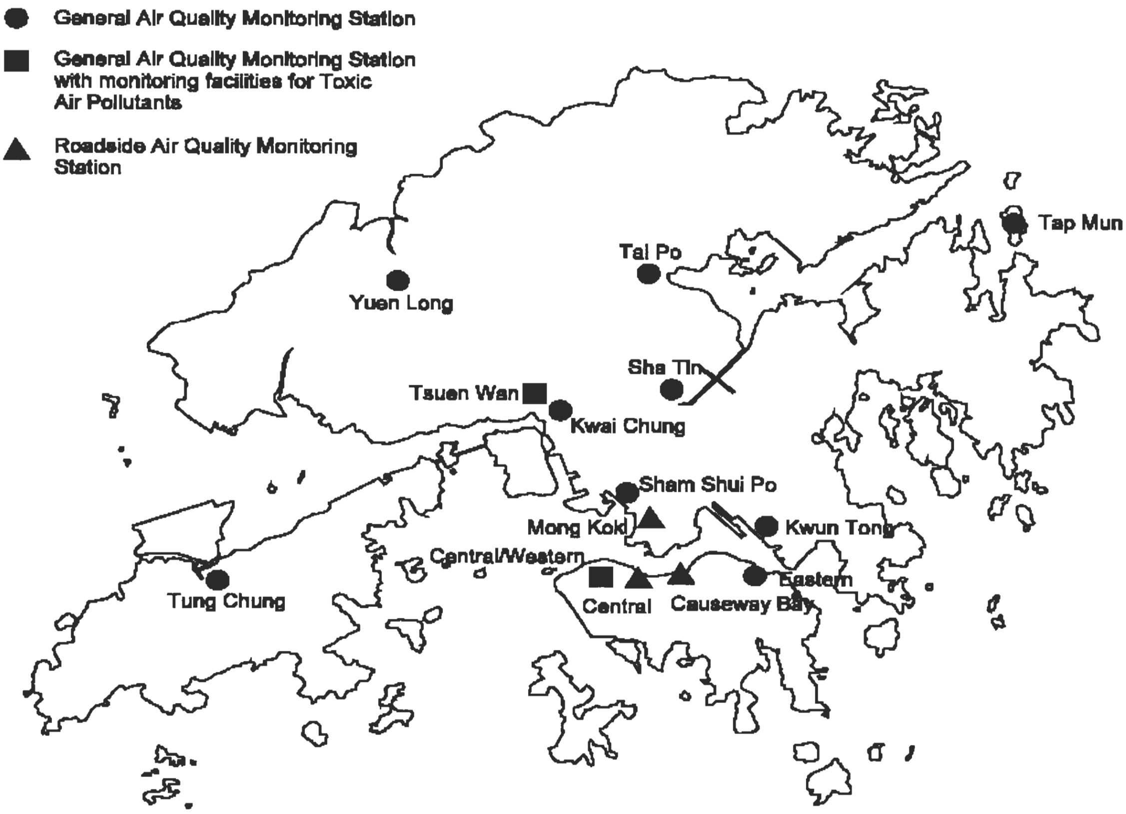


Figure 2.6. Air Pollution Monitoring Stations in Hong Kong (HK ESD ASG, 2000).

According to Loh (1997), the reason that these statistics produced by the monitoring stations are often a misrepresentation of the actual pollution respired by the people of Hong Kong, is because the monitoring stations do not take measurements at ground level. She points out that most of the monitoring stations take readings from higher up. Consequently, the actual pollution levels on the street level will often be about 20 percent higher than the recorded levels. Loh expounds on this notion by explaining that if the API says that the pollution is at a high moderate level, such as 70 or 80, for a given day, the actual air being breathed in on the streets is closer to an API of 100 or more. Therefore, an API reading of moderate can often represent air pollution levels that are unhealthy. Furthermore, she points out how this illustrates a more significant air pollution problem. According to Loh (1997), the EPD estimates that thirty percent of days have an API of 70 or above. This indicates that nearly one in three days in Hong Kong has significantly unhealthy levels of air pollution.

2.3.2 Current Environmental Projects

In recent years Hong Kong has begun to identify its problems with air pollution and has started to put into effect a strategy to remedy the air pollution dilemma. Legislation and research concerning air pollution have become increasingly abundant. Over the last decade, several measures have been introduced in an attempt to reduce the current levels of air pollution, such as the Air Pollution Control Ordinance of 1989, the Ozone Protection Ordinance of 1993, and numerous government measures to improve fuel quality (WWF HK, 2001). Many of these new laws are completely revolutionary within the Hong Kong judicial system in that pollution control legislation has traditionally been extremely rare, but there still remains much to be done (HK ESD ASG, 2000). Currently, Hong Kong consistently violates pollution level guidelines set by the Hong Kong government Special Administrative Division (HK ESD ASG, 2000). These high levels of pollution have caused an increasing number of people to realize that steps must be taken in an attempt to solve the pollution problem. Further steps that go beyond the current legislation concern numerous research projects being conducted that have helped clarify the extent of the pollution problem and identify possible short term and long-term solutions. According to the Hong Kong Environmental Protection Department (2000), some of the more ground-breaking of these scientific inquires have been the Environmental Impact Assessment reports that have been conducted prior to any operations that could potentially have a major effect on the Hong Kong environment. These reports have helped set guidelines and regulations for major projects and have helped further the understanding of the Hong Kong pollution situation.

2.3.3 Current Levels of Aircraft Air Pollution

Although research and legislation have led to significant progress, there are still many facets of air pollution that have been left unattended. One of the most prominent examples of this is the contribution of air traffic to air pollution in the Hong Kong area. Several studies have been conducted world wide, that have shown that aircraft often are one of the top contributors to air pollution (HK EPD, 2000).

More importantly, the Hong Kong Environmental Protection Department (2000) explicitly indicates the percent of total pollution for several toxins contributed by Hong Kong aircraft. This organization identified the five largest contributors to pollution in Hong Kong as vehicle emissions, power generation, aircraft emissions, marine emissions, and fuel combustion (domestic, commercial, and industrial), and accumulated figures of each of these contributors (See Table 2.3 and Figure 2.7). They identified that aircraft in 1999 were accountable for .4% of airborne particulate matter released, .6% of SO_2 emissions, 4.1% of NO_X emissions, 3.7% of VOC emissions, and 2.3% of CO emissions (see Appendix 8.7). Although these percentages represent a fairly insignificant portion of the total pollution produced for 1999, they are misleading, as discussed in the next paragraph.

Table 2.3. Aircraft Pollution Statistics in Tonnes from 1990 – 1999 (Hong Kong Environmental Department, 2000).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
CO	1,627	1,708	1,848	2,065	2,186	2,265	2,379	2,432	2,299	2,165
NO_X	2,843	3,014	3,306	3,771	4,052	4,162	4,337	4,424	4,218	4,096
Particulate	27	29	31	34	36	37	39	41	39	40
SO_2	254	272	301	346	378	391	404	409	384	363
VOC	545	573	611	670	704	712	739	741	690	628

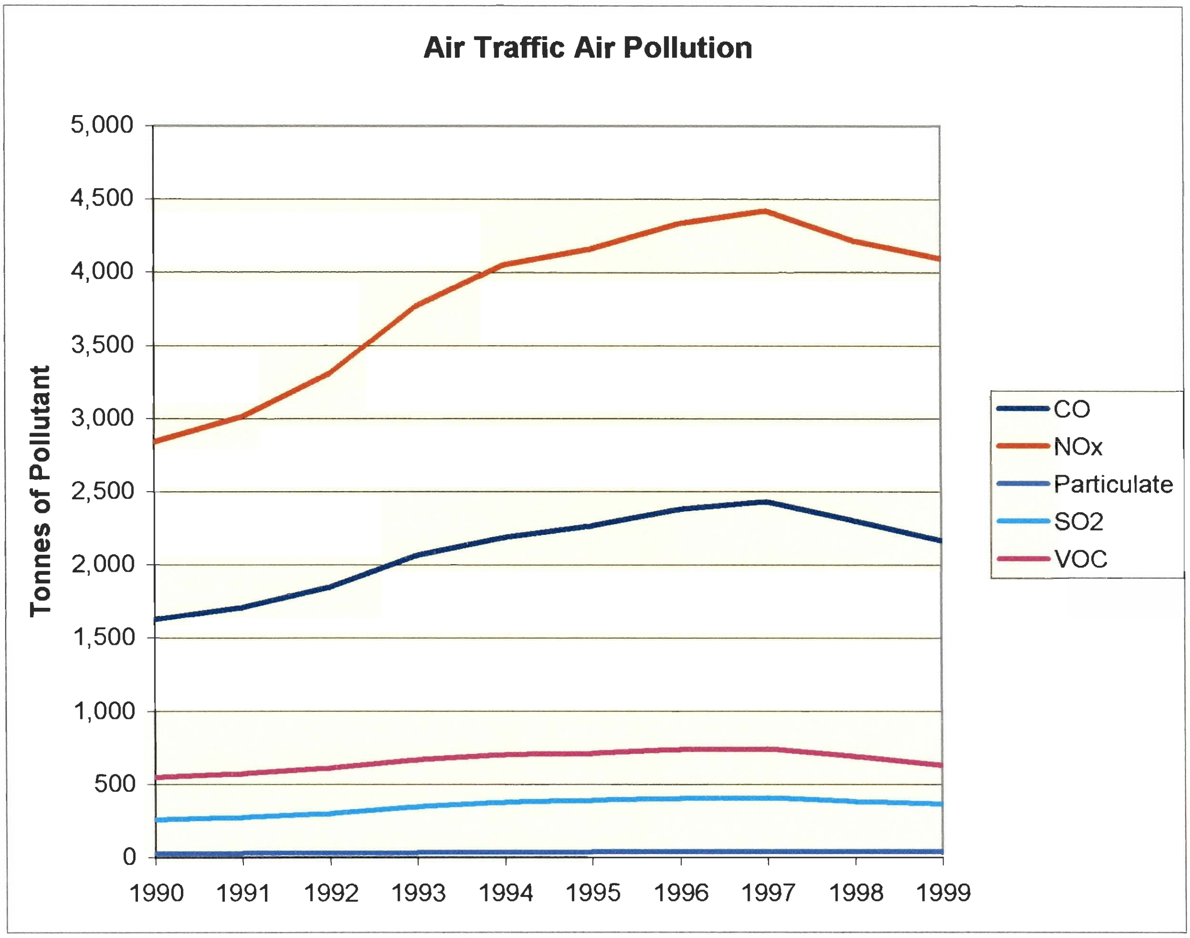


Figure 2.7. Aircraft Air Pollution from 1990 – 1999 (Hong Kong Environmental Department, 2000).

As can be clearly determined in the Hong Kong Environmental Protection Department's data (2000), Hong Kong currently has an extreme problem with motor vehicle pollution. These high levels of pollution produced by automobiles, dwarfs the air pollution issues related to aircraft pollution. If the pollution figures for automobiles are not considered, in an attempt to view the contribution of aircraft without the extreme vehicle figures making the problem seem diminutive, the results are far different. Without the vehicle figures, aircraft contribute .9% of airborne particulate matter released, .62% of SO_2 emissions, 6.5% of NO_X emissions, 30.0% of VOC emissions, and 19.3% of CO emissions. This suggests that although aircraft pollution is nowhere near the level of motor vehicle pollution, it is a strong competitor when compared with the other three significant sources of pollution. In Table 2.3

and Figure 2.7 the actual levels of each pollutant produced by aircraft between 1990 and 1999 can be seen. (For a comparison between aircraft and the other major sources of pollution in Hong Kong, see Appendix 8.7)

2.3.4 Projected Levels of Aircraft Air Pollution

2.3.4.1 Growing Air Traffic Demands

Our study's inquiry into air traffic air pollution is particularly important in Hong Kong due to the construction of the new Hong Kong International Airport, which officially opened on July 6, 1998 (Provincial Airport Authority, 2001). This airport is of particular consequence due to its current size and its even greater potential for growth. Currently, the Hong Kong Provincial Airport Authority's Airport Master Plan for 2020 (2001) indicates that the Hong Kong International Airport supports an annual volume of 34 million passengers, 2200 tonnes of cargo, and nearly 190 thousand aircraft movements. Furthermore, the Master Plan for 2020 indicates that with almost fifty percent of the world's population within a five-hour flight, the Hong Kong International Airport's geographic situation has elevated the airport to a global aviation center. Consequently, the Hong Kong Airport Authority has projected staggering future demands for the airport including a 6% annual increase in passengers, 12% annual increase in cargo, and an 8-10% annual increase in aircraft movements.

2.3.4.2 Airplane Makes and Models

In order to assess the environmental consequences of the HKIA and other airports in the area, several aspects must be taken into consideration. The most significant of these will be the types of aircraft being used in the area. This will be of high consequence because each make and model of aircraft has a specific engine type, capacity, weight, and efficiency. All these aspects, in coordination with the quantity of each aircraft in use, will affect the levels of pollution for the area.

2.3.4.3 Changing Fuel Quality

The types and amounts of fuel will be of significant consequence in the levels of pollution produced by air traffic. According to O'Rourke, generally jet fuel is of fairly high quality, but there are still varying degrees of purity (O'Rourke Interview, Appendix 8.2). He stated that low quality fuels would be high in sulfur and nitrogen content causing increased emissions of SO_x and NO_X when the fuels were burned. Furthermore, he continued saying that poorly refined fuels could also contain contaminants that created Hazardous Air Pollutants that were incinerated into the atmosphere when the fuel was burned. This creates a possible issue in Hong Kong because since the transfer of Hong Kong to China, a majority of the total Hong Kong fuel supply comes from China. In fact, nearly 60% of the total Hong Kong fuel supply is imported or smuggled in from China. Often, this fuel obtained from China is of poor quality and low refinement (Addison, 2000). Recently, however, the Hong Kong Special Administrative Region has lowered taxes on low-sulfur fuels, allowing them to compete with lower quality fuels (Dr. Alexis Lau, personal interview, January 15, 2002). Provided that these lowered taxes remain in effect, the fuel being used in the Hong Kong area will be of a quality such that its impact on air pollution will be negligible.

2.3.5 Effects of Air Pollution

The current and projected pollution statistics described above indicate that air traffic is a source of fair amounts of air pollution. As identified, the major chemicals released into the atmosphere from an airport include NO_X, ozone, CO, SO_x, VOC's, and particulates. These toxins can have a wide variety of detrimental effects. Determining the extent and area of these effects is hard to gauge due to the complex nature of air pollution (O'Rourke

Interview, 2001). The factors that must be taken into account are the pollution sources, meteorological patterns, and chemical data.

2.3.5.1 Air Shed of the Hong Kong area

Hong Kong University of Science and Technology (UST) publishes daily air pollution indices (API) for the Hong Kong region (Dr. Alexis Lau, personal interview, January 15, 2002). What is interesting about their calculations is that they are primarily based on daily wind currents, not on daily emissions. The University has discovered that because the amount of emissions per day stays relatively constant, and varies predictably with the seasons, emissions have relatively minor effects on a given day's API. Therefore, by creating a listing of pollution sources in an area, or an emissions index, the general pollution for any given day can be foretold fairly accurately. Consequently, wind is the deciding factor because it can move, remove, dissipate or even concentrate airborne pollution. These winds tend to create localized areas called air sheds. An air shed is a meteorological zone in which air circulates. Consequently, pollution generally remains in the air shed where it was created.

Some environmentalists in Hong Kong have speculated that much of Hong Kong's pollution is actually caused by China (Dr. Alexis Lau, personal interview, January 15, 2002). The belief is that this pollution is created hundreds of miles away in Mainland China and is then transported by southerly winds to Hong Kong. This is not the case, however. Research carried out by a UST research group, The Center for Costal and Atmospheric Research, suggests that pollution in Hong Kong comes mostly from local and regional sources, regional referring to the Pearl River Delta area. This suggests that by reducing emissions in Hong Kong and Guangdong the amount of air pollution in the area can be decreased significantly. With the use of satellites that are able to detect the amount of particulate in the air, scientists have seen that the effects of the Nan Lang or "Southern Mountains" of China create two distinct air sheds, one south of the mountain range in the Hong Kong area, and one in the northern China area. This is the result of the height of these mountains which blocks winds from the north, essentially locking in air pollution in northern China in the area containing the city of Beijing. This occurs because usually airborne pollution does not rise above the mixing zone and most particulate pollution is heavy and concentrates at ground level.

This phenomenon can be seen in Figures 2.8 and 2.9. Figure 2.8 shows a map of China where the Nan Lang can be clearly seen. On this map the Nan Lang is the mountain range that can be seen between the Yangtze River to the north and Pearl River to the South. On this map Hong Kong is located at the mouth of the Pearl River. Figure 2.9 shows a satellite map of the same area. In Figure 2.9 the level of pollution in the area increases from white to red. The red spot on the southern coast represents the pollution in the Hong Kong area. This red area shows that the levels of pollution in Hong Kong are fairly significant. Furthermore, it can be seen that although the pollution is significant, it is also localized to the Hong Kong area. Looking further north on the map, several large areas of extreme pollution can be seen within Mainland China. Comparing these large areas of pollution in Figure 2.9, to the map in Figure 2.8, it can be seen that these areas of pollution in China, outline the Nan Lang. This shows that the Hong Kong area is in a separate air shed from the rest of China. Although this means that generally pollution remains in the area in which it was created, in extreme cases, wind can move airborne pollution thousands of miles, and across several air sheds.

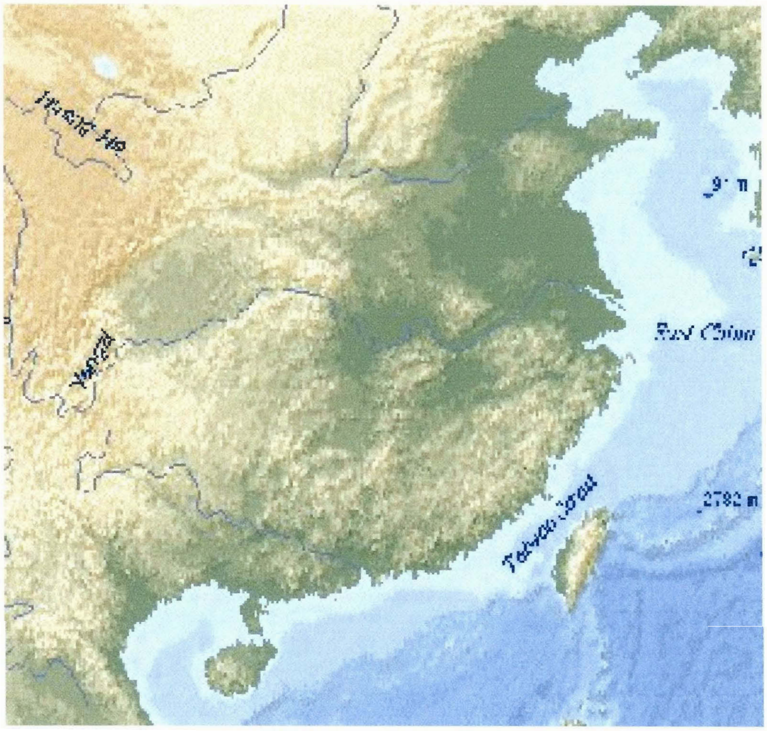


Figure 2.8. Geography of China and the Surrounding Area (Provided by Alexis Lau, 2002).

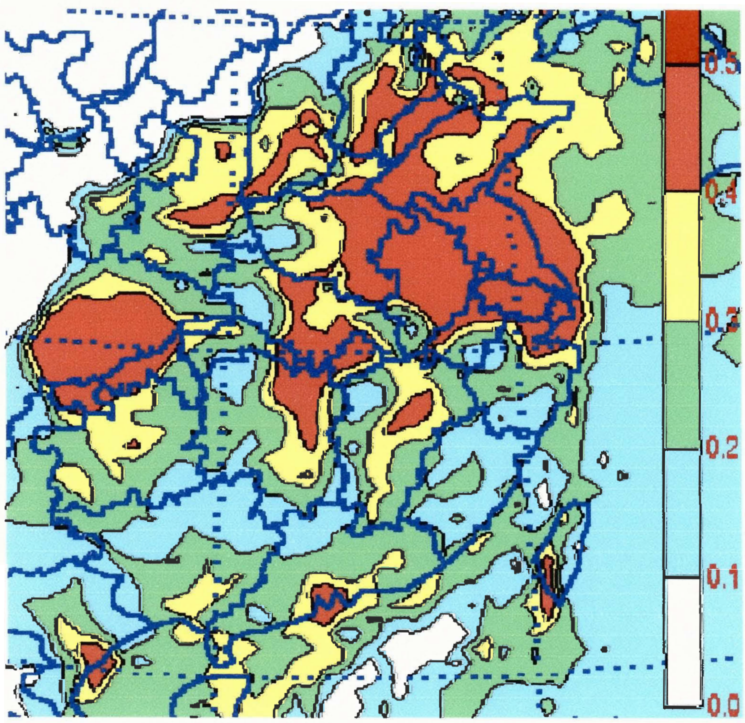


Figure 2.9. Satellite Pollution Index of China and The Surrounding Area (Provided by Alexis Lau, 2002).

Rare severe weather events that transport pollution from China to Hong Kong occur several times a year (Dr. Alexis Lau, personal interview, January 15, 2002). These include sandstorms and large cold fronts. During a sandstorm huge quantities of dust and small sand particles are kicked high into the atmosphere and can be transported around the globe. These particles are small enough that they are classified as suspended particles, similar to particulate emitted through combustion. In 1996 China experienced a dust storm of unusual severity. Through the use of satellite imagery, researchers at the Hong Kong University of Science and Technology were able to track the path of dust kicked up into the atmosphere. They were able to track dust that traveled as far as the great lakes region of the United States. Dust storms in China, which affect Hong Kong only occur two to three times a year. Their effects can be seen in unnaturally high API on affected days. Severe cold fronts can sometimes form over China and move south, carrying pollution with them, over the southern mountains. These large cold fronts only affect Hong Kong five to ten times a year, but when they do occur, they can increase the daily API in Hong Kong significantly for several days.

2.3.5.2 Meteorological Patterns

The mixing zone in Hong Kong varies greatly in height depending on the season and time of day (Dr. Alexis Lau, personal interview, January 15, 2002). In the summer, the mixing height around Hong Kong can be as high as 5000 feet during the day, and 1750 feet at night. In the winter the mixing height can range from 3000 feet during the day to under 1000 feet during the night. The seasonal difference occurs because of the temperature variation between winter and summer and because the direction of the prevailing wind changes. On the other hand, the prevailing winds in Hong Kong tend to flow from the East to the West, as shown in Table 2.4.

Table 2.4. Prevailing Winds in Hong Kong (Hong Kong Observatory, 2001).

Month	Prevailing direction (deg)	Mean wind speed (km/h)	Maximum gust (km/h)
Jan	080	14	63
Feb	080	14	72
Mar	080	17	74
Apr	090	15	63
May	090	13	72
Jun	200	14	88
Jul	210	13	72
Aug	150	13	108
Sep	090	12	113
Oct	090	13	67
Nov	090	13	61
Dec	030	12	61
Annual	090	14	113

This wind pattern is nearly constant for all seasons, changing only during severe or unusual weather situations such as large weather fronts (Dr. Alexis Lau, personal interview, January 15, 2002). The prevailing winds in the Northerly and Southerly directions are far more complex. During the summer the wind typically comes from the south, but these summer winds change direction slightly between the day and night (EPD, personal interview, January 17, 2002). During the night the wind flows over the land in reasonably straight paths from south to north. During the day, however, the warming of the air, due to the sun, creates circulating breezes around the Hong Kong area. This phenomenon can be seen in Figure 2.11. Figure 2.10 depicts the prevailing winds for a typical winter night, while Figure 2.11 shows the circular wind patterns that form during a winter day in Hong Kong. This circular motion of the air often keeps air pollution locked within the Hong Kong area (Dr. Alexis Lau, personal interview, January 15, 2002). The wind patterns that occur at night bring pollution into Hong Kong from Guangdong. During the winter the day and night air patterns are more similar, but the wind comes from the north rather than the south. This means that the breezes in the winter are generally less clean because they are bringing in more polluted air from Guangdong. During the winter Hong Kong's average API is also typically similar to the summer, because of the decreased use of air conditioners.

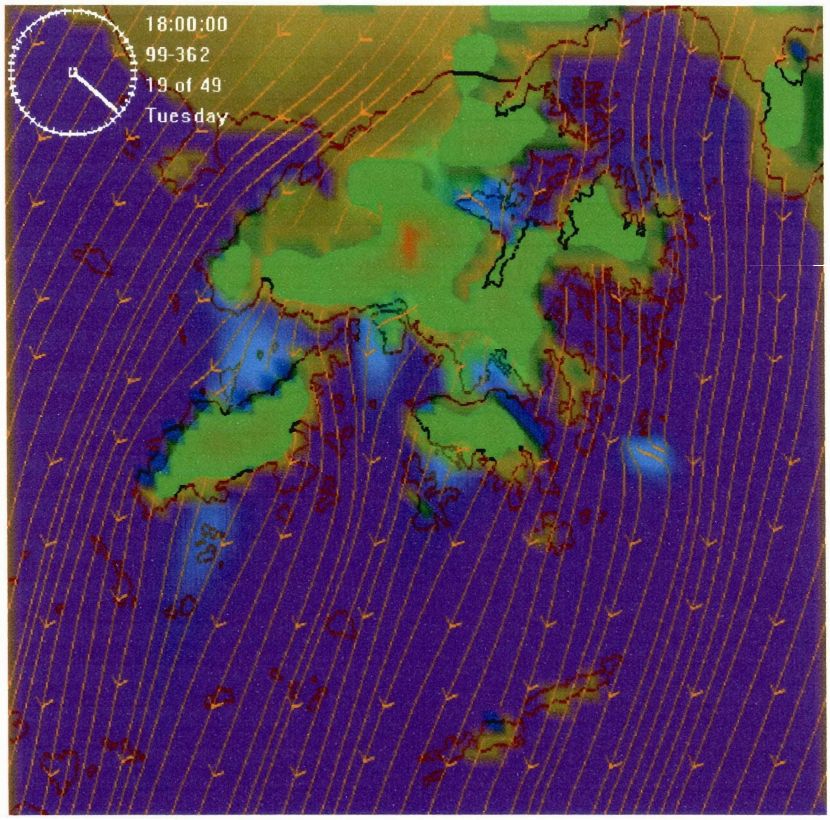


Figure 2.10. Prevailing Winds for a Winter Night in Hong Kong (Provided by Alexis Lau, 2002).

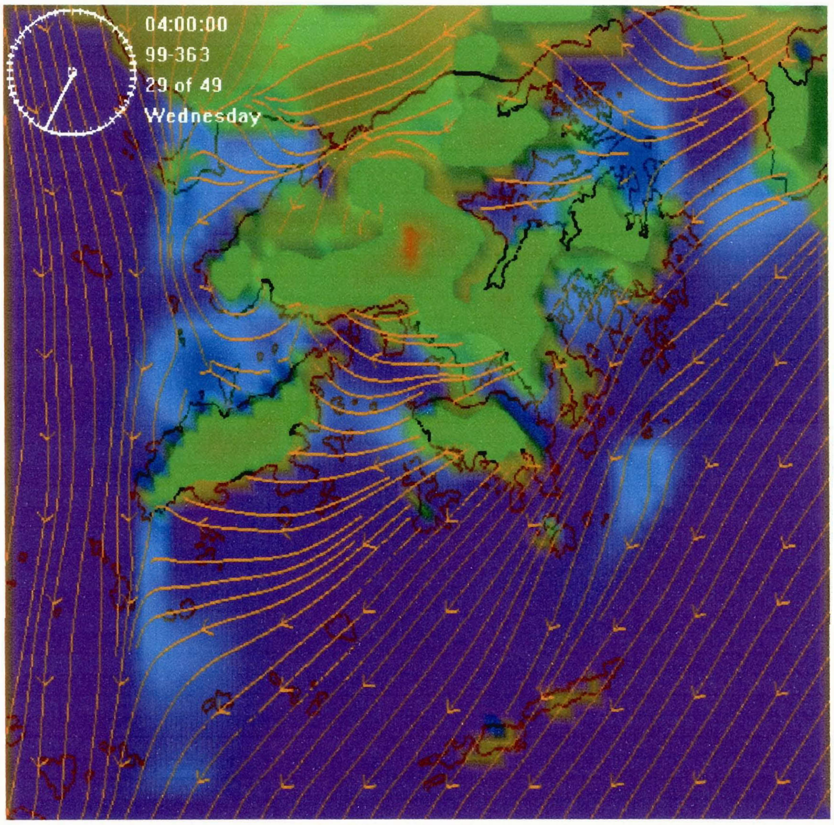


Figure 2.11. Prevailing Winds for a Winter Day in Hong Kong (Provided by Alexis Lau, 2002).

Hong Kong Special Administrative Region is lucky in that it benefits greatly from being located on a peninsula and islands that are subject to regular ocean breezes (Dr. Alexis Lau, personal interview, January 15, 2002). These breezes carry away much of the pollution created in Hong Kong and replace it with cleaner air off the ocean. Even with these wind patterns, however, Hong Kong's average API is near 70. Most parts of the US have APIs below 30, with only a few areas averaging above 50. Hong Kong's situation can also be seen in the amount of haze that is observed on a daily basis.

A "hazy" day is classified as a day during which visibility drops below eight kilometers (Dr. Alexis Lau, personal interview, January 15, 2002). Haze is the result of airborne particles blocking light. Usually the smaller the particles are, the more effect they have in diminishing vision distance. Thus small particulate, i.e. PM 2.5 (particulate matter smaller than 2.5 micrometers), is the greatest contributor to haze. Natural haze can occur on smaller than 2.5 micrometers), is the greatest contributor to haze. Natural haze can occur on humid days but does not occur often, especially in breezy costal areas. Hong Kong's haze is caused by high particulate matter and NO_X emissions in the air. During the early 90's, only 4% of the days in the year could be classified as hazy in Hong Kong. In the late 90's this increased to 10%. In 2001 the number of hazy days was up to 15%. This increasing haze represents not only worsening pollution amounts that affect citizens' health and the ecology of the area, but it also detracts from the beauty of the city and may have a negative impact on tourism and the economy.

2.3.5.3 Chemical Complications

Solar patterns can have a strong influence on pollution. As a result of ultraviolet radiation, airborne toxins can become involved in photochemical reactions that often significantly alter their specific nature and effects (O'Rourke Interview, 2001). Due to Hong Kong's geographic location relatively near the equator, there is a substantial amount of direct sunlight. O'Rourke explained that the complications of this ultraviolet radiation would most prominently be seen in the generation of ozone. When the upper atmosphere contains NO_X and VOC, ultraviolet radiation breaks the chemical bonds in these pollutants in a photochemical reaction allowing them to re-form into ozone. Also, chemical reactions in air pollution can be seen in the reaction between NO_X and ozone. When NO_X and ozone are in the atmosphere, the NO_X will remove an oxygen molecule from the ozone changing the ozone from O_3 to O_2, normal oxygen. Therefore an increase in the levels of NO_X will cause a decrease in the levels of ozone, but, following similar logic, decreasing NO_X emissions will result in an increase in ozone pollution. This phenomenon can be seen in Figures 2.12 through 2.15. Figure 2.12 shows the levels of NO_X generally found in Hong Kong, while Figure 2.13 shows the levels of NO_X that would result if all power plants were removed from Hong Kong. Comparing Figures 2.12 and 2.13, it is clear that there is a significant decrease in the levels of NO_X when the power plants are removed. It would seem like this decrease in NO_X would be completely beneficial, but that is not necessarily the case. Figure 2.14 shows the levels of ozone that are generally found in Hong Kong, while Figure 2.15 shows the levels of ozone that would result if all the power plants were removed from Hong Kong. Comparing Figures 2.14 and 2.15 surprisingly show a significant increase in ozone with the removal of the power plants. Thus, removing sources of NO_X can have the result of increasing the levels of ozone. Since these reactions represent a change in chemical composition of the pollutants, the resultant ramifications of the pollution will also be different. According to Loh (1998), historically, Hong Kong has not had high levels of ozone pollution, but in recent years, the levels of ozone have been increasing at phenomenal rates. She explains that in the last seven years there has been more than an eighty percent increase in ozone in Hong Kong.

2.3.6 Current Measuring Strategies

Currently Hong Kong has several methods that it uses to determine levels of pollution in the area, and it has plans for even further, more advanced systems for the future (Dr. Alexis Lau, personal interview, January 15, 2002). There are two ways that the air pollution is measured in Hong Kong. The first is by source sampling. In source sampling, an air pollution source is initially identified. Once the source has been identified there are two basic methods to determine the levels of pollution produced by that source. The first is by directly measuring the contaminants being released by the pollution source and the levels of pollution in the surrounding area. The second method of source sampling is more indirect. In this method, the source is examined, and then separated into the factors within the source that cause pollution. Once the polluting sectors have been identified within the source, the mean output of each pollution factor is calculated based on an interval of time and then summed to create a total output for a given period of time.

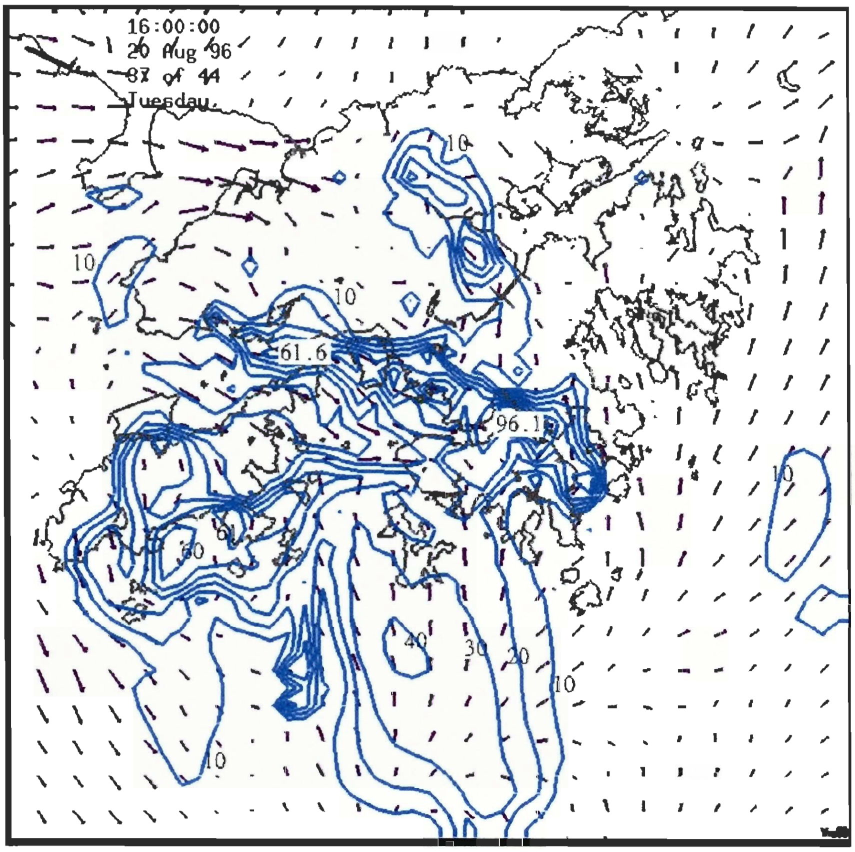


Figure 2.12. NO_X Levels Generally Found in Hong Kong (Provided by Alexis Lau, 2002).

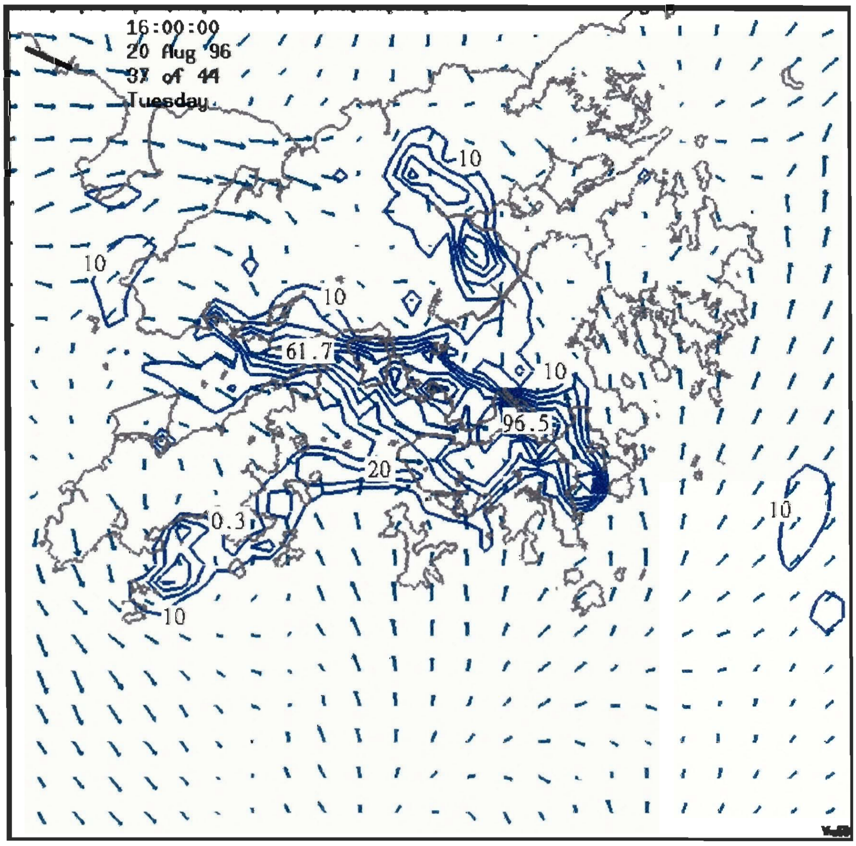


Figure 2.13. Level of NO_X in Hong Kong if Power Plants were Removed (Provided by Alexis Lau, 2002).

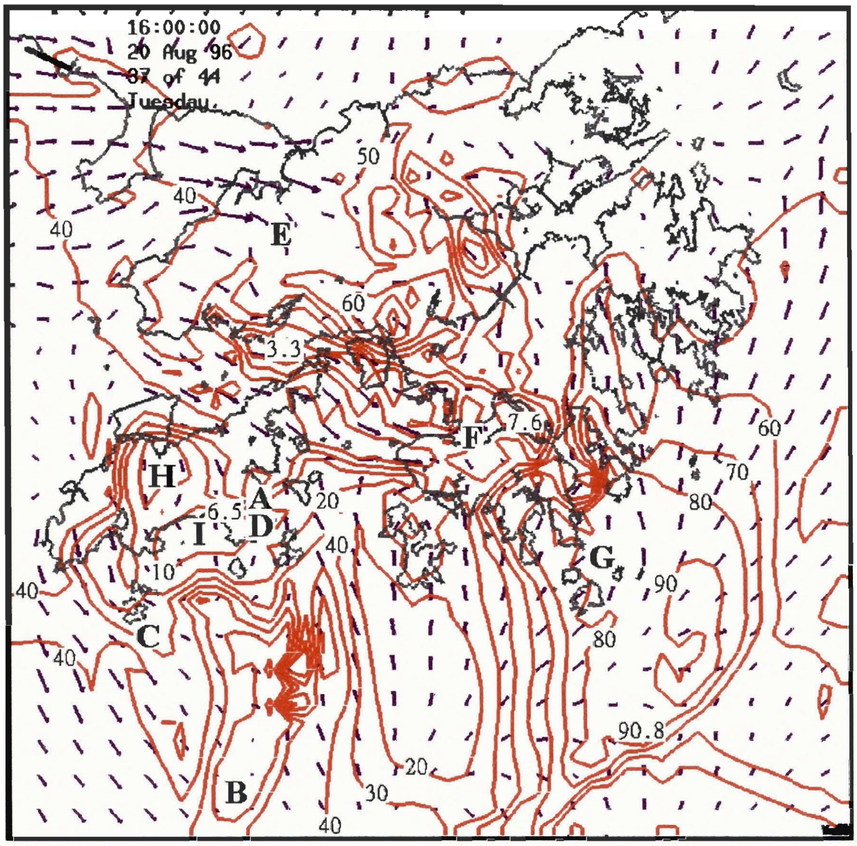


Figure 2.14. Ozone Levels Generally Found in Hong Kong (Provided by Alexis Lau, 2002).

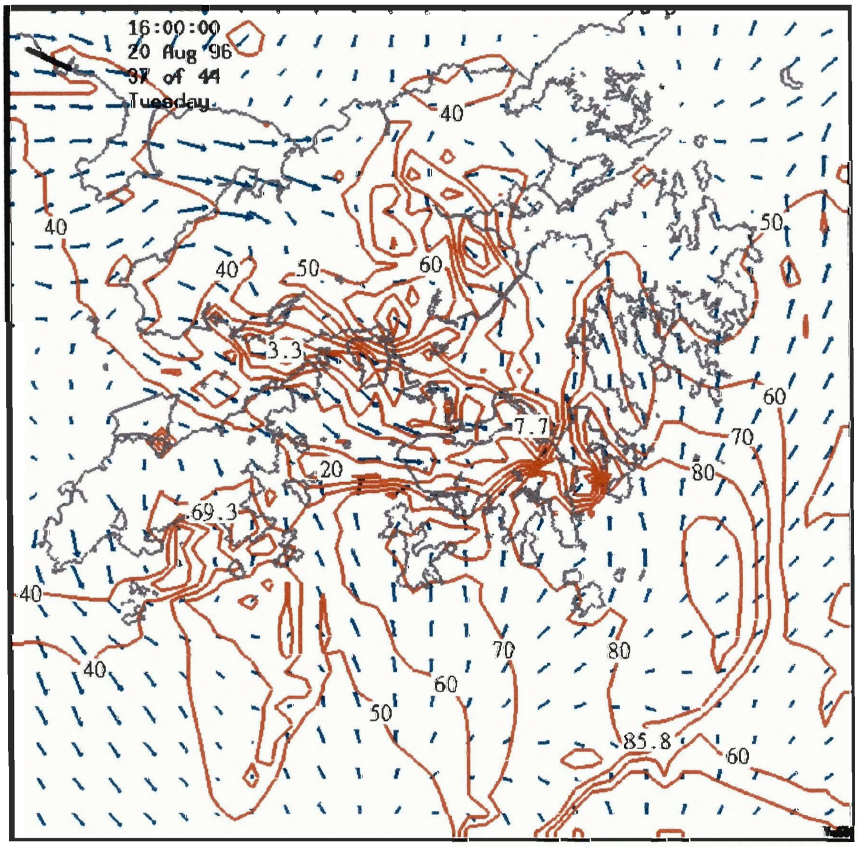


Figure 2.15. Level of Ozone in Hong Kong if Power Plants were Removed (Provided by Alexis Lau, 2002).

Both these methods have their advantages and drawbacks. While the direct method provides far more accurate data, the data only represent a short interval of time. Therefore, it can be difficult and costly to determine long-term effects because several measurements must be done. The indirect method solves this problem by providing a more in-depth understanding of the source. This analysis provides an easier method for calculating long-term outputs, but because it may not necessarily cover all the polluting factors within a source, it can be far less accurate. Hong Kong currently employs both methods of source sampling in developing their emissions inventory.

In addition to source sampling, Hong Kong also uses a wide variety of ambient sampling techniques. Ambient sampling gives a clear idea of the current pollution conditions, but it does not provide data on the source of the pollution. Some of the ambient sampling techniques used in Hong Kong are fixed monitoring stations, aircraft monitoring, fixed laser monitoring, and satellite pollution monitoring. Monitoring stations and aircraft are used to determine the current pollution levels at a given point. Using this technique, several monitoring stations must be placed in different locations in order to gain an idea of the current pollution levels. Similarly, when using aircraft to monitor pollution levels, several aircraft must be used to scan the pollution, each traveling along varied paths, in order to obtain the current pollution levels. These two methods of monitoring are relatively old compared to the satellite and fixed laser monitoring.

These two methods, the satellite and fixed laser monitoring, are fairly groundbreaking, and while these are now partially active, they are currently in the process of being established. The unique aspect of these systems is that they allow pollution to be tracked as well as measured. Laser monitoring is currently being established along the borders of Hong Kong. Using these fixed laser stations, the levels of pollution entering and exiting Hong

Kong can be measured. More significantly, the newly established satellite monitoring system will allow for further tracking of pollution on a far wider scale. These satellites, only one of which has been launched so far, can peer down upon the pollution levels on a very wide area and gain a far more accurate view of the current pollution levels. It does this by capturing an image of pollution for the entire area, instead of approximating the pollution level from data collected at several locations. Furthermore, this satellite system can, over time, view changes in the pollution situation allowing pollution to be tracked more accurately than it was possible prior to its establishment.

2.3.7 Political Nature of Air Pollution

The idea of pollution disregarding international borders aggravates the fragile political balance that often circulates with pollution. Air pollution, especially in Asia, is politically controversial, and therefore air pollution control and research may be hindered or outright blocked by political factors. Pollution control is often blocked by politics because of the high costs associated with it. Not only does it cost governments large sums of money to control pollution, but also often many of the sources of pollution are large industries that have immense political clout. Furthermore, the difficultly in determining the actual source of ambient pollution can also be a factor in hindering pollution control. Policy makers desire noticeable results to come from their actions.

The inability to determine from where pollution comes creates a problem in Hong Kong due to the speculation as to whether pollution in Hong Kong is the result of pollution being moved in from other countries. Recent data suggest that this is not the case, but many still believe that a significant part of the pollution problem is coming from other parts of Asia. If this were the case, reducing pollution output within Hong Kong would have a marginal effect on the pollution levels within Hong Kong. This notion slows the development of pollution control strategies and legislation.

Further political conflicts can occur, especially in Hong Kong, due to the public awareness of pollution. In Hong Kong, it is difficult not to be aware of the pollution problem. As a result, being identified by the public as an entity responsible for furthering the pollution problem can have devastating effects. Therefore, many businesses and organizations are hesitant to release air pollution related data. They fear that this information could potentially implicate them as a significant pollution source or could be misconstrued or taken out of context. Consequently, this makes the data more difficult to obtain, thereby hindering pollution control and remediation. This lack of data sharing even exists on a larger scale. On the international level, many countries are wary to release pollution or pollution source information for similar reasons. This, in turn, further complicates the local understanding of air pollution levels and makes a global understanding of air pollution nearly impossible.

2.4 Closing Points

As identified by the Hong Kong Department of the Environment (2000), aviation, like all other forms of transport, will inherently cause adverse environmental impacts. The Department of the Environment suggests the reduction of adverse effects through the identification and evaluation of the externalities of aviation. They identify these externalities as actions performed by an individual or organization that adversely affect a population. Our study will focus on the externalities which cause air pollution resulting from aircraft. These externalities will be identified and the quantified in order to extrapolate the health and environmental effects in the Hong Kong area.

Chapter 3

Methodology

3.1 Overview

The goal of this study was to determine the levels of air pollution contributed by air traffic in Hong Kong and Guangdong and to identify any effects and possible remedial actions. This goal was accomplished through the completion of thirteen tasks that fell into three main categories: the acquisition of general and aircraft specific air pollution statistics, the acquisition of aircraft data and quantity, and the acquisition of data concerning health and environmental effects. Data for each of these three categories were collected through a combination of interviews, quantitative data collection, and qualitative data collection. Interviews were conducted from a sample frame of environmental scientists, airport employees, aircraft specialists, and health care officials, while qualitative and quantitative data were collected through the analysis of reports, case studies, and the observation of air pollution and airport activities. Once the data for the study were collected, they were analyzed to determine the levels and effects of aircraft air pollution, and possible trends, patterns, and formulas that were ultimately used to understand the future of aircraft air pollution.

3.2 On Site Interviews

Several on-site interviews were conducted in order to determine the experts' opinions concerning the air pollution contribution of aircraft in Hong Kong. These interviews focused on individuals from a variety of disciplines. Candidates were environmental scientists, health care officials, airport employees, and aircraft specialists in the Hong Kong area. This wide coverage within the different interviewees provided a broad overview of Hong Kong's issues as related to aircraft and the effects of the air pollution produced. The candidates for these interviews were knowledgeable in a fairly specific array of data. Consequently, random selection was not appropriate, and non-random, key informant interviews were conducted. Also, the interviews were informal and semi-structured informal for the most part, with some of the questions we asked being listed in Appendix 8.5.

Initial meetings were scheduled with environmental scientists. Three experts were interviewed from this group so that we could obtain at least some contrasting views. We interviewed Dr. Alexis Lau, Associate Director of the Center for Coastal and Atmospheric Research and Adjunct Associate Professor of Mathematics at the Hong Kong University of Science and Technology. We also interviewed Dr. Chris Fung, Senior Environmental Protection Officer, and his associate Dr. Hin-chung Lau of the Hong Kong Environmental Protection Department. A third interview was conducted with Mr. Wing-mo Wong, Senior Scientific Officer, and his associate Mr. Kim-po Wong, Chief Experimental Officer, both of whom work with the Hong Kong Observatory. These interviews provided an overview of the most up-to-date pollution levels in Hong Kong. Also, these interviews helped to conclude that there were substantial environmental issues in the Hong Kong area, as represented by the data obtained from the literature. Furthermore, these interviews were useful in determining the local environment of Hong Kong and how the toxins associated with air traffic affected the ecosystem in the area. In addition to learning about environmental effects, these interviews provided insight into how this pollution was affected by the meteorological patterns of Hong Kong. Also, detailed and current statistics from environmental reports that were obtained from these scientists were incorporated into our literature review. Finally, these interviews helped provide some information on possible effects of the pollution on the people of Hong Kong.

For more information on health effects from pollution, interviews were conducted with health care professionals in Hong Kong. We interviewed two experts from this group so that we could obtain a clear understanding of air pollution health consequences in Hong Kong. This interview was conducted with Professor Moira Chan of the Hong Kong University who is also associated with Queen Mary Hospital as a researcher, and Benson Yeung, Senior Environmental Protection Officer with the Hong Kong Environmental Protection Department. These meetings provided current data on the general health of the Hong Kong population, as well as data related to health effects in Hong Kong that were the result of high levels of pollution. Furthermore, these interviews provided information on how the specific toxins from aircraft affected the health of Hong Kong's population. Finally, Dr. Chan and Mr. Yeung assisted us by showing us pollution and health related sources on the Internet that helped us gain an understanding of pollution and health trends in the Hong Kong area.

To determine the pollutants that come from aircraft, interviews were also conducted with aircraft experts in the area. We interviewed one expert from this grouping so that we could obtain data on pollution produced by the types of aircraft used in the Hong Kong area. We would have liked to interview more of these specialists, but due to the current situation surrounding aircraft information since the collapse of the World Trade Center in New York City, and the difficultly in obtaining interviews with this type of specialist, we decided to aim for one interview. This interview was conducted with Mr. Jeffery Law, Senior Operations Officer of the Hong Kong Civil Aviation Department. From him we gained information concerning pollution levels produced by different makes and models of planes used in the Hong Kong area. Although a large quantity of this sort of data was collected through background research, these interviews provided a pivotal tool for validating the background information as well as gaining new information concerning types of aircraft and engines that were unique to the Far East or were not allowed into American airspace due to pollution violations. Furthermore, data were gained concerning the toxic emissions during different aspects of the airplane and engine uses, such as taxiing, take off and landing cycles, refueling, and flight. The pollution statistics gained through these interviews in conjunction with airport data were of paramount importance in determining more precisely what levels of pollution were resultant from aircraft.

In order to acquire other similar airport statistics, interviews were conducted with airport specialists. We interviewed Mr. Sui Fai Ng, Airfield Assistant General Manager for the Hong Kong International Airport, and Ms. Yuyu Tse and Mr. Tommy Wang, Environmental Scientists for the Hong Kong Airport Authority. An additional interview was conducted with Mr. Savio Chan, Reliability Engineer for Cathay Pacific Airways. From these interviews, data concerning the makes, models, engines, and numbers of planes in use were obtained, as well as information concerning the specifics of airport operations and ground crew scheduling. These interviews also provided data concerning aircraft movements in the Hong Kong area for each aircraft make and model. The data from the Hong Kong Airport Authority and Cathay Pacific, and the statistics obtained through the aircraft expert interviews with the Hong Kong Civil Aviation Department, when combined, produced a broad view of the level of pollution created by aircraft.

3.3 Data Collection

3.3.1 Quantitative

While in Hong Kong, there were several different places from which we gathered information. One of these was existing environmental reports concerning the effects that aircraft had on the local environment, such as the New Airport Master Plan Environmental Impact Assessment, which was obtained through an interview with the Hong Kong Airport

Authority. This report helped us calculate the emissions from moving aircraft and provided us with a sound understanding of operational procedures currently in place in the airport. There were also data at the local air pollution monitoring stations to which we gained access through interviews with the EPD. Furthermore, the local airports keeps statistics on what types of aircraft flew into and out of the port, and also what types of fuels they were using. By gathering data such as these, we were able to calculate the actual amount of pollutants that were emitted into the air by each type of aircraft, and also the constituents of these pollutants. In order to determine the actual effects of the pollutants, however, we needed to gain access to the current pollution related health data. Since it was statistically impossible to relate these effects directly to aircraft pollution, this report focuses on the effects resultant from ambient pollution in Hong Kong. According to Professor Chan, the reason that effects of aircraft pollution cannot be explicitly determined is because once pollution from several sources are mixed within the atmosphere, it is impossible to determine what effects come as a result of each source. Therefore, in order to determine some sort of connection between the effects of ambient pollution and aircraft pollution, once the levels of aircraft pollution and effects of ambient pollution were determined, the levels of each type of pollution were compared to obtain a link between the two sets of data. In order to strengthen this correlation, further data were obtained through pollution locality models created by the Environmental Protection Department. These models provided an idea of where the aircraft pollution became situated within a given year.

3.3.2 Qualitative

There was also some qualitative data collection that was done, mostly in the areas of the airport and the general pollution of Hong Kong. By observing and recording the activities at the airport, we gained a better understanding of the processes that occurred under day-to-day operations. We also observed and recorded the ambient pollution levels in Hong Kong and any health effects that we saw from the public, hoping to gain a better understanding of the more specific problems that people in Hong Kong faced from the growing pollution problem. Although these data did not provide a very tangible platform for argument, they provided us insight into the possible results we found early on, as well as providing us with alternate avenues in which to pursue further research.

3.4 Analysis

To analyze properly the contribution of aircraft to air pollution in Hong Kong, it was not only necessary to collect a large amount of both qualitative and quantitative data but also to analyze these data in meaningful and scientifically correct ways.
Thus, the analysis of these data was separated into two parts; quantitative and qualitative. The qualitative data obtained through our informal observations were used to describe the situation in a general manner. This type of data needed little modification before it was incorporated into the research and occasionally into the final report. The raw quantitative data, on the other hand, needed a greater amount of processing to make it meaningful to the target audience of the study. The United States EPA's Procedures for Emissions Inventory Preparation, Volume IV: Mobile Sources (1992) describes methods to calculate the contribution of aircraft to an inventory. This method requires certain data. These data include the mixing height for the specific locale, the number of LTO's for the given airport, the fleet make-up at the airport and estimated time-in-mode (TIM).

Time-in-mode is dependent on the mixing height for the given area. An area with a higher mixing zone will have longer approach and climb-out modes. The equation for adjusting TIM's in areas with a mixing height different from the standard 3000ft is as follows:

Climbout: $TIM_{adj} = TIM_{dflt} * \left[\frac{MixingHeight - 500}{3000 - 500} \right]$ (1)

Approach: $TIM_{adj} = TIM_{dflt} * \left[\frac{MixingHeight}{3000} \right]$ (2)

Where TIM_{adj} is the adjusted TIM, TIM_{dflt} is the default TIM for the given aircraft, and Mixing Height is the mixing height determined for the given area. These equations assume the height at which takeoff becomes climb out is 500 feet (EPA, 1992).

Weighted averages of emissions per 1000 pounds of fuel, $\overline{EF}_{ijk}$, are calculated using the following formula:

$$\overline{EF}_{ijk} = \sum_{m=1}^{NM_j} \left(X_{mj} * EF_{imk} \right) \quad (3)$$

where $\overline{EF}_{imk}$ is the emission factor for pollutant *I*, in pounds of pollutant per 1000 pounds of fuel for engine model *m* and operating mode *k*; X_{mj} is the fraction of aircraft type j with engine model m; and *NMj* is the total number of engine models associated with aircraft type j (EPA, 1992).

Total emissions per LTO cycle for a given aircraft type are calculated using the following equation (EPA, 1992):

$$E_{ij} = TIM_{jk} * \frac{FF_{jk}}{1000} * \overline{EF}_{ijk} * NE_j \quad (4)$$

where TIM_{jk} is the time in mode *k* (min) for aircraft type *j;* FF_{jk} is the fuel flow mode *k* (lbs/min) for each engine used on aircraft type *j*; EF_{ijk} is the weighted average emissions calculated above; *NEj* is the number of engines on aircraft type *j*.

Once the above calculations are performed for each aircraft type, total emissions for that aircraft type can be found as such (EPA, 1992):

$$E_i = E_{ij} * LTO_j \quad (5)$$

E_{ij} is the total emissions for pollutant i from aircraft of type j and LTOj is the number of LTOs for aircraft type j. Using these final data, the total emissions per aircraft type can be added together for all aircraft to get the total contribution of aircraft to the local inventory.

Because it was possible to locate aircraft emissions data in pounds per minute form, it was possible to simplify the above equations. The part of the formula which describes pollutant emission rate, $\frac{FF_{jk}}{1000} * \overline{EF}_{ijk}$, was replaced with the simple emissions by pound per minute available through the EPD (see Appendix 8.8)

Using the calculated data above, it was possible to determine the percentage of pollution that aircraft contribute to the overall air pollution situation in Hong Kong. These data helped determine what the effect of the air pollution from aircraft had on Hong Kong and its population.

Chapter 4
Results and Discussion

4.1 Aircraft Data

Studying the air pollution from aircraft in the Hong Kong and Guangdong area requires that these two regions be studied together because they both share the same air shed (EPD, personal interview, January 17, 2002). As a result, the air pollution produced in both areas will mix and have detrimental effects on both regions. After looking at the airports in both areas, it becomes clear that although there are several airports in the Pearl River Delta area, these airports are regional, serving only a limited part of Asia. As a result, these airports have relatively few flights, and of the flights that they have, the planes that are used are smaller, domestic carriers that produce limited amounts of pollution. Therefore, in determining the air pollution from aircraft in the Pearl River Delta area, the only pivotal airport that needs to be taken into consideration is the Hong Kong International Airport, due to its international status. It supports a far greater volume of flights that include aircraft that are of far greater size, capacity, and impact.

In 1998 Hong Kong officially opened its new airport at Chek Lap Kok. This new airport was an incredible step forward from the old airport at Kai Tak, which was rated one of the ten most dangerous airports in the world (EPD, personal interview, January 17, 2002). The new Hong Kong International Airport is unusual in that it was constructed nearly entirely on reclaimed land. This allowed the designers to design an airport that was safe, functional, practical, and beautiful (Airport Authority, personal interview, January 5, 2002). Furthermore, this new airport moved air traffic away from the center of Hong Kong's busy Kowloon peninsula, to the outlying island of Lantau. This move generated several benefits related to noise and air pollution thus decreasing the negative impact of the airport. Although this new airport was an important step forward for Hong Kong, its relatively large distance from the urban areas had an "out of sight, out of mind" effect on the people of Hong Kong, who focused themselves on other issues. As a result, airport pollution has been set aside and has not been seriously addressed or analyzed for nearly three years.

During the last three years air traffic in Hong Kong has increased, taking advantage of the potential of the new airport (CAD, personal interview, January 30, 2002). This increase in air traffic is one of the few positive notes in the slowly declining Hong Kong economy. Even after the World Trade Center disaster in New York City, which crippled air traffic around the world, the Hong Kong airport has been able to show traffic increases. In fact, these increases have been steady since the opening of the new airport (Airport Authority, personal interview, February 5, 2002). Since 1997 aircraft passenger traffic in Hong Kong has increased from 29.5 million in 1997 to 33 million passengers in 2001, while freight moved has increased similarly from 1.56 million to 2.08 million tonnes. This is an amazing growth considering the already enormous amounts of air traffic flying in and out of Hong Kong. In 1997 the Hong Kong Airport at Kai Tak was rated the third busiest airport in the world for international passengers and first in the world for international cargo throughput in the world. Furthermore, additional annual increases of four to five percent are expected through 2004 at which time the increase is expected to slow to a 2 percent annual growth rate. Following this trend, the airport should have an annual passenger count of more than 37.12 million, and an annual rate of 2.34 million tonnes of freight moved by the end of 2004. These numbers are projected to increase to 42.64 million passengers and 2.69 million tonnes of freight by the end of 2011.

With a 29 percent expected increase in passengers and freight in the next decade, the negative impact of the airport on the environment becomes of increased concern. An increase in passengers and freight will naturally mean an increase in flights. With an increase in flights into and out of the airport, there will also be an increase in the significance of the airport as a pollution source. Currently the Hong Kong International Airport maintains 550,000 square meters in the passenger terminal with 48 gates in operation allowing it to support ten major carriers and several smaller airlines (Airport Authority, personal interview, January 5, 2002). These airlines support a fleet of 97 different makes and models of aircraft. In 2001 these aircraft made 196,805 movements, which was an 8.2 percent increase over the previous year. This suggests that increases in aircraft movements are not proportional to the increases in passenger and freight movements, since the passenger and freight increases for the same year were only about half the increase in movements. Therefore, with a 29 percent increase in passengers and freight expected over the next decade, there will likely be a far more significant increase in aircraft movements.

4.2 Pollution Data

4.2.1 Inventory Calculation Methods

Using the flight movement data provided by the EPD, it was possible to get a clear picture of the air traffic coming in and out of Hong Kong. These data are presented in Appendix 8.9. Of the 196,805 movements, most were by large commercial passenger aircraft, with the Boeing 747-400 being the most common aircraft, with more than 30,000 movements. Other common aircraft at HKIA include the Airbus Industrie A330 and A340. Data were available regarding the emissions of commercial aircraft through the US EPA. Data for aircraft that were not in the US EPA study were found through the EPD and through estimation. Estimation of aircraft emission rates was done by using data of aircraft with similar weight and configuration. The US EPA data were determined to be the primary source of emissions rates because the EPD described its own data as unreliable. Thus, in several cases, EPD figures for specific aircraft not included in the US EPA report which differed significantly from aircraft of similar type were often replaced with a number that was logical considering the aircraft's characteristics

Using these emission data along with the guidelines for generating a standard airport air emissions inventory, it was possible to calculate an EPA standardized figure of the total tonnage of CO_2, VOC, NO_X and SO_2 for HKIA. Comparing these numbers to the 1999 numbers calculated by the EPD, it appears that there is a reduction in the amount of pollution being generated by HKIA. This, however, should not be the case because the amount of air traffic has increased, and the emission rates per aircraft used were the same as those used in 1999. This decrease is due to the fact that the US EPA standard format is significantly different from the conditions present at HKIA.

Studying the movements of aircraft, taking into account their makes and models, is an important part of calculating the emissions generated by aircraft at a specific airport, but in order to gain a more accurate calculation of the actual pollution, further inquiry must be completed (CAD, personal interview, January 30, 2002). The United States EPA guidelines provide default numbers to be used in calculating a standard inventory. However, to gain more accurate figures it is necessary to use local data that adjust for a specific airport's characteristics. An adjusted inventory was calculated in order to provide the most accurate inventory possible. These adjustments are detailed below.

Because the US EPA uses time-in-mode to calculate total emissions, the adjustments made to accommodate different airports come in the form of changes to the average time for each mode. The simplest mathematical adjustment was made to the takeoff part of the cycle. As can be seen in Table 4.1, the runway occupancy time for departing aircraft varies slightly maintaining a range of between 30 seconds and 47 seconds. Accounting for the percentages of each type of aircraft, this yields a weighted average of slightly over .72 minutes. Because the EPD used the time of .7 minutes for its 1999 inventory, the previous figure (.72) was rounded down to .7 .

Table 4.1. Runway Occupancy Times for Arrivals and Departures (CAD, personal interview, January 30, 2002).

Aircraft Type	Arrival (min:sec)	Departure (min:sec)
A300	01:04	00:34
A320	01:04	00:39
A330	01:01	00:44
A340	01:05	00:47
B737	01:05	00:39
B747	01:15	00:43
B757	01:06	00:35
B767	01:02	00:41
B777	01:01	00:40
MD11	01:09	00:30
MD80/90	00:58	00:40
Average	**01:04**	**00:39**

The second adjustment made to account for HKIA's unique properties was in the taxi portion of the LTO. As can be seen in Tables 4.2 and 4.3, the taxi times for aircraft can vary widely, depending on the approach or takeoff pattern. Table 4.2 shows the taxi times for departures, which can vary from 3 minutes and 35 seconds to 11 minutes and 18 seconds, depending upon the distance that the aircraft has to travel from the gate to the runway. The average time for departures works out to be 7 minutes and 35 seconds.

Similarly, the taxi times for arrivals varies in the same manner. As can be seen in Table 4.3, the taxi times vary from 2 minutes and 26 seconds to 9 minutes and 24 seconds, depending on the distance from the runway to the gate. In order to accommodate arriving passengers, the airport is more efficient for arriving aircraft than departing aircraft, thereby giving an average taxi time for arrivals of 5 minutes and 24 seconds.

Table 4.2. Taxi Times for Departures (CAD, personal interview, January 30, 2002).

Departures		
From	**To**	**Taxi Time (min:sec)**
Cargo Apron	Right Runway	09:17
North Apron	Right Runway	11:18
South Apron	Right Runway	08:38
West Apron	Right Runway	08:15
Cargo Apron	Left Runway	05:53
North Apron	Left Runway	07:52
South Apron	Left Runway	03:35
West Apron	Left Runway	05:57
	Average	**07:35**

Table 4.3. Taxi Times for Arrivals (CAD, personal interview, January 30, 2002).

Arivals		
From	**To**	**Taxi Time (min:sec)**
Right Runway	Cargo Apron	02:26
Right Runway	North Apron	05:52
Right Runway	South Apron	09:24
Right Runway	West Apron	06:00
Left Runway	Cargo Apron	04:54
Left Runway	North Apron	03:27
Left Runway	South Apron	07:02
Left Runway	West Apron	04:10
	Average	05:24

Because data were not available to calculate weighted averages for these taxi times, some judgment was necessary to obtain the best estimated times. The final number was obtained by averaging the total taxi time submitted by the HKCAD with the number used by the EPD in its 1999 inventory (24 minutes). The average was calculated to be 18 minutes.

The last two LTO segments, climb-out and approach, both vary with the mixing height. The mixing height in Hong Kong varies greatly between night and day and also seasonally (EPD, personal interview, January 17, 2002). The average of these, weighted by the number of flights typical for the time periods (assuming equal flight traffic in summer and winter), is 3,750 feet. Using the formulas provided by the EPA, and presented in Appendix 8.8, the average climb-out time is 2.9 minutes and average approach time is 5 minutes.

After calculating the new time-in-modes for the specific airport, the next step in calculating the inventory was to find the total emissions for each aircraft type with its total time in each mode. For example, for a specific aircraft for the landing part of the LTO the calculation was as follows: L * TIM * EMrate. Where L is the number of landings, TIM is time in the given mode (in this case "approach", or 5 minutes), and EMrate is the emissions rate for the given pollutant. This calculation was repeated for each type of aircraft, for each part of the LTO cycle and for each pollutant, and the results of the calculation are included in Appendix 8.8.

This information is imperative because significantly different emissions result from the different aspects of the landing & takeoff cycle. Additional important airport information includes the protocols for the airport. Some of these important protocols are the use of reduced engine taxing, reduced thrust takeoff, reduced reverse thrust, and auxiliary power unit use (Cathay Pacific, personal interview, February 5, 2002). The Hong Kong International Airport has accepted some of these practices but rejected others. Reduced engine taxiing is not practiced at the airport. This is due to the fact that the average turn around time for aircraft at HKIA is only forty minutes. If the engines were turned off, they would not cool properly, which can cause damage to the engines, leading to safety concerns as well as reduced efficiency. The airport does, on the other hand, practice reduced thrust takeoffs (Cathay Pacific, personal interview, February 5, 2002). Due to the extensive length of the runways at the airport and the relaxed climb rate, there is no need to use a 100 percent throttle during a typical takeoff. As a result, most aircraft use between 90 and 98 percent thrust, and in some cases below 90 percent. This reduces the amount of fuel burned per minute but also increases the time spent in the mixing zone. During landings at the airport, again due to the long runways, reverse thrust is used less than at typical airports, and with the increased popularity of carbon brakes, even less reverse thrust is used.

The final aircraft emission factor to take into account at HKIA is the use of APU's. An APU, or auxiliary power unit, is a power source on an aircraft that provides electricity to an aircraft through the use of the aircraft's engines (Cathay Pacific, personal interview, February 5, 2002). Therefore, when an aircraft is using its APU it continues to emit pollutants. The alternative is ground-based power provided by the airport, which allows the aircraft to reduce its engine use and therefore emit less pollutants. Unfortunately, APUs are typically used at the Hong Kong International airport, which leads to the increase of emissions while an aircraft is grounded.

4.2.2 Discussion of General Aircraft Emissions

For aircraft the important issues to consider are the makes and models of the aircraft that fly into and out of the airport (CAD, Personal interview, January 30, 2002). This is an important factor because the pollutants that different aircraft emit can vary widely. The differences between makes and models of aircraft that cause these differences in emissions are the weight, size, engine type, number of engines, and number of movements. These factors are fairly interrelated. The larger the aircraft, the more it weighs, and with the increased weight, there is an increase in the engine power needed to lift off, maintain altitude, and land. This increase in engine power requires more engines with more power, thereby increasing the emissions of the aircraft in all aspects of its operation. Furthermore, the type of the engine is an imperative factor to consider (Zurich Airport Authority, 1998). Besides the size and power of the engine, the manufacturer and technology used within the engine are also important. Even within the same make and model of aircraft, the engine qualities can differ, making the emissions of the same type of aircraft differ. As can be seen in Figure 4.1, the newer the engine is the less NO_X and VOCs are produced. Therefore, aircraft that have not upgraded their engines for some time, or older aircraft, will have far larger emissions than the newer and more efficient aircraft.

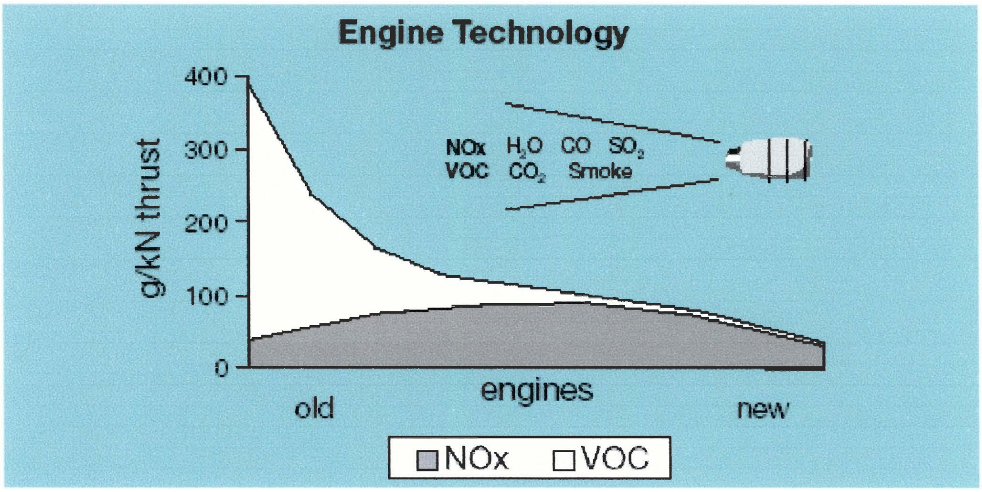


Figure 4.1. Emissions Rates for Changing Engine Technologies (Zurich Airport Authority, 1998).

4.2.3 Aircraft Emissions at HKIA

Using the EPA's guidelines for obtaining an inventory from a specific airport, the standard total emissions figures were calculated. The results of the calculation are presented in Figure 4.2. As shown in the figure, the calculated US EPA standard emissions totals are all somewhat lower than those of the 1999 EPD data. This is due to several factors at HKIA for which the standard United States EPA methodology does not account. The most significant of these factors are as follows: first, that the default mixing height used by the United States EPA is lower than the mixing height in Hong Kong, which causes time-in-modes to be shorter than the actual Hong Kong numbers; second, that the US EPA uses a significantly lower taxi time than the EPD estimate of HKIA's taxi time.

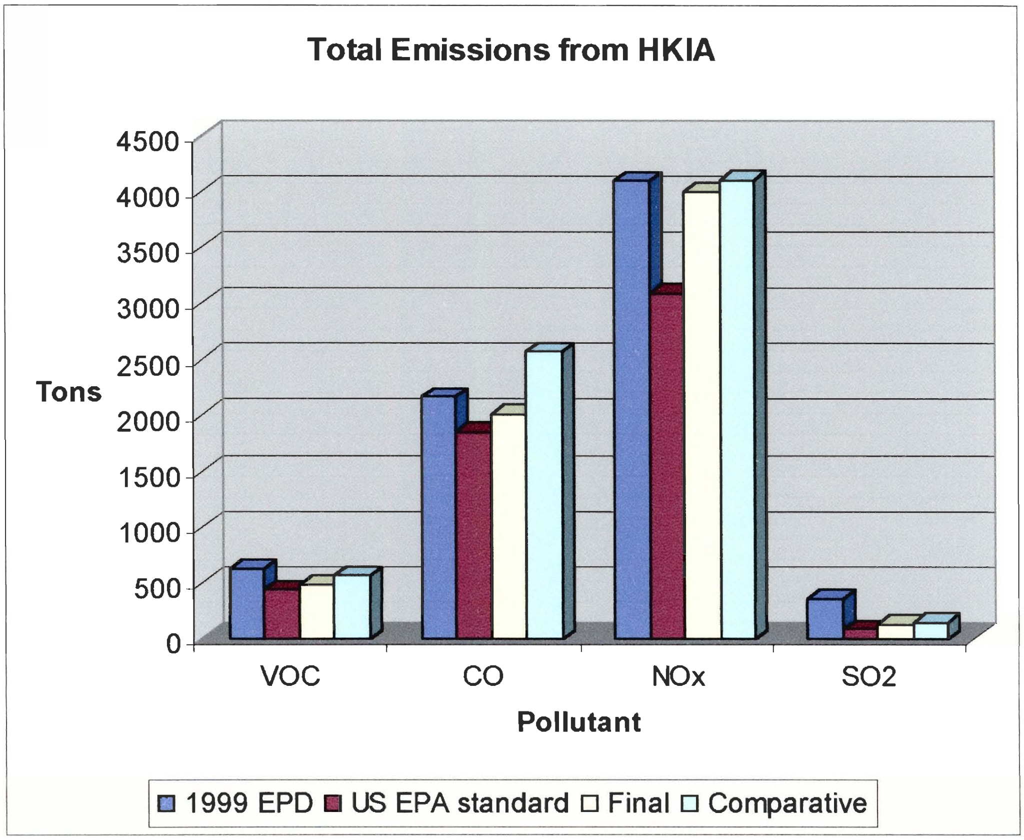


Figure 4.2. Calculated 1999 and 2001 Aircraft Emission Totals (tonnes).

After recalculating the data in order to account for the specific conditions at HKIA, and following the guidelines presented by the US EPD, the final Emissions totals were calculated. These totals still fall short of the 1999 EPD numbers however. This goes against prevailing logic due to the fact that air traffic increased from 1999 to 2001. The difference in the totals is a result of the fact that the EPD used an estimate of 26 minutes of average taxi/idle time. This figure is significantly higher than the US EPA standard of 19 minutes, and more than double the estimates supplied by the Hong Kong Civil Aviation Department (approx. 13 minutes). In order to show that the difference in taxi time could account completely for the difference in total emissions, a third total emissions figure was calculated using the EPD taxi time of 26 minutes. This data set was labeled "Comparative." As can be seen in figure 4.3, the comparative data show there is a slight increase in pollution from 1999 to 2001. This increase is less than the expected 5% that would correlate with the increase in air traffic. This can be partially attributed to the fact that SO_2 emissions factors are much lower than the 1999 EPD figures in all three 2001 calculations. This is interesting considering that the emissions rates data were obtained from the EPD, and also suggested far lower levels of SO_2. Because the primary data used were supplied by the US EPA, whose SO_2 emissions rates are much higher than those from the EPD, it would be expected that the 2001 SO_2 figures would be higher than the 1999 EPD figures. This is not the case as can be seen in Figure 4.3.

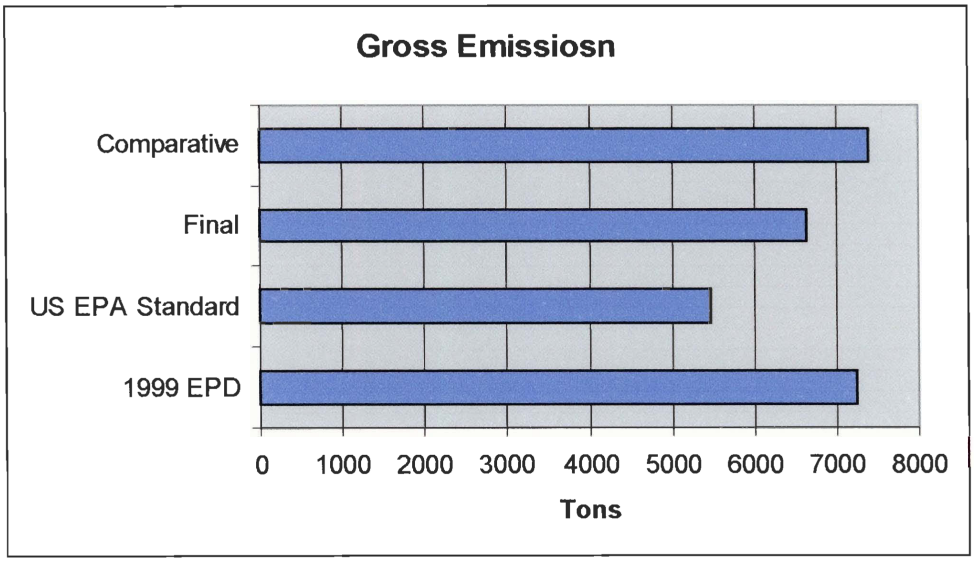


Figure 4.3. Gross Emissions Totals for All Four Data Sets.

4.2.4 Sample Calculations

In order that the reader can understand better the exact mathematical method for the calculation of an air pollution inventory at a given airport, provided below is a sample of these calculations.

After completing the adjusted time-in-mode calculations as described in section 4.2.1, the next step is to find the total emissions from each make and model of aircraft for the entire year in each mode and for each pollutant. For example take Boeing's 747-400 passenger airplane. The HKCAD data show that Boeing 747-400's took off 15,572 times from HKIA and landed 15,565 times. To calculate the total emissions of CO for the year in the Takeoff portion of the LTO, the procedure is to multiply the total number of takeoffs (15,572) by the amount of time spent in that operating mode (.7 minutes) by the amount of emissions of CO per minute emitted by that airplane type (.3727 lb/min). This product is the total pounds of CO emitted during the year by 747-400 passenger planes in the takeoff portion of the flight. The next step is to substitute the emission rate and time in mode figures for the three other modes of the LTO (climb-out, taxi/idle and approach). After the emissions for CO is calculated for all the modes, then it is necessary to do all the previous steps again for the other pollutants (SO_2, NO_x and VOCs). Then it is necessary to repeat all of the previous steps using the data from each make and model of aircraft. After the final totals for each make and model of aircraft are calculated then the total pounds can be obtained by adding the totals of each pollutant in each mode. Dividing these totals by 2,000 gives the amount in tonnes of each pollutant produced by HKIA over the course of one year. A complete listing of calculations is available in Appendix 8.8.

4.2.5 Hong Kong Pollution Inventory

Though the air pollution levels in Hong Kong have been decreasing over the last decade, the levels of air pollution are still high. Table 4.4 shows estimated air pollution levels for Hong Kong from the five most prominent pollution contributors in the Hong Kong area. The aircraft values were calculated using the inventory calculations described in 4.2.4. The other four sources were estimated using data from 1990 to 1999 by averaging the percentage of contribution for each source to the total air pollution levels. Once a general contribution was established for each source, the total air pollution was estimated based on the rate of change over the last ten years. Finally, the emissions from the four sources were calculated as their average percentage of contribution to the estimated figures for the total pollution. These values serve as a basis for comparison, so that the levels of aircraft pollution calculated can be viewed in relation to the total ambient air pollution levels for 2001.

Table 4.4. Estimated 2001 Pollution Statistics in Tonnes for Hong Kong.

	SO_2	NO_X	VOC	CO
Fuel Combustion *	8,268	6,192	307	5,357
Power Generation *	37,779	45,775	266	3,055
Aircraft	116	4,044	553	2,343
Marine Vessel *	672	7,216	987	2,318
Motor Vehicle *	1,895	26,753	15,027	79,405
TOTAL	48,732	89,980	17,141	92,477

* Estimated from the 1990 – 1999 pollution data

As can be seen in Figure 4.4, 4.5, and 4.6, comparing the NO_X, VOC, and CO emissions from aircraft to the ambient air pollution levels shows that NO_X, VOC, and CO from aircraft contributed 4%, 3%, and 3% respectively, to the total NO_X, VOC, and CO levels in Hong Kong for 2001. Although this may seem like a fairly minute percentage of the total air pollution, there are some factors that make this contribution more significant. Primarily, it must be considered, as shown in Table 4.4, that the four percent contribution of NO_X equates to 4,044 tonnes of pollutant released into the environment. Similarly, VOC and CO levels account for an additional 2,895 tonnes of pollutants released into the environment. Furthermore, the nature of the pollution sources listed in Table 4.4 are very different. Looking at Figures 4.4, 4.5, and 4.6, it can be seen that the major contributors to the air pollution levels are power generation and vehicles. The locations of these sources are in different places. Hong Kong uses several power plants that are separated geographically. This causes the pollution to be released at several separate points across Hong Kong. Likewise, vehicle use is separated even further, making the emissions from vehicles extremely dissipated across the Hong Kong area. Air traffic, on the other hand, follows a very different pattern. All air traffic in Hong Kong is centralized around the Hong Kong International Airport. This results in the aircraft pollution being far more densely situated than the other major air pollution sources, thereby potentially magnifying the effects of this pollution.

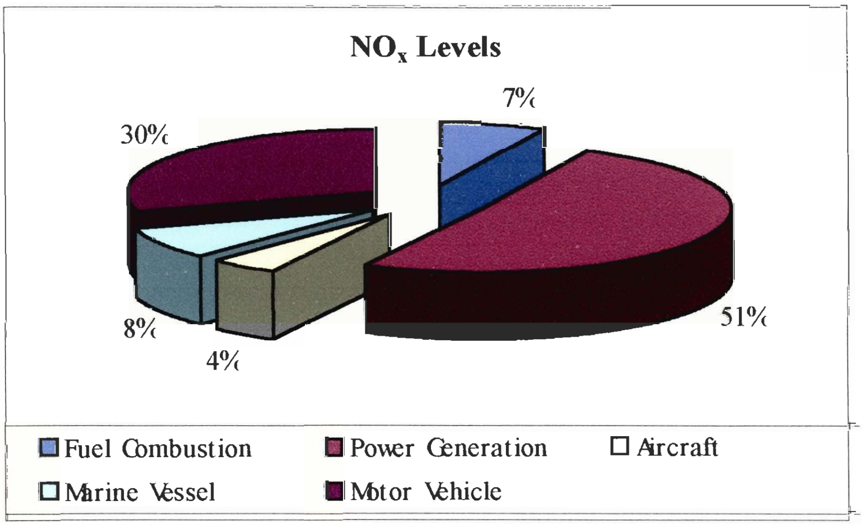


Figure 4.4. NO_X Levels for 2001.

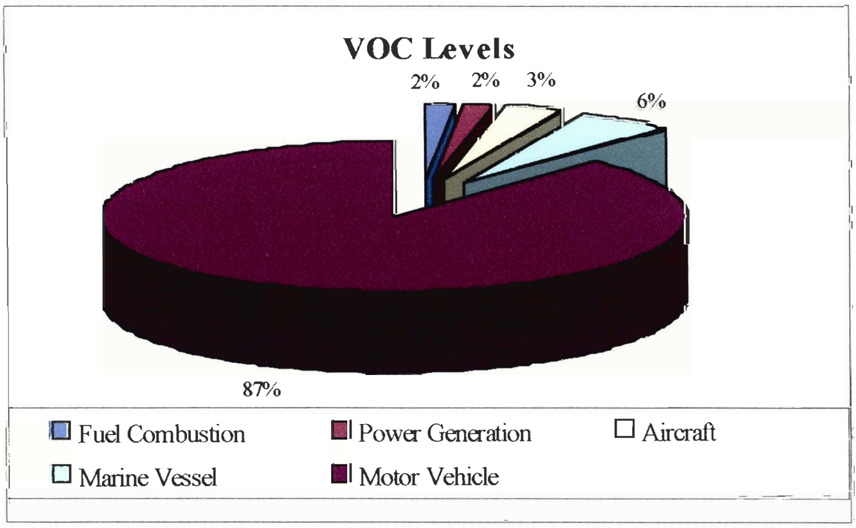


Figure 4.5. VOC Levels for 2001.

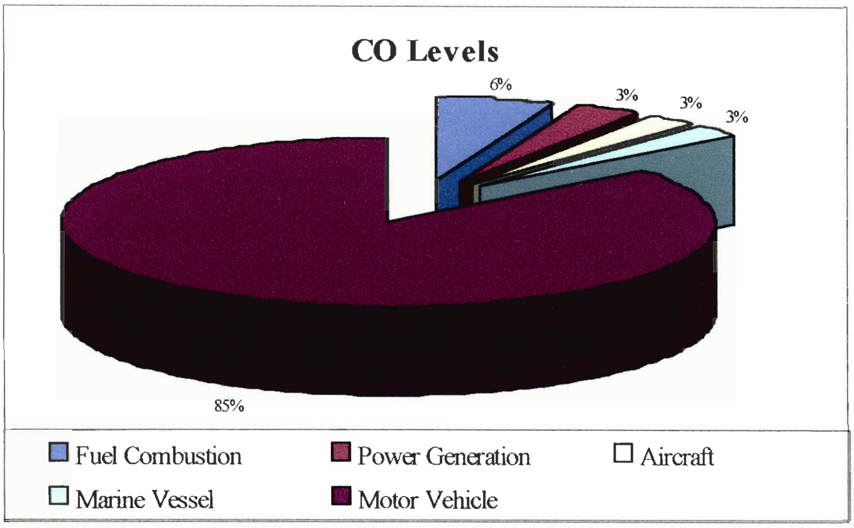


Figure 4.6. CO Levels for 2001.

Additionally, Figure 4.7 shows that the fraction of aircraft's contribution to the SO_2 levels is extremely small, being only .2%. Furthermore, it can be seen in Figure 4.8 that the SO_2 emissions from aircraft appear to be decreasing. Therefore, the effects of SO_2 emissions from aircraft will not be significant in Hong Kong.

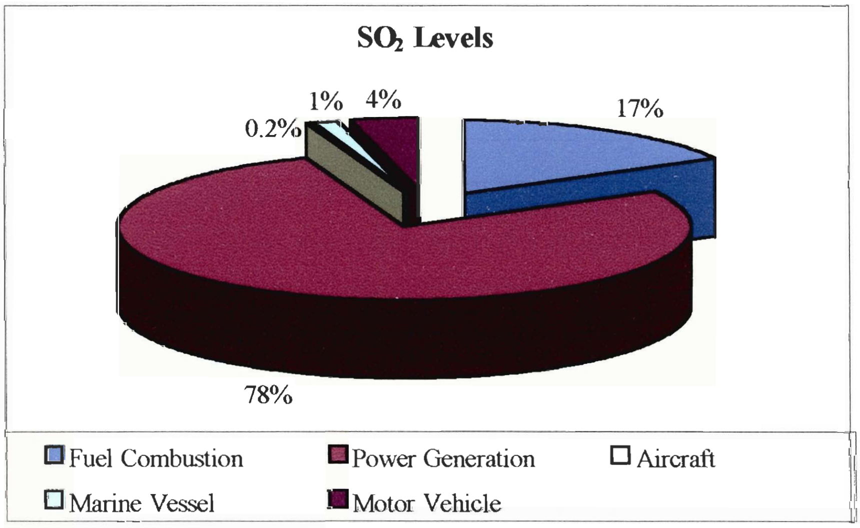


Figure 4.7. SO_2 Levels for 2001.

Considering the future trends for air traffic pollution, it can be seen in Figure 4.8 that since 1997, air traffic pollution has been decreasing. This is most likely due to the introduction of the new airport at Chek Lap Kok, which is far more efficient than the old airport at Kai Tak. Looking at the 2001 figures for NO_X and VOCs it seems that this decrease is slowing down and may possibly halt within the next few years, especially considering the projected 29 percent air traffic increase forecast for the next ten years. Looking at the levels of CO, it can be seen that the levels of CO are already increasing and will likely continue to increase over the next several years. The levels of SO_2 have decreased significantly for 2001. This is due to the recent introduction of lower taxes on higher quality fuels. Therefore, the levels of SO_2 will most likely not significantly increase over the next decade.

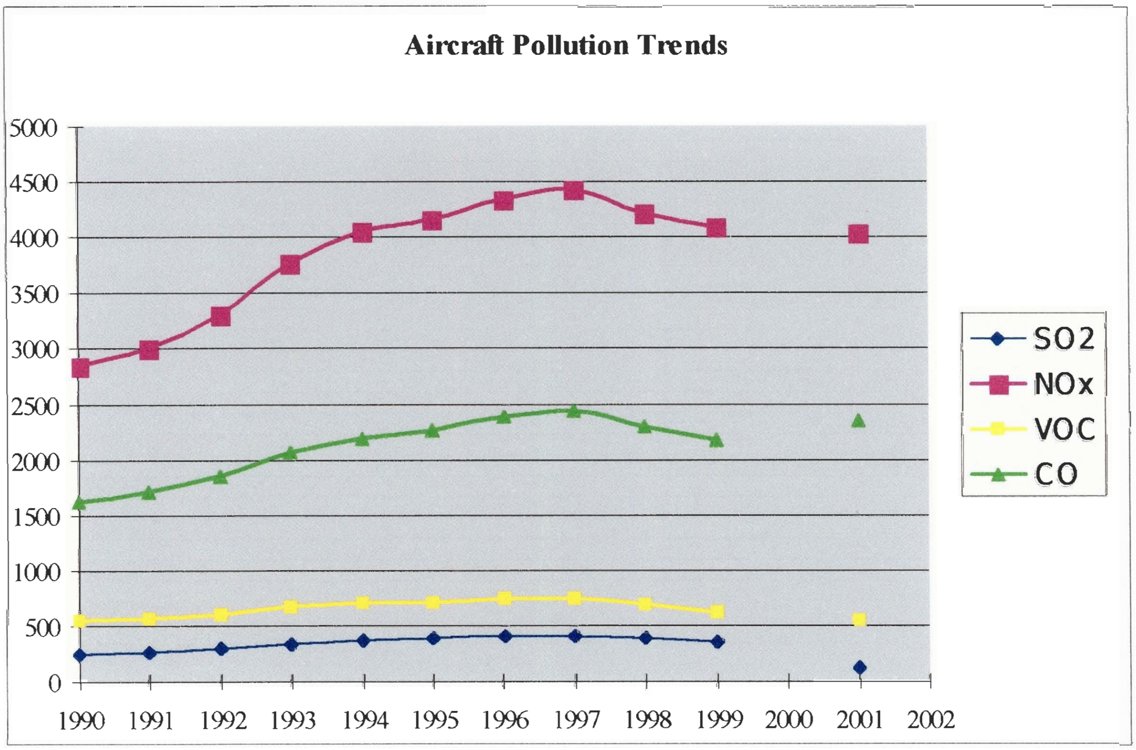


Figure 4.8. Aircraft Emission Trends from 1990 to 2001.

4.2.3 Dispersion Data

Once data on the aircraft and airport operations have been taken into consideration, the actual pollution levels can be determined. In order to understand the effects and consequences of this pollution, the dispersion of the pollutants must be analyzed (Dr. Alexis

Lau, personal interview, January 15, 2002). This provides an idea of where the pollution will become situated once it has been generated. In order to understand dispersion, both local and regional wind patterns must be analyzed. The local wind patterns are mostly the coastal winds that affect the area directly surrounding the airport, while the regional wind patterns are the prevailing wind tendencies for the greater Hong Kong area.

The local wind patterns surrounding the Hong Kong International Airport are fairly radical (Hong Kong Observatory, personal interview, January 28, 2002). They are comprised of the sea breezes that come off of the ocean surrounding the airport. The wind blows in off the ocean in every direction except from the east, the side of Chek Lap Kok that is closest to Lantau Island and therefore does not have a significant sea breeze influence. As a result, a predominant easterly wind is created. This causes the pollution that would be produced over the airport to be blown over Lantau Island. Once the pollution has moved away from the influence of the local sea breezes, it is dispersed by the prevailing wind patterns in the Hong Kong area. The regional prevailing winds of Hong Kong have a tendency to blow in a westerly direction (Dr. Alexis Lau, personal interview, January 15, 2002). This wind pattern is nearly constant for all seasons, changing only during severe or unusual weather situations such as large weather fronts. This westerly wind would have the tendency to trap pollutants from the airport over Lantau Island forcing it south during the winter and north during the summer. During the summer these northerly winds would move the pollution up to the western New Territories area, as can be seen in Figure 4.9.

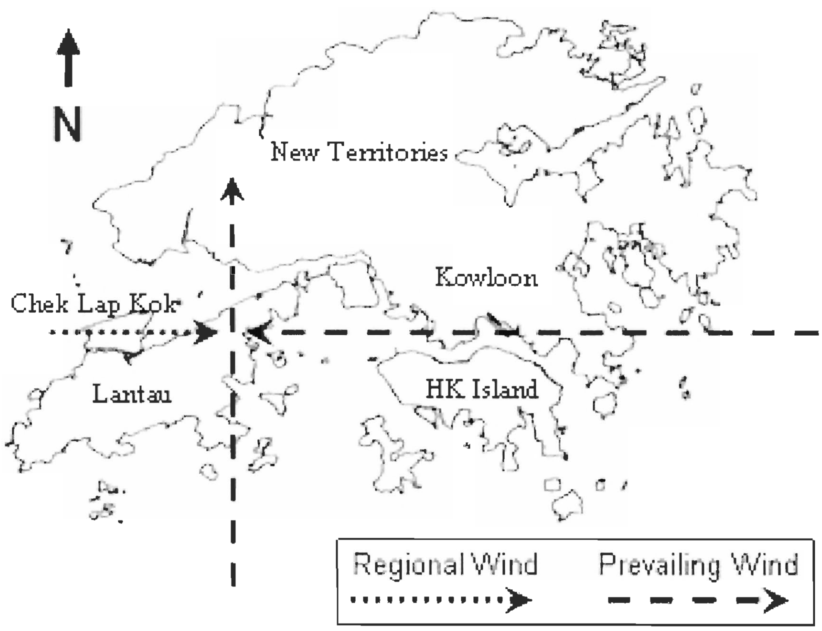


Figure 4.9. Summer Wind patterns for the Chek Lap Kok Area (Dr. Alexis Lau, personal interview, January 15, 2002).

Since the summer winds are generally cleaner because they are bringing in clean air from over the ocean, the Lantau Island and Chek Lap Kok area would have reduced levels of pollution.

During the winter the wind typically comes from the north, but these winter winds change direction slightly between the day and night. During the night the wind flows over the land in reasonably straight paths from north to south. These night patterns would move the pollution down across Lantau Island and off onto the ocean, as can be seen in Figure 4.10.

During the day, however, the warming of the air due to the sun creates circulating breezes around the Hong Kong area. This circular motion of the air would enhance the easterly wind off of the airport and keep the airport pollution locked within the Hong Kong area causing it to spread over Hong Kong Island and the Kowloon area, as can be seen in Figure 4.11.

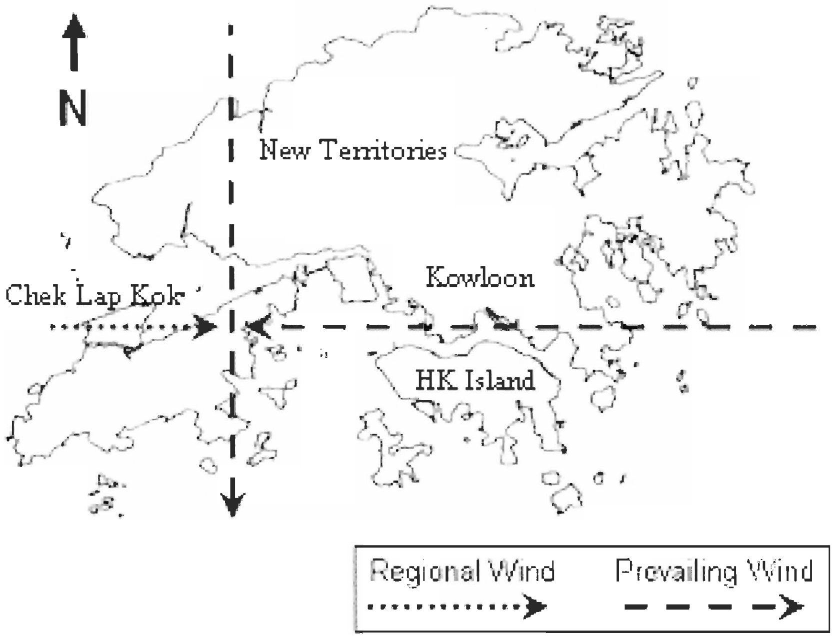


Figure 4.10. Winter Night Wind patterns for the Chek Lap Kok Area (Dr. Alexis Lau, personal interview, January 15, 2002).

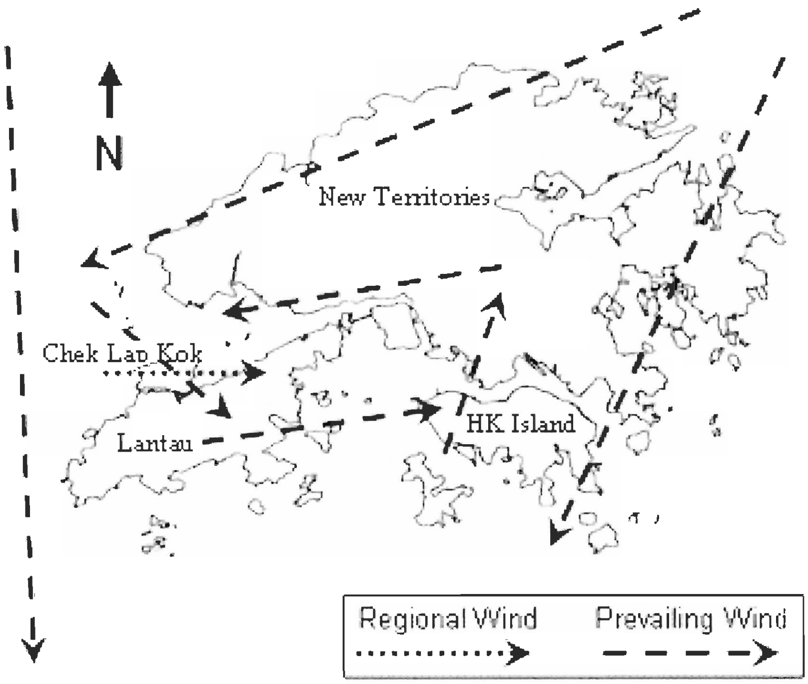


Figure 4.11. Day Wind patterns for the Chek Lap Kok Area (Dr. Alexis Lau, personal interview, January 15, 2002).

4.3 Effects of Air Pollution in Hong Kong

Air normally consists of 21 percent oxygen, 79 percent nitrogen and a number of other trace gasses that include carbon dioxide, argon, and also water vapor (World Health Organization, 1999). At normal levels, these gases help maintain the delicate balance of life, but as they increase beyond these levels and as additional components are added into the air, harmful effects to humans, animals, and plants can result. These additional components are often particulate matter, which has a wide range of harmful effects, and numerous carcinogens that can have disastrous effects. Consequently, the amounts of all of these pollutants must be monitored to ensure an accurate account of their impacts on the ecological balance in the area they affect. However, monitoring each pollutant individually will not necessarily give a precise representation of what is happening, as some will act in a collaborative manner, with various combinations of other pollutants, to create effects that are far more significant than their individual impacts.

As the concentration and duration of exposure to a pollutant increase, there is also an increase in the chances for health consequences. Both the concentration and duration can be difficult to judge for a given pollutant because determining the source of a pollutant can be complicated due to the multitude of different emissions sources in most urban areas. Furthermore, different people have different sensitivities to the effects associated with each pollutant, and therefore they will react to toxins in different ways and degrees. Despite these obstacles, it is possible to determine the risk to the general population using an average of all the general characteristics associated with the effects of a pollutant. Clinical studies can be done in order to estimate health effects associated with a number of pollutants, many of which are associated with aircraft.

4.3.1 Air Pollutants Associated with Aircraft

Several air pollutants are associated with emissions from airports. These include ozone (O_3), which is not directly emitted but is formed from the combination of NO_X and VOCs, carbon monoxide (CO), nitrogen oxides (NO_X), volatile organic compounds (VOCs), and particulate matter. Each of these components has varying effects on both health and the environment. Furthermore, as the amounts and durations of exposure change, so do the resultant effects of each toxin. Therefore, in order to understand the nature of each pollutant fully, the amount, exposure, and type must be understood. A summary of the general effects for the pollutants associated with aircraft is listed in Table 4.5.

Table 4.5. Aircraft Pollution Related Health Effects (EPA, 1999).

Pollutant	Representative Health Effects
Ozone	Lung function impairment, increased susceptibility to respiratory infection, pulmonary inflammation, and lung structure damage
Carbon Monoxide	Cardiovascular effects, especially in those persons with heart conditions (e.g. decreased time to onset of exercise-induced angina)
Nitrogen Oxides	Lung irritation and lower resistance to respiratory infections
Particulate Matter	Premature mortality, aggravation of respiratory and cardiovascular disease, changes in lung function and increased respiratory symptoms
Volatile Organic Compounds	Eye and respiratory tract irritation, headaches, dizziness, visual disorders, memory impairment

4.3.1.1 Ozone (O_3)

Health effects due to the exposure to ozone can be seen on a very short-term (1 to 2 hours) basis when individuals are under heavy exertion (EPA, 1999). Also, ozone effects can be seen on a more prolonged basis (6 to 8 hours) when individuals are engaged in moderate exertion. These long-term and short-term health effects can be seen on an acute level through the development of transient pulmonary function responses, transient respiratory symptoms, effects on exercise performance, increased airway responsiveness, increased susceptibility to respiratory infection, increased hospital admissions and emergency room visits, and transient pulmonary inflammation. These health effects have been observed following exposures to concentrations of ozone as low as 0.08 ppm (Kleinman, 2000). Those who are most affected by ozone are active children, outdoor workers, and individuals with preexisting respiratory disease. In addition to these highly susceptible groups, some individuals are unusually sensitive to ozone and can experience far more severe symptoms. Chronic health effects of ozone occur when there are repeated, long-term exposures to ozone. The result of chronic exposure to ozone often can be seen in inflammation of and physical damage to lung tissue and a decline in lung function.

4.3.1.2 Carbon Monoxide (CO)

Carbon monoxide (CO) is an odorless, colorless gas that is a product of the incomplete burning of fuels. CO reduces oxygen carrying capacity of blood and weakens the contractions of the heart (Kleinman, 2000). It does this by bonding to hemoglobin, the oxygen-carrying molecule within red blood cells, thus making it impossible for oxygen to be carried by that cell and therefore reducing the amount of oxygenated blood pumped to various parts of the body. For a healthy person, this effect can significantly reduce the ability of persons to perform physical exercise and can cause dizziness (EPA, 1999). Adverse effects have been observed in periods of exposure as short as one to two hours. The effects of carbon monoxide vary widely depending on the health of the person exposed. Those that are more athletic tend to show fewer symptoms, while individuals who are more prone to the effects of carbon monoxide are those with chronic heart disease. For patients with weakened hearts the effects can make it difficult for daily activities to be performed because the body is unable to function on the reduced levels of oxygen, even to perform the simplest tasks

(Kleinman, 2000). Carbon monoxide pollution is also likely to cause such individuals to experience debilitating symptoms during even short periods of exercise.

4.3.1.3 Nitrogen Dioxide (NO_2)

Nitrogen containing compounds called NO_X (NO_2 and NO), form a brown gas that largely contributes to the visible smog effect evident in major metropolitan areas (EPA, 1999). Healthy individuals experience respiratory problems when exposed to high levels of NO_2 for even short periods of time (less than three hours). Asthmatics are especially sensitive, and fairly low levels of NO_X can cause breathing problems during high levels of exertion. Furthermore, there have been connections made between NO_2 exposures and increased respiratory illness rates in young children. More importantly, NO_2 can impair respiratory defense mechanisms. This decrease in the immune system associated with the respiratory system can greatly increase susceptibility to infection. Therefore, the effects of NO_X are often seen in the development of seemingly unrelated diseases. Also, chronic exposure to relatively low levels of NO_2 can cause structural changes in the lungs. These changes can reduce lung capacity and make breathing difficult. These adverse effects can be easily seen in extremely high levels of exposure, but specific levels and the exposure duration that cause such effects have not yet been specifically determined, suggesting that effects of NO_X are highly individual.

4.3.1.4 Particulate Matter (PM)

Particulate matter is the general term for a class of diverse substances that exist as tiny particles that remain suspended in the air, either as liquid droplets or solids that exist in a wide range of sizes (Kleinman, 2000). Particulate matter originates from a variety of stationary and mobile man-made sources as well as several natural sources. These particles can be emitted directly from a source or formed in the atmosphere by the chemical transformation of gasses such as NO_X, VOCs, and sulfur oxides. The chemical and physical properties of particulate matter vary greatly with region, meteorology, and source, therefore complicating the exact health consequences, but there are general effects that are common to all regions. PM_{10} refers to particles with a diameter of less than or equal to 10 micrometers. PM_{10} particles or smaller, called fine particles, can be dangerous because with their small size they are able to penetrate more deeply into the lungs. The most dangerous of this category is $PM_{2.5}$ which is comprised of particulate matter with a diameter less than or equal to 2.5 μm. The effects that are associated with ambient fine particles include premature mortality, increased respiratory and cardiovascular disease, changes in lung function, increased respiratory symptoms, changes in lung tissue and structure, and altered respiratory defense mechanisms (EPA, 1999). Furthermore, coarse particles, those that are larger than PM_{10}, are associated with an increase in asthma symptoms and other cases of respiratory illness. Also, there can be chronic health effects associated with long-term exposure to high concentrations of coarse particles. Individuals who are more sensitive to particulate matter are those with respiratory or cardiovascular disease, the elderly, children, and asthmatics.

4.3.1.5 Volatile Organic Compounds (VOCs)

Organic chemicals emitted into the atmosphere, or VOCs, can also have health consequences. This type of pollution can arise from evaporation but is more commonly produced through the incomplete combustion of fuel (Kleinman, 2000). VOCs can be difficult to describe because they are composed of a wide variety of different substances. As a class, VOCs react with NO_X in the atmosphere to form ozone, but individual VOCs may have several additional health effects. Some VOCs have little or no known health consequences, but others have disastrous health effects, the most notable of which are the carcinogens (EPA, 1999). The extent of these effects is determined by the level of exposure and length of time exposed. Some of the problems related to short-term exposure to VOCs can be eye and respiratory tract irritation, headaches, dizziness, visual disorders, and memory impairment. Long-term exposure to VOCs can cause a far wider range of effects including a multitude of diseases, the most notable of which is cancer.

4.3.2 Air Pollution Health Statistics for Hong Kong

There are different environments in which one experiences air pollution, with each of them having varying amounts of contaminants. Typically, these environments are divided into indoor and outdoor microenvironments, with the outdoor microenvironments often containing a much higher amount of pollutants (WHO, 1999). While both short-term and long-term effects have been identified for both of these microenvironments, the short-term effects can generally be correlated with specific pollutants, whereas the long-term effects can only be correlated with the existence of pollution. Therefore, it is far more difficult to understand the nature and effects of pollution on a long-term basis. Furthermore, studying pollution on a long-term basis requires records that reach back several decades in order to obtain an accurate image of pollution consequences within a larger time frame. Since Hong Kong has only confronted its pollution issues within the last decade, there are not enough data to support long-term analysis of pollution effects.

In fact, Hong Kong has only measured the health effects of various pollutants over the past 6 years and has thus far only released full data from 1995 to 1998 through reports published by the Hong Kong Environmental Protection Department (EPD) (1999). The pollution data in these reports were gathered from the various air pollution monitoring stations around Hong Kong. Most pollutant levels were gathered at several separate locations, but the data for fine particulates were only gathered at one station, and therefore, they are not totally representative of all of Hong Kong. In their latest study released in 1999, the EPD measured the daily hospital counts of people who were treated with the following health problems:

- Respiratory Disease
- Chronic Obstructive Pulmonary Disease (COPD)
- Asthma
- Cardiac Disease
- Ischaemic Heart Disease (IHD)

The EPD also recorded hospital deaths due to respiratory and cardiovascular diseases. The various types of admissions were sub-categorized as follows:

- Respiratory Disease: 0-14, 15-64, 65-74 and 75+ age groups
- Asthma: 0-14 and 15-64 age groups
- Cardiac Disease: 15-64, 65-74 and 75+ age groups
- IHD: 15-64, 65-74 and 75+ age groups

These categories for all ages and specific age groups formed 19 categories of health outcomes for our analysis.

The hospital data include data from publicly funded hospitals staffed with an emergency department, accounting for 90 percent of the hospital beds in the Hong Kong area. Also, one additional hospital from the most polluted area of the S.A.R. was included in the study. These data were tabulated as shown in Table 4.6. In this table the data for 1995 to 1997 are combined, with the next column that contains the six-month average for these figures. The last column contains the most recent numbers that represent the first six months of 1998. This column can be compared to the 1995 to 1997 six-month averages to determine trends in pollution related diseases. As presented in the table, a majority of diseases increased. Respiratory disease increased nearly 27% for all age categories, with significant increases for all age groups. Chronic obstructive pulmonary disease increased 10% in the same time period, suggesting an upward trend in incidents of both these diseases. There were further slight increases in the cases of cardiac disease and ischaemic heart disease, while there was a surprising 5% decrease in asthma between the 1995 to 1997 six month average and the first six months of 1998. Also comparing the same time frames for pollution related deaths, an increase can be seen in respiratory deaths, while there was a slight decrease in the number of deaths due to cardiovascular related ailments.

Table 4.6. Number of Patients Admitted Between 1-1-1995 and 6-30-1998 by Discharge Diagnoses and Age Groups (HK EPD, 1999).

		Number of cases		
Discharge diagnosis	Age groups	1995-1997	1995-1997 Six month average	1998 (Jan-June)
Respiratory disease	All ages*	223,225	37,204	46,877
	0-14 yrs	74,164	12,361	16,450
	15-64 yrs	48,909	8,152	9,451
	65-74 yrs	38,783	6,464	7,640
	75+	61,318	10,220	13,329
Chronic obstructive pulmonary disease	All ages*	53,374	8,896	9,795
Asthma	All ages*	27,080	4,513	4,286
	0-14 yrs	14,005	2,334	2,133
	15-64 yrs	8,520	1,420	1,332
Cardiac disease	All ages*	108,150	18,025	18,835
	15-64 yrs	37,195	6,199	5,961
	65-74 yrs	32,205	5,368	5,715
	75+	37,356	6,226	6,976
Ischaemic heart disease	All ages*	39,483	6,581	6,940
	15-64 yrs	14,259	2,377	2,402
	65-74 yrs	13,969	2,328	2,507
	75+	11,201	1,867	2,029
Deaths: Respiratory	All ages*	11,798	1,966	2,095
Cardiovascular	All ages*	11,202	1,867	1,779

* Including patients without information on age.

Tables 4.7 shows the summary of the statistics from all the hospitals separated so that pre-1998 data are in the second column, while the data for the first half of 1998 are in the third column. These data help support the fact that there is an increasing trend in pollution related diseases. These figures follow the same trend as the cases of each disease but presented the data as hospital admissions, which show a far greater economic consequence. Increases in hospital daily admissions can be seen for respiratory diseases, cardio obstructive pulmonary disease, cardiac disease, and ischaemic heart disease, while there was a corresponding decrease in the cases of asthma between the 1995 to 1997 period and the first half of 1998. Similarly, the increase in respiratory deaths and the decrease in cardiac deaths can be seen once again.

Table 4.7. Summary Statistics of Daily Hospital Admissions (and deaths) by Disease Groups (1995-97 and 1998 Jan-June) (HK EPD, 1999).

Cause of Admission	1995-1997	1998 Jan-June
Respiratory	203.7	259.0
Asthma	24.7	23.7
COPD	48.7	54.1
Cardiac	98.7	104.1
IHD	35.0	38.3
Death:		
•Cardiovascular	10.2	9.8
•Respiratory	10.8	11.6

IHD - Ischaemic heart disease

With such significant increases in the levels of air pollution related diseases, it is important to understand the correlation between the cases of the disease and the levels of air pollution. Table 4.8 shows correlative data that link air pollution with health effects. This is calculated by looking at the number of hospital admissions for a given day compared to the levels of pollutant for that day. These values are then evaluated through comparison with the effects of temperature and humidity in a given area, which provide a comparative control for the resultant values. Due to the complex nature of pollution, it is difficult to correlate pollution levels to health effects. Consequently, a correlation coefficient of .4 is considered a strong relationship, and although it is considerably lower than a typical strong correlation, it still shows an association. In fact, making such a link between pollution levels and the health of a population is such a complex link that a correlation coefficient greater than .20 is considered suggestive of some sort of relationship. As can be seen in Table 4.8 NO_2 was shown to have a fairly strong correlation with all the different health problems, while SO_2 was shown to have weak or no correlation with the various health problems. Respirable Suspended Particulates (RSP), otherwise known as PM-10, had a strong correlation with asthma, and a weak correlation with Cardiac Disease. Ozone also had a strong correlation with asthma but was seen to have little correlation with any of the other illnesses. The data for Fine Suspended Particulates (FSP) were not shown to have significant correlation with any one disease, but because this was only monitored at one station, and also because some of the data proved to be missing, the connections with health problems will need to be further studied. Increased temperatures were shown to have negative correlation with COPD and asthma, while humidity was also shown to have negative correlation with asthma. For a complete list of how the data were divided by age and effect, please see Appendix 8.9.

Table 4.8. Spearman's Rank Correlation Coefficient Between Daily Concentrations of Pollutants, Meteorological measures and Hospital Admissions (1995-97) (HK EPD, 1999).

Illness →	Respiratory	COPD*	Asthma	Cardiac	IHD
Pollutants ↓	Correlation Coefficient	Correlation Coefficient	Correlation Coefficient	Correlation Coefficient	Correlation Coefficient
SO_2 (24-hr)	0.10	0.14	-0.04	0.15	0.07
NO_2 (24-hr)	0.11	0.24	0.27	0.23	0.15
RSP (24-hr)	-0.01	0.13	0.27	0.16	0.11
O_3 (8-hr)	-0.07	-0.08	0.26	-0.02	0.01
FSP (24-hr)	-0.06	0.10	0.17	0.08	0.02
Temperature	-0.01	-0.35	-0.21	-0.14	-0.04

Humidity	0.10	0.04	-0.30	-0.07	-0.06

* Excluding Asthma

In the daily number of hospital admissions for all ages, there was a 4-8% increase in respiratory disease admissions for every 50-ug/m^3 increase in pollutant, a 5-15% increase due to chronic obstructive pulmonary disease, and an 11-22% increase due to asthma. There was also a 3-7% increase in admissions due to cardiac disease. There was a 3-5% increase due to cardiovascular disease, which includes cardiac disease as well as cerebrovascular disease and diseases of arteries, arterioles, capillaries, veins and lymphatics. In the daily number of hospital deaths for all ages, there was a 10% increase due to respiratory disease and 8% increase due to cardiovascular disease for every 50-ug/m^3 increase in NO_2. For other pollutants the increases were not significant.

4.3.3 Economic Effects

There are different ways of measuring the economic effects of air pollution. However, many of these effects have not been studied. The Hong Kong Environmental Protection Department (EPD) conducted a study on the effects due to air pollution and its impact on health, using several different ways to calculate the damage done in a dollar amount (Yee, 1998). One way is to use the Cost of Illness method (COI) which factors in both direct and indirect costs, as shown below:

Direct Costs:
- Buying medicine over the counter
- Defensive expenditure – special diet, equipment
- Doctor Consultation
- Hospital Stay expenditures

Indirect Costs
- Off Work day
  - Assuming accompanying costs for those under 14 and those over 65 (with the average of $10,000 HKD per month wages)

The other method for calculating costs is the Willingness to Pay method (WTP), which takes into account the average amount that people are willing to pay in order to avoid a day in the hospital along with how much they are willing to pay in order to avoid the symptoms during the actual sickness. Table 4.9 shows the results from the COI and WTP methods, grouped by the pollutant potentially involved in the illness. The combination of respiratory and circulatory diseases is not the addition of the two separate categories, but rather a separate category in which patients have both infections.

Table 4.9. Results of Economic Valuation Using COI and WTP Approaches (Yee, 1998).

Relative Risk 50 ug/m^3	COI/WTP /D.C.*	Respiratory Diseases (HK$ million)	Cardiovascular Diseases (HK$ million)	Combination of Respiratory and circulatory Diseases (HK$ million)
NO_2	COI	522.20	451.90	852.34
	D.C.	269.21	239.57	445.18
	WTP	626.97	1,044.42	1,462.46
SO_2	COI	195.82	282.44	487.05
	D.C.	100.95	149.73	254.39
	WTP	235.11	652.76	835.69
RSP	COI	326.37	169.46	487.05
	D.C.	168.26	89.84	254.39
	WTP	391.85	391.66	835.69
O_3	COI	652.75	395.41	852.34
	D.C.	336.51	209.62	445.18
	WTP	783.71	913.87	1,462.46

*Note: * D.C. = Direct Cost*

When calculating the costs for mortality, a slightly different method was used in each case. For the COI approach, a human capital figure was calculated. It is age specific and attempts to estimate the value of the individual's life contribution to society by calculating wages earned for the rest of his or her life, and discounting it by a set standard amount. The EPD study assumed the individual was in good health and that he or she would retire at the set age of 65. Their earnings took into account taxes and were also adjusted for inflation.

For the WTP method, a change in risk that would affect loss of life was calculated. The WTP method is used to measure the private valuation individuals place on small reductions in the risk (probability) of death (i.e., m/Δp where, m is the WTP for the benefit of living and Δp is the change in risk). The result obtained indicates the value per statistical life. Table 4.10 shows the economic value placed on each of these diseases grouped into the various pollutant types that may have a causal relationship with the disease.

Table 4.10. Results of Economic Valuation Using COI and WTP Approaches (Yee, 1998).

Relative Risk 50ug/m^3	Method of Calculation	Respiratory Diseases (HK$ million)	Cardiovascular Diseases (HK$ million)	Combined of Respiratory and circulatory Diseases (HK$ million)
NO_2	COI	1301.93	1,397.56	2,793.02
	WTP	1805.84	1,868.12	3,789.61
SO_2	COI	743.96	-	-
	WTP	1031.91	-	-
RSP	COI	464.98	698.78	931.01
	WTP	644.94	934.06	1,263.20
O_3	COI	2,045.89	2,096.34	1,629.26
	WTP	2,837.75	2,802.19	2,210.60

Note:
There is probably an inconsistent relationship between cardiovascular diseases/ combined respiratory and cardiovascular diseases and the pollutant SO_2. *Under such circumstances, it would not be appropriate to estimate the economic cost.*

Therefore, because of air pollution related health problems, there is an associated health cost totaling between 14 and 17 billion Hong Kong Dollars. As you can see, NO_2 and O_3 account for most of the cost, accounting for approximately 12 billion Hong Kong dollars.

4.3.4 Ecological Effects

There are currently several studies being conducted around the world (mostly in the United States) concerning the ozone, NO_X, and SO_2 levels of pollution on plants. However, not many conclusive data have come out of these projects as of yet (Forest Monitoring, 1998). Environmental effects can be determined in a general sense by studying the ecology surrounding an emissions source. In this manner, some of the effects of toxins on plants have been determined, and Table 4.11 shows some of the representative effects that pollutants can have on different aspects of the environment.

Table 4.11. Representative Environmental Effects of Air Pollutants (EPA, 1999).

Pollutant	Representative Environmental Effects
Ozone	Crop damage, damage to trees and decreased resistance to disease for both crops and other plants.
Carbon Monoxide	Similar health effects on animals as on humans.
Nitrogen Oxides	Acid rain, visibility degradation, particle formation, contribution towards ozone formation.
Particulate Matter	Visibility degradation and monument and building soiling, safety effects for aircraft from reduced visibility.
Volatile Organic Compounds	Contribution towards ozone formation, odors and some direct effect on buildings and plants.

4.3.4.1 Ozone

Ozone enters a plant's leaves during normal gas exchange and causes several different symptoms, including chlorosis and necrosis (Munster, 1998). Other symptoms such as flecks (tiny light-tan spots), stipples (small dark colored areas), bronzing, and reddening often occur between the veins of older and middle-aged leaves but may also appear in other places. Studies conducted at North Carolina State University (Munster, 1998) have repeatedly verified that flecking, stippling, bronzing, and reddening on plant leaves are classic plant responses to ozone. Plants grown in a special chamber with filtered ambient air with a

Figure 4.12. Ozone's Effects on a Potato Plant (Munster, 1998).

Ground-level ozone causes these symptoms by interfering with the ability of plants to produce and store food. This results in the degradation of the growth, reproduction and health of the plant. By weakening trees and other plants, ozone can make plants more susceptible to disease, insect attacks, harsh weather, and can lead to the eventual death of the plant (EPA, 1999). These symptoms are first seen in the leaves of the plant. Ground-level ozone can also kill or severely damage the leaves to a degree that they fall off the plants too soon or become spotted or brown. These effects can significantly decrease the natural beauty of an area, such as in national parks and recreation areas.

There have also been studies conducted to measure the seasonal exposure to ozone on various crops trying to determine the effects of ozone on crop yield (Munster, 1998). Agricultural yields for many economically important crops can be reduced, and the quality of some crops may be damaged, thereby reducing their market value. The National Crop Loss Assessment Network (NCLAN) conducted the most extensive research in this area from 1980 to 1987 at five different locations. Focusing on the most important crops nationally, they were able to determine that dicot species (soybean, cotton, and peanut) are more sensitive to yield loss caused by O_3 than monocot species (sorghum, field corn, and winter wheat). Figure 4.13 shows how an increase of ozone affects each crop individually.

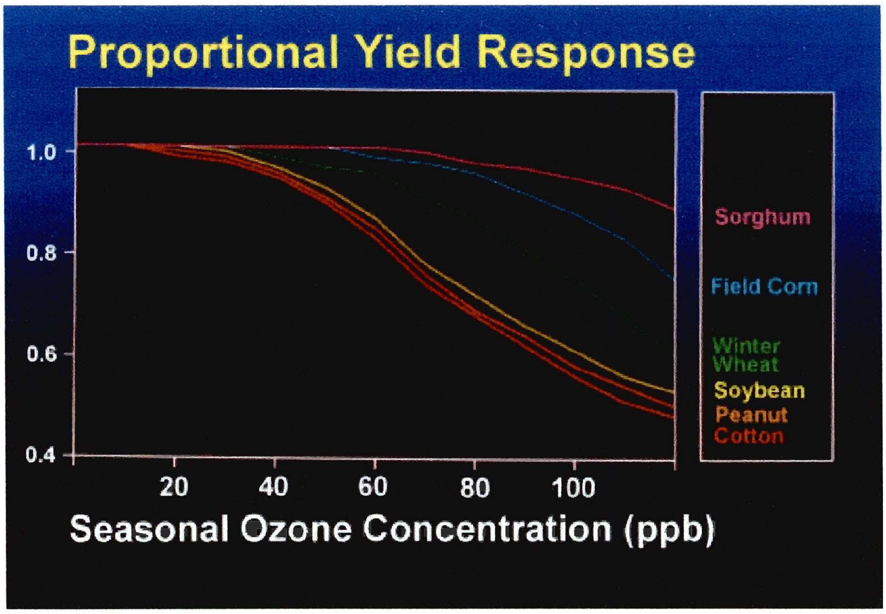


Figure 4.13. The Effects of Ozone on Various Crops (Munster, 1998).

4.3.4.2 Nitrogen Dioxide (NO_X)

NO_X is an important precursor to both ozone, the effects of which are described above, and acidic precipitation, which harms ecosystems on both the terrestrial and aquatic level. Acid rain causes surface water to become more acidic (Gow & Pidwirny, 1997). This occurs as a result of the rainwater reacting with NO_X in the atmosphere to produce HNO_3 and HNO_2. The formation of HNO_3, nitric acid, decreases the pH of the rainwater, thereby making it more acidic. A summary of these reactions can be seen in Figure 4.14. Similarly, SO_2 can also react with precipitation to create acid rain, but due to the low levels of SO_2 in aircraft emissions, this is not a significant factor in the ecological consequences of aircraft pollution.

$$NO + 1/2O_2 \rightarrow NO_2$$
$$2NO_2 + H_2O \rightarrow HNO_2 + HNO_3$$

Figure 4.14. Acid Rain Chemical Properties (Gow & Pidwirny, 1997).

The acidic rainwater damages trees at high elevations and nearly all other facets of ecology. As the rainwater runs into the ground water, plants are affected through the acidification of the soil. The nature of these effects are that increasing acidity results in the leaching of several important plant nutrients, including calcium, potassium, and magnesium, and the reductions in the availability of these nutrients causes a decline in plant growth rates. Furthermore, aluminum can become more mobile in acidified soils, which can result in damage to roots and the interference with plant uptake of other nutrients such as magnesium and potassium. Reductions in soil pH inhibit the germination of seeds and the growth of young seedlings. Also, microorganisms often cannot survive in soils with a pH below 6.0. The death of these organisms can inhibit decomposition and nutrient cycling, making the soil a poor medium for growth and causing the buildup of dead biomass. Within an aquatic ecosystem, the buildup in acidity due to acid rain can cause acid shock in smaller fish, aquatic microorganisms, amphibians, and can disrupt or even halt the spawning of nearly all fish. In addition to the ecological effects of acid rain, acid rain accelerates the decay of building materials and paints, including irreplaceable buildings, statues, and sculptures that are part of our cultural heritage (WRI, 1999). Further contributions of NO_X are seen in the addition of NO_X to the formation of particulate matter in the atmosphere, that have several health and environmental effects.

4.3.4.3 Particulate Matter (PM)

The environmental effects of particles fall into the two general categories of visibility and soiling (EPA, 1999). The visibility impacts are immediately apparent through haze.

Visibility impairment can result from either the direct emission of particles or the formation of particles from NO_X and VOCs. This reduced visibility can affect the beauty of an area, as well as have mild effects on ecology. Long periods of reduced visibility can decrease the level of direct sunlight received by plants. This phenomenon can have the effect of changing the types of plants that can grow in a given area based on the level of direct sunlight required by the flora. The soiling effect of particles is observable on buildings, vehicles, monuments, and, in extreme cases, trees. There is an additional safety problem for aircraft operating in areas of reduced visibility in the terms of landing, takeoff, and avoidance of other aircraft.

4.3.4.4 Volatile Organic Compounds (VOCs)

VOCs can cause a variety of environmental effects depending on the chemical nature and quantity of the compounds present (EPA, 1999). At high levels, VOCs can have a damaging effect on plants, crops, and buildings. These effects, however, are often minimal as the levels of VOCs required for damage are extreme. Thus, the principal environmental effect of VOCs is their contribution to the formation of ozone, which can have extreme environmental and health effects. Likewise, VOCs can contribute to the formation of particles, which have further environmental and health effects as discussed in Section 4.3.1.4.

4.4 Methods of Reducing Pollution in Hong Kong

4.4.1 Reducing Aircraft Emissions in Hong Kong

Reducing the levels of aircraft pollution can be difficult to accomplish. This is because pollution is often of low consequence when it comes to the aircraft industry. Instead, factors such as safety and economics take priority over the pollution created by aircraft. Therefore, many recommendations that could potentially reduce aircraft pollution become inconsequential because the result of these recommendations interferes with the safety or economics associated with flights. For example, changing flight paths such that they did not cross over the land masses of Hong Kong would help to move the pollution away from the Hong Kong area, but because flight paths have already been optimized with safety in mind, it would be impossible to make such changes. Furthermore, recommendations such as the use of single engine taxiing would also be impossible because this technique, although it reduces the emissions from an aircraft, damages the engine, which would jeopardize both safety and the economics associated with the flight. Other, simpler recommendations would also be futile such as suggesting that the levels of air traffic be reduced. This would have a damaging effect on the economics of the growing Hong Kong International Airport, as well as potentially damaging the economy of Hong Kong as a whole. Taking into consideration these limitations on air traffic, there are few options remaining which could effectively reduce the levels of pollution emitted, while still taking into consideration the importance of maintaining safety and economy.

Furthermore, in the Hong Kong area, the Hong Kong International Airport is the only international airport with a significant number of flights of large aircraft. Although many of the surrounding airports are either extremely small or regional, meaning that they only cater to limited amounts of smaller aircraft, the importance of these airports has the potential to increase with escalating air traffic demands. Therefore, an understanding of these airports should be established early on as well as communications such that when these airports do increase in importance, the groundwork will have been laid out to reduce their emissions, and understand the consequences. Instituting this type of partnership would be an important first step in fostering communication within the Pearl River Delta area in order to decrease pollution from the myriad of common sources by sharing emissions data and air pollution reduction techniques and technology.

4.4.1.1 Taxing Aircraft Fuel

Aircraft fuel currently has a worldwide tax-free existence, allowing for the use of cheap fuels (Zurich Airport Authority, 1998). By placing taxes on airline fuels, it will encourage the more effective use of the fuel and will essentially reduce the emissions coming from the aircraft. However, to decrease the emissions levels further, a higher tax should be placed on low quality fuel, thus encouraging the use of the highest quality fuels. By replacing domestic ticket taxes with an aviation fuel tax, it would have no financial impact on consumers but would provide airlines with an incentive to replace aging and inefficient aircraft with newer, cleaner, quieter and more fuel-efficient planes (NRDC, 1996). Another approach to taxing would be to associate the tax with airplanes coming into the airport, assessing a fee based on the size, type, and emissions history of the aircraft type. By increasing the landing price for aircraft that are older, less efficient, and greater pollution sources, there would be an incentive for airlines flying into Hong Kong International Airport to keep their aircraft technology current. Since newer planes are generally more efficient and produce less pollution, their use would decrease the levels of emission from the airport.

4.4.1.2 Viewing Airports as Polluters

Subjecting airports to the same reporting requirements as other major polluters, including public notification, would also help reduce overall airport air pollution emissions (NRDC, 1996). Currently, the airport is not responsible for calculating its effects on the environment and reporting the levels of pollution it produces. This is contrary to nearly all other major polluting industries, which have to report publicly the levels of pollution that they produce. This practice would provide a better understanding of the significance of aircraft pollution as well as making environmental scientists and the general public more aware of the airport as a major source of pollution. This is particularly important in Hong

Kong because of the location of the new airport. The old airport at Kai Tak was very apparent to the general population of Hong Kong, being located centrally in a heavily populated area. The new airport at Chek Lap Kok, is located far from the center of Hong Kong in an area that is far less populated. Although this is beneficial in that any pollution from the airport is farther away from any densely populated regions, it allows the airport to fade from people's consciousness, as it is not having as direct of an effect on their lives. Requiring the airport to publish its emission's levels would help to bring the airport back into the limelight as a fairly significant source of pollution. Furthermore, this practice would help to inform the general public of the potential consequences of the airport, as well as providing a good source of data for future emissions inventories. Once these data are made more widely available, the global understanding of aircraft pollution ramifications could increase. Currently, airports are not considered hazardous pollution sources. Most people do not even make an air pollution connection when considering air traffic. As a result, the understanding of aircraft emissions on an international level is lacking, when compared to other major air pollution sources. Encouraging or even enforcing the publication of pollution levels would provide a step forward in this understanding and hopefully lead to reduced aircraft emissions on a wide scale.

4.4.1.3 Use of Auxiliary Power Units

An APU, or auxiliary power unit, is a power source on an aircraft that provides electricity to an aircraft through the use of the aircraft's engines. Therefore, when an aircraft is using its APU, it continues to emit pollutants. The alternative is ground-based power provided by airports, which allows the aircraft to reduce its engine use and therefore emit a lesser amount of pollutants. Unfortunately, APUs are typically used at the Hong Kong International airport, primarily because of the low turnaround times and secondly because although the airport is equipped to provide ground based power to the aircraft, this power is often not of sufficient quality to be used by the sensitive computers used on today's aircraft. Fluctuations in power can cause computer failures that sometimes delay flights significantly. Thus, carriers rarely use the airport's ground power unless they will be grounded for an extended period of time. If the ground power stability in the Hong Kong International Airport were improved, and if the connection process to the ground power were made more efficient, then the use of this ground power would increase. This increase in the use of ground power would decrease the use of engines while aircraft were on the ground and would therefore decrease the emissions of aircraft in the airport.

4.4.2 Reducing Hong Kong's general Air Pollution Problem

4.4.2.1 Information and Resource Sharing

Often, one of the major problems encountered during the information gathering stage of a research project is the lack of information and resource sharing among the various organizations. In the Hong Kong area this seems to be a fairly significant problem. This creates difficulties in that while conducting pollution studies there is the lack of data with which to compare results. As a result, the studies that are completed in the area can contradict in findings. This makes it difficult to ascertain the specifics concerning a pollution related problem. This issue is even more important in the Hong Kong area because, for the most part, pollution studies have only been conducted within the last decade. Therefore, unless researchers have carried out a study for several years, they are not able to see trends in their data, and even if they have studied it for an extended period of time, researchers have difficulty knowing if their methodology is appropriate. Furthermore, beyond the collaboration of pure knowledge, there are problems with resource sharing as well. Different organizations with newer and more advanced equipment are often wary to allow others to utilize these resources.

Considering this problem on a larger scope causes this predicament to become even worse. Within the Hong Kong area, it is possible to obtain most data, if one has the time and energy to expend, but on the international level, obtaining data can be simply impossible. These international data limitations make large scale pollution studies nearly impractical, and because pollution gives no regard to international borders, this can make reducing or even understanding an area's pollution problems unviable. One of the most significant cases of this problem is the refusal to share pollution inventories. Organizations in both China and Hong Kong have pollution inventories that detail the types and quantities of pollutants released by major pollution sources. These data, if shared, would provide a far better understanding of the current pollution trends and levels. Unfortunately, since these data are not shared, many statistics have to be estimated on both sides, causing the understanding of pollution to be far less concrete then it could potentially be.

The predominate reason behind these data and resource sharing problems, both on the local and international level, is the strong politics that have become associated with pollution. Political conflicts often occur due to the public awareness of pollution. In Hong Kong pollution is a problem that is taken very seriously by nearly all residents. As a result, being identified as an entity responsible for furthering the pollution problem can have devastating effects. Therefore, many businesses and organizations are hesitant to release air pollution related data. They fear that this information could potentially implicate them as a significant pollution source or could be misconstrued or taken out of context. This lack of data sharing exists also on a larger scale. On the international level, many countries are wary to release pollution or pollution source information for similar reasons. The solution would be to get beyond these issues and to further communications between groups working on similar problems. If organizations were to share their results and data, they would be able to refine their methodologies and provide better results and predictions to the government and public.

4.4.2.2 Calculate emissions data for other pollution sources

The new 2001 data for the aircraft emissions are not very helpful without the information concerning the other sources of air pollution. The EPD has calculated emissions from major pollution sources for 1990 to 1999, but the 2000 and 2001 figures are as of yet not out. Recently, vehicle emissions have been reduced by an unknown amount due to government subsidizing taxicabs' change from diesel to LPG. Furthermore, taxes on low sulfur diesel have been significantly reduced, causing this fuel source to be an economically comparable alternative to lower grade fuels. The data concerning how much of a reduction in air pollution these changes have caused have not been released, however, and could not be used in this report. Due to the complex nature of pollution, it is difficult to estimate pollution levels without a large amount of very recent data. Without these data, we were only able to approximate just how large of a contribution aircraft air pollution is currently having on the overall air pollution problem.

4.5 Closing Points

The Hong Kong Airport Authority expected the contribution of aircraft to air pollution to rise by 4% from 2000 to 2001. Our results confirm this expectation. VOC and NO_X emissions have remained fairly constant, while CO emissions have risen by nearly 10%. SO_2 emissions appear to have dropped almost 200%, but this appears to be due to differences between the EPD and United States EPA inventory calculation methods. EPD emissions estimates in lb/min were in some cases significantly less than their United States EPA counterparts. Despite these limitations in the data, there does seem to be an overall increasing trend in the air pollution resultant from aircraft. This increase would suggest that over the next decade the pollution from aircraft will increase in significance, particularly considering the estimated 29 percent increase in air traffic expected over the next ten years.

Furthermore, the importance of aircraft as a pollution source will increase as other sources of pollution decrease. Currently, one of the largest sources of pollution in Hong Kong is motor vehicles. Over the last few years, though, the significance of this source has been decreasing. With the introduction of low sulfur diesels and liquid petroleum gas taxis, vehicles are emitting fewer pollutants. Also, there has been a recent trend for industry to move out of the Hong Kong area and into China. This shift in industry could further reduce the pollution levels in Hong Kong provided that they move outside of the Pearl River Delta area.

Because of the nature of the atmosphere and air pollutants, it is impossible to correlate directly specific aircraft emissions, or changes in those emissions, with their effects. This is for several reasons. First of all, the amount of emissions coming from aircraft is relatively small, when viewed from the complete air pollution picture. Secondly, the amount of mixing that occurs within the atmosphere is sufficient to make exact tracking of the pollutants of a specific contributor nearly impossible. It is however, reasonable to conclude that increases in air pollution emitted by aircraft will have a consequential effect on people and the environment. Furthermore, the nature of aircraft pollution is different from other sources of pollution. Many of the significant sources of air pollution in Hong Kong are mobile sources of pollution, such as vehicles, or a combination of several fixed sources, such as power plants. Aircraft pollution on the other hand, is a single fixed source of pollution. All of the pollution that comes from aircraft emanates from the Hong Kong International Airport area. This concentration of the pollution to one locality causes the levels of aircraft pollution initially to be far less dispersed. Since the effects of pollution are highly dependent on the concentration of levels of the pollutant, this characteristic of aircraft pollution would have a tendency to make the effects of the pollution more significant on a localized basis.

The effects of air pollution span a wide range from health to economic effects, as highlighted in this report. The specific effects of pollution generated by aircraft cannot as of yet be statistically linked to the effects of air pollution in Hong Kong. In order to make this connection, more specific data are required. Currently, the technology is available to create in depth pollution dispersion models. The development of these models for aircraft pollution would allow for a more concise understanding of where the pollution is being situated once it has been generated. Looking at the wind and meteorological patterns for the Hong Kong area provides a general understanding of this dispersion, but in order to establish a strong connection between the pollution and the effects meteorological pattern data would need to be calculated. Furthermore, the method for calculating the effects would have to be improved. Currently, health and environmental data are either lacking or poorly organized. Therefore, in order to further the understanding of the effects, better data would be required.

Even if a concrete understanding of aircraft pollution levels and their relation ship to health effects could be established, this information would not necessarily lead to the solution to the air pollution problem. Hong Kong's pollution levels and atmospheric conditions are such that reducing the output of a single emitter within the Hong Kong region will not have a significant effect on the people of the region. Furthermore, because Hong Kong and the Guangdong region share the same air shed, they also share the same pollution. Therefore, the only foreseeable means by which Hong Kong will be able to see a positive change in its air pollution problem is through large-scale projects that involve multiple emitters not only within Hong Kong, but in Guangdong as well.

Chapter 5
Conclusions and Recommendations

5.1 Conclusions

HKIA and Aircraft Conclusions

- HKIA air traffic is expected to increase by approximately 29 percent over the next 10 years.
- The LTO cycles for the HKIA are slightly lower than the international standard.
- The use of reduced thrust take-off, limited reverse thrust, and ground power supplies helps reduce airplane emissions, while reduced engine taxiing has not been implemented for safety and cost reasons.
- Differences in emissions depend on the weight, size, engine types, number of engines, and number of movements of aircraft.

Air Pollution Conclusions

- Aircraft pollution is not currently a major contributor to Hong Kong's air pollution, but with increased pressure on reducing vehicle emissions and factory emissions, as has been the case in recent years, it will soon become more important.
- SO_2 emissions have decreased significantly over the last few years, while NO_X, CO and VOCs have stayed approximately the same.
- The local wind patterns around Hong Kong cause the air pollution to become trapped over the islands during the day and allow them to blow away during the night.

- Because of the predominant southerly winds during the summer, a large portion of the pollution from the Pearl River Delta is blown into the Hong Kong region, accounting for much of the haze and other pollution problems during that time period.

Effects Conclusions

- While a direct association has not been made, data have been presented that suggest a correlation between health effects and air pollution increases.
- High levels of pollutants, ozone in particular, cause adverse effects on plants.
- The economic costs of adverse health effects attributed to air pollution are between 14 and 17 billion Hong Kong Dollars per year.
- Acid rain is formed from NO_X and SO_2 emissions and in addition to adverse health effects, it can have devastating effects on structures, flora, and fauna.

General Conclusions

- Large-scale projects not only within Hong Kong, but in Guangdong as well, are required to have a large impact on the pollution problem.

5.2 Recommendations

- Information on other airports in the Guangdong area should be gathered before their size increases and the pollution generated from them is too large to conduct an accurate estimation.
- Communications among airports and also among people who are modeling the pollution conditions around Hong Kong and China should be encouraged in order to increase accuracy in their model predictions.

- Taxes on aircraft fuel should be considered in order to decrease fuel use. Higher taxes should be placed on high sulfur fuel to discourage its use.
- A landing fee on airplanes coming into the airport based upon size, type, and emissions history of the aircraft should be initiated.
- The HKIA should be subjected to the same reporting requirements as other polluters, including public notification of its effects.
- Inefficient or malfunctioning ground power units in the airport's apron should be repaired or replaced with those that provide a steady power supply and have efficient connection methods.
- The emissions data for other air pollution sources should be calculated in order to gain a more complete picture of the air pollution problem in Hong Kong.

Chapter 6

References

Addison, Keith (2000, June. 2). "Biodiesel in Hong Kong." [Online]. Available: http://journeytoforever.org/biodiesel_hk.html [2001, Nov. 20].

Burton, B. (1991). Air Pollution Control Methods. *Kirk-Othmer Encyclopedia of Chemical Technology* [Online]. Available: Kirk-Othmer Encyclopedia of Chemical Technology. [2001, November 3].

Crystal, David (Ed.) (2000). Cambridge Fact Finder (4th Ed.). New York: Cambridge University Press.

Earth Justice (2001, May). "Effects of Air Pollution on Health, Agriculture, and Forests." [Online]. Available: http://www.earthjustice.org/backgrounder/display.html?ID=46 [2001, November 24].

Environmental Protection Agency (1998) Children's Environmental Health Yearbook. US Government Printing Agency, DC.

Environmental Protection Agency (1999). Evaluation of Air Pollutant Emissions from Subsonic Commercial Jet Aircraft. FAA Report Number - EPA420-R-99-013.

Environmental Protection Agency (2001, June 26). Effects of Acid Rain: Visibility Reduction. [Online]. Available: http://www.epa.gov/airmarkets/acidrain/effects/visibility.html [2001, November 11].

Environmental Protection Agency (2001, June 26). Effects of Acid Rain: Human Health. [Online]. http://www.epa.gov/airmarkets/acidrain/effects/health.html [2001, November 11].

Federal Aviation Administration (2000). National Airspace System Architecture Version 4.0. [Online]. Available: http://63.73.31.242/nasiHTML/nas-architecture/v4p.htm [2001 December 6].

Forest Monitoring (1998). "Effects of Air Pollution/Climate on Forest Ecosystems – International Studies." [Online]. Available: http://www.rfl.psw.fs.fed.us/atdep/cw_2.html [2002, January 20].

Gow, Tracy and Pidwirny, Michael (1997). "Acid Rain and Precipitation." [Online]. Available: http://royal.okanagan.bc.ca/mpidwirn/atmosphereandclimate /acidprecip.html [2002, February 7].

Hong Kong Citizens Party (1997, Nov. 18). "Citizens Party and Doctors Speak Out on

Air Pollution." [Online].
Available: http://www.citizensparty.org/environment/speakout.html [2001, November 25].

Hong Kong Citizens Party (1998, May). "Your Right to Safe Food and a Clean Environment." [Online].
Available: http://www.citizensparty.org/environment/right.html [2001, November 25].

Hong Kong Civic Exhange (2001, November). "The Hong Kong Civic Exchange Website." [Online]. Available: http://www.civic-exchange.org/main.htm [2001, November 24].

Hong Kong Civil Aviation Department (1998, October). Situation Report on Aircraft Noise (ACE Paper 43/98) [Online].
Available: http://www.pelb.gov.hk/copy%20of%20committees/ace/paper44.htm [2001, December 6].

Hong Kong Environmental Protection Department (1999). "Short-term Effects of Ambient Air Pollution." [Online]. Available: http://info.gov.hk/epd/air/ [2002, February 7].

Hong Kong Environmental Protection Department (2000, Dec). "Hong Kong Pollutants Emission Inventory." [Online].
Available http://www.info.gov.hk/epd/ [2001, November 25].

Hong Kong Environmental Services Department Air Services Group (2000). Air Quality in Hong Kong 2000 (Publication No. EPD/TR1/01). Hong Kong: The Government of Hong Kong Special Administrative Region Printing Department.

Hong Kong Observatory (2001, March). "Monthly Mean Wind Measurements." [Online]. Available: http://www.hko.gov.hk/aviat/amt_e/clk_month_e.htm [2001, November 24].

Japanese National Institute for Environmental Studies (2001). Health Impact. [Online]. Available: http://www.nies.go.jp/gaiyo/panf/18kenkoeikyo-e.html [2001, November 29].

Kleinman, Michael T. (2000). "The Health Effects of Air Pollution on Children." Air Quality Management District. [Online]. Available: http://www.aqmd.gov/forstudents/Kleinman_article.htm [2001, November 20].

Loh, Christine (1998, October 14). "Improving Air Quality." [Online].
Available: http://www.citizensparty.org/environment/air_qual.html [2001, November 24].

Loh, Christine (1999, May 2). "RTHK Letter to Hong Kong." [Online].
Available: http://www.citizensparty.org/environment/letter_hk.html [2001, November 25].

McConnell, Rob et.al. (1999). Air Pollution and Bronchitic Symptoms in Southern California Children with Asthma. Environmental Health Perspectives. v.107 (9). pp. 757-760.

McGeveran, William (Ed.) (2001). The World Almanac and Book of Facts 2001 USA: World Almanac Education Group.

Munster, M.J. (1998). "Effects of Ozone Air Pollution on Plants." [Online] Available: http://www.ces.ncsu.edu/depts/pp/notes/Ozone/ozone.html [2002, January 20].

National Resource Defense Council (1996). "Airports Overlooked as Major Polluters." [Online]. Available: http://www.nrdc.org/air/transportation/nairport.asp [2002, February 1].

Provisional Airport Authority. Hong Kong International Airport Master Plan 2020. [Online]. 29 October 2001.
Available: http://www.hkairport.com/eng/corporate/MP2020.pdf [3 November 2001].

Swedish Civil Aviation Administration (2000). Environmental Data. [Online]. Available: http://www.lfv.se/site/lfv/environment/eng/environmentdata.asp [3 December 2001].

United States Environmental Protection Agency (1996). Clean Air Act Stationary Source Civil Penalty Policy. Office of Enforcement and Compliance Assurance: Washington, DC.

University of Colorado (2001). Lecture 2. [Online]. Available: http://irina.colorado.edu/lectures/Lec2.html [2001, December 5].

World Bank Group, The (2000). Indoor Air Pollution [Online]. Available: http://wbln0018.worldbank.org/sar/sa.nsf/2991b676f98842f0852567d7005d2cba/95ee1c18873abcef852569d0004f83c2 [2001, November 11].

World Health Organization (1999). "Air Quality Guidelines." [Online]. Available: http://www.who.int/environmental_information/Air/Guidelines/Chapter2.htm [2002, January 20].

World Resources Institute (1999). Rising Energy Use:
Health Effects of Air Pollution. [Online]. Available: http://www.wri.org/wri/wr-98-99/airpoll.htm#outdoor [2001, November 11].

World Wide Fund For Nature Hong Kong (2001). Air Pollution and Associated Health Problem in Hong Kong. [Online]. Available: http://www.wwf.org.hk/eng/pdf/references/factsheets/factsheet24.PDF [22 November 2001].

Yee, Dr. Lai Wan (1998). "Study of Economic Aspects of Ambient Air Pollution on Health Effects." [Online]. Available: http://info.gov.hk/epd/air/ [2002, February 7].

Zumdahl, Steven S. (1998). Chemical Principles. Boston: Houghton Mifflin Company. pp. 820-1.

Zurich Airport Authority (1998). "Aircraft Engine Emission Charges at Zurich Airport." [Online]. Available: http://www.zurich-airport.ch [2002, February 8].

Chapter 7

Bibliography

Caplen, J.G.F. (2000). Southampton international airport: an environmental approach. Eco-Management and Auditing, 7(1), 43-49.

Environmental Protection Agency (1997). United States EPA Office of Compliance Sector Notebook Project: Air Transportation Industry, US Government Printing Agency, Wash, DC.

Federal Aviation Administration (1998). The Impact of National Airspace Systems (NAS) Modernization on Aircraft Emissions. FAA Report Number – DOT/FAA/SD-400-98/1

Hong Kong Civil Aviation Department (2001). "Flight Paths." [Online]. Available: http://www.info.gov.hk/cad/english/sitemap.htm [2001 December 6].

Hong Kong Civil Aviation Department (2001). Hong Kong International Airport Civil International Air Transport Movements of Aircraft, Passenger and Freight. [Online]. Available: http://www.info.gov.hk/cad/english/p-through.htm [2001 December 6].

Karapanagiotis, Dimitris and Kalligas Yannis (1998). Atmospheric Pollution in Athens, Greece. IQP Report, Gordon Library, WPI.

Liu, Wilson (1998). "Aircraft Pollution." [Online]. Available: http://www.soton.ac.uk/~engenvir/index/air_pollu.html [2001, December 6].

Meere, Kate (Ed.) (2001). World Airport Guide 2001 London: Columbus Publishing.

National Resource Defense Council (1997). Air Pollution FAQ. [Online]. Available: www.nrdc.org. [13 Nov. 2001].

Nirel, R and Dayan, U. On the ratio of sulfur dioxide to nitrogen oxides as an indicator of air pollution sources. Journal of Applied Meteorology, volume 40, no.7, 2001.

Proctor, Paul. "Air Hubs Major Polluters?" New York: Aviation Week & Space Technology, Volume 153, issue 10, 2000.

United Nations Department of Economic and Social Affairs (1999). Statistical Yearbook (4^{th} Ed.). New York: United Nations Press.

V. V. Anh, K. C. Lam, Y. Leung, Q. M. Tieng (2000). Multifractal analysis of Hong Kong air quality data. Environmetrics, 11(2). 139-149.

Zekai Şen, Ahmet Öztopal (2001). Assessment of regional air pollution variability in Istanbul. Environmetrics, 12(5), 401-420.

Chapter 8

Appendix

8.1 The Civic Exchange

(Hong Kong Civic Exchange, 2001)

8.1.1 Overview

The Hong Kong Civic Exchange has taken on the role of sponsor for this project. This agency represents an independent, non-profit, public policy think tank with the goals of promoting civic education, public awareness and participation in governance by strengthening civic participation in public life. Furthermore this organization frequently undertakes research and development in economics, social, and political policies as wells as practicing to help shape the breadth and depth of public policy debate in order to advance policies that are sustainable, resilient, non-violent, economically efficient, just, participatory, locally appropriate and spiritually rewarding. These features of this group provide for a natural integration of skills and experience across various disciplines including academia, business, politics, finance, technology and the non-profit sectors.

The chief executive officer and one of the principal founders of the Civic Exchange is Ms. Christine Loh. With the help of cofounder Lisa Hopkinson, Christine Loh established Civic Exchange in September 2000. She summarizes her purposes for creating the organization by saying, "thinking gets better when we think often. Thinking is fun because it creates new possibilities in the way we live our lives. Research helps drive thinking. Thinking in groups helps leverage our collective intelligence and can lead to breakthroughs. I want the Civic Exchange to produce pragmatic solutions to public policy problems. I also want to be able to synthesize and publicize other people's good ideas." In addition to Ms. Loh and Ms. Hopkins, a board of directors, consisting of Mr. Stephen Brown and Mr. Winston Chu, also governs the Civic Exchange. Stephen Brown is Research Director at Kim Eng Securities and has had a long banking career with a number of leading multinational financial institutions, while Winston Chu is a consultant to the law firm Winston Chu & Company. Beneath this executive hierarchy there are a number of thinkers, researchers, and facilitators, as well as numerous organizations that help support the Civic Exchange. These members of the Civic Exchange formed a team that has developed an organization that is one of the leading research centers in the Hong Kong area.

8.1.2 Organization Profile

8.1.2.1 Mission

Civic Exchange is an independent, non-profit, public policy think tank established with the mission to:

1. Promote civic education, public awareness and participation in governance by strengthening civic participation in public life;
2. Undertake research and development in economics, social and political policies and practices to help shape the breadth and depth of public policy debate and so to advance policies that are sustainable, resilient, non-violent, economically efficient, just, participatory, locally appropriate and spiritually rewarding; and
3. Integrate skills and experience across various disciplines including academia, business, politics, finance, technology and the non-profit sectors.

8.1.2.2 Work style

Civic Exchange works "virtually". Its thinkers, researchers and facilitators work independently and communicate via the use of modern telecommunication means. They do not have to share the same workspace and work the same office hours. Civic Exchange's office is more like a clubhouse for people to meet to exchange ideas and share experiences. Workspaces are reserved for activities more than for specific individuals. The wireless system enables anyone to go there and plug-in to work.

Location:

Room 601, Hoseinee House
69 Wyndham Street
Central, Hong Kong

Founded:

September 2000

Co-Founders:

Christine Loh (Chief Executive Officer)
Lisa Hopkinson

Board of Directors:

Stephen Brown
Winston Chu

Thinkers and Researchers:

William Barron
Cecilia Chu
Joanna Clark
Richard Cullen
Lynne Curry
Julia Gilkes
Elizabeth Hutton

John Hyslop
C S Kiang
Kelley Loper
Simon Ka-wing Ng
Amanda Olsson
Pooja Pradhan
Suzanne Skinner
Rachel Stern
John Russell Taylor
Kylie Uebergang
Joyce Y Wan
Elizabeth Willmott
Paul S F Yip
Yan-yan Yip
Peggy Yung

Civic Exchange Volunteer Workers:

Ateesh Chanda
Benjamin P Chang
Josephine Ming Mei Chen
Sarah Chee Chow
Angel Cheung
Christine L. Dobridge
Dennis Hung Chi Ho
Michelle Lam
Dennis K W Li
Dick Ma
Bing Zeat Mah
Andrew Chen Maconnell
Mary Elizabeth Morales
So Hoi Ying
Rachel Stern
Edward Stokes
Eunice Tai
Tam Pui Ying
Evan Thorpe
Vincent Wong

Collaboration Partners and Organizations:

The Hong Kong Polytechnic University
Asia Foundation
Bloomberg
Urban Direction Limited
Hong Kong Discovery Magazine
The Nature Conservancy
International Marinelife Alliance
Worcester Polytechnic Institute
Association for Sustainable & Responsible Investment in Asia

8.2 Interview with Tom O'Rourke

Personal Interview with Tom O'Rourke

INTERVIEW WITH TOM O'ROURKE
23 NOV 01
13:00-15:00

Central Massachusetts Department of Environmental Protection
627 Main St.
Worcester, MA 01609

Important People to contact:

John Lane
(978) 975 1138

Mark Dukem
(Contact through John Lane)
Springfield, Laurence Lab
Department of Environmental Protection

Bob Quilanvin (Sp?)
No Information

NOTE: While not all of this information is directly pertinent to our IQP, we should keep much of it in mind when searching for possible contributions to the pollution problem.

Interview Summary Notes:

6 Criteria that all cause immediate threat:

Lead
NO_X
SO_2
CO
VOC (Volatile Organic Compound)
Particulates – usually combinations of NO_X & SO_2 with other particles

Also watch O_3, but not as much… comes as a combination of NO_X and VOC's in the air
And HAP (Hazardous Air Pollutants) such as Benzene has an effect over the course of years, but it is not immediate.

Internal Combustion

High Pressure -> more NO_X

Poor Combustion -> more CO, however, this is often less of a concern
Fuel Efficiency and Weight are very important factors.

It is possible to control NO_X with "dirtier combustion"

There is currently a lot of work on making Jet Engines much cleaner; he suggested that we check www.faa.gov

Particulate & VOC may be the problem if they aren't studying sulfur & NO_X, or if they haven't reached the technological level to produce SO_2 and NO_X.

Sulfur is dependent on where fuels come from, and their cost

Major Problems:

Fuel Types –

SO_2 and NO_X produce Acid Rain, with cleaner fuels containing less of each of these constituents. No. 6 fuel contains the most pollutants… it's almost like sludge. With No. 2 being the cleanest, and also the most viscous. The absolute worst you can burn in MA is No. 6, which contains 2.2% Sulfur, more particulate matter, and more nitrogen than #2 oil. The cost of these values also varies, becoming more expensive the cleaner they are. Ranging from 35¢ for #6 oil to 50¢ for oil with 0.5% SO_2.

Stage 1 fuel recovery: excess vapor from evaporated fuel is pumped back into the transporting container for proper disposal. Usually done with large shipments such as trucks

Stage 2 fuel recovery: same as stage 1, except applied to passenger vehicles.

Effects of Regulations –

Soviet Aircraft are probably dirtier and louder than other aircraft, as regulations regarding them are less strict. If Hong Kong is not regulating the aircraft that is flying into their airport, then it is possible that other countries are flying in aircraft that is polluting their airspace.

Organization –

See the Massachusetts Air Quality Report for information on how to determine where pollution comes from. Also research the wind conditions of HK and determine if monitoring stations are upwind and downwind of the airport. Be sure they are measuring for both short term and long term toxins, such as benzene and metals. Also determine the amount of taxi time, and the amount of time spent in the air waiting for landing. Another possibility is that of outside contaminants from China following weather patterns into HK.

Possible Ideas for Methodology

1. Identify the Sources of Pollution
2. Determine Possible Solutions
3. Check Feasibility and Determine Outcomes

Useful Websites (or partial clues that he gave as websites):

www.state.ma.us/dep/
www.faa.gov
www.epa.gov/ttnguide/ (may not be correct site)
Emission factors are located in a file AP-42
www.epa.gov

Also locate a program called TANKS that will help analyze pollution effects of fuel

Various airplane manufacturers:
Pratt and Whitney
Boeing
Airbus

8.3 Civic Exchange and the IQP

Our expected findings include an estimate of the amount of pollution created by commercial aircraft in Hong Kong and Guangdong, focusing on the Hong Kong International Airport. We will concentrate on the impact of jet emissions, disregarding the contributions from non-aircraft ground transport, such as those included in taxiing and construction projects. We will determine the levels of pollution produced, the effects of that pollution on the local health and environment, and also attempt to devise possible solutions to the pollution problem. However, our solutions will be in the form of recommendations and figures and not a detailed plan to solve the issues we discover.

Our sponsor, the Civic Exchange, will certainly be interested in our findings, where they may possibly be used to help decrease the amount of pollution that is affecting the health of the people and the ecological footprint of Hong Kong. By bringing this data into the eyes of the public and educating them on the effects of air pollution, Civic Exchange can help to improve environmental conditions all throughout the area. They can also share their results with other Civic Exchange locations to help improve those situations. The Hong Kong International Airport and the Government of China may also use these results to assess the quality of air pollution produced at the airport may also use these results. Another potential user of these data reports are the designers of a new airport being built in Guangzhou, who could use the data to help predict the environmental impact of their design, and the effects that it will have approximately 5 years later.

We are currently in correspondence with our sponsors in Hong Kong concerning the nature of what we will be doing there. As of 11/19, we plan to collect data in several ways. First, by collaborating with local agencies that have current data on air pollution. Second, by searching for past data at libraries etc. Lastly, by contacting (and interviewing) individuals who are experts or involved in the field of air pollution and/or aircraft movement. Because of the nature of this project, it is important to gather as much current data as possible. Because there is a chance that the above methods will not yield the desired amount/quality of data, the team is currently researching/considering collecting and analyzing data itself. More research on the methods of analyzing air samples is necessary to access the practicality of this method at this time.

The Interdisciplinary Qualifying Project was designed with six goals in mind:

1. To create an awareness of socially related technological interactions
2. To enable the identification of socio-technological systems, subsystems, and the linkages between them
3. To cultivate the habit of questioning social values and structures
4. To develop and integrate the skills of evaluation and analysis in the societal, humanistic, and technological disciplines
5. To provide methods for assessing the impact of technology on society and human welfare, and the impact of social systems on technological developments
6. To encourage the recommendation of policy.

The Air Pollution Caused by Air Traffic project meets each one of these criteria. The project is directly related to an interaction between technology and society: the effect of air traffic pollution on Hong Kong and its people. Through the research we will do in Hong Kong, we will gain some awareness of socio-technological systems there. During our time in Hong Kong we will come into contact with unfamiliar social values and structures, resulting in our contemplation of them. This project requires the analyzing of not only technical data but of general data of non-technical nature. The goal of this project is to judge the impact of a technology on human welfare; we must develop methods to achieve this goal. Lastly, the aim of our project includes the recommendation of possible changes we come up with that can improve the situation in Hong Kong.

8.4 RTHK Letter to Hong Kong

(Loh, 1999)

RTHK Letter to Hong Kong

Christine Loh

2nd May 1999

There is no arguing anymore that air quality has deteriorated significantly in Hong Kong over the last few years. There is also no dispute today that air pollution is not only bad for our health but bad for business. If it is just bad for our health, may be it would not have been enough for the Government to take it seriously. After all, many of us have been pressing the point for a long time. Now that we have had the Chief Executive's Council of International Business Advisers say to him that Hong Kong must clean up its environment, the Government seems to have gotten the message at last. It was perhaps fortuitous that the international advisers arrived on a day when air pollution was so bad and visibility had dropped so much that fog horns needed to be used in the harbour. Remember that awful day in February?

To give credit where credit is due, many local business leaders have also been speaking up vigorously in recent years for the environment. The various international chambers of commerce and the Hong Kong General Chamber have formed active environmental committees who have been calling for change consistently.

My colleagues in the Legislative Council seem to have also woken up to the fact that the environment is important, and that there may even be votes in it. People used to say to me that ordinary folks are concerned about housing and jobs, and that only the middle class and expatriates are interested in environmental protection. Hopefully, more and more people will realize that a bad environment affects the under-priviledged worse and that the environment is a cross-sectoral issue. In the course of 1999, we have heard my honourable friends the banker David Li, the tycoon James Tien and democracy fighter Martin Lee - who come from different sides of the political divide - all spout about the need to improve the environment. I look forward to feeling less lonely in the legislature soon!

It is crucial to have as many people as possible on the side of the environment and on public health. Beyond mouthing generalities, we are going to have to put our money where our mouth is. I hope you are prepared for this.

I know that you are angry with the amount of pollution coming from the backsides of Hong Kong's diesel vehicles. How many times have you had to cover your nose and mouth when you crossed the streets? You must be sick of seeing black smoke belching out of too many of this city's diesel-powered lorries, taxis, mini-buses and passenger buses. There is no excuse for that. Poisonous and harmful vehicular emissions can be cut down substantially by regular maintenance and improving driving techniques.

Are we being unfair to diesel vehicle owners? No - they cover most of the miles travelled in this city and poorly maintained diesels pump out most of the poison. I am not suggesting that fixing them will clean up all of Hong Kong's air pollution problems but making sure that diesels are maintained to the highest standard will reduce the level of respiratory suspended particulates, or RSP, in the air. The RSP are very fine and they stick to our respiratory systems, and they are the main culprits chipping away at our health.

Why should you and I use our health to subsidize the transport trade? From the number of complaints I have received from ordinary residents in the last six months, I think you are as fed up as I am. I have had mothers complain about how air pollution is affecting their children. I have had elderly people complain how bad air make them wheeze. I have had doctors express concern about the rising incidents of respiratory illnesses they are having to deal with and which they believe is caused by air pollution. I have even had dog owners say that their puppies are particularly affected because their pets' noses are at exhaust pipe level when they are walked in the streets.

There is now a chance for us to actually show our discontent in a very effective way. We can increase the fixed penalty for smoky vehicles from the currently paltry $450 to something that would be a real encouragement to get vehicle owners to improve maintenance and driving habits.

The Government has put together an omnibus piece of legislation, called the Revenue Bill, to put into effect all the revenue raising proprosals in the Financial Secretary's 1999-2000 Budget. One of the proposals is to increase the smoky vehicle fine to $570 - that is, an additional $120. That is not nearly good enough. The Government's increase is simply an inflation-linked one based on the years that have elapsed since the last time the penalty was put up several years ago. It appears that the transport trade would not even accept $570.

I am proposing to increase the fine to $5,000. I expect everyone to agree with me in principle about the need to deal severly with offenders but all hell will break loose. I will be called names. I will be accused of being unrealistic and unsympathetic of the transport sector. The Government will squirm and feel discomfort. I expect them to come out against the substantial increase. I expect the Government to stick to their inadequate $570. I expect legislators and political parties to really feel the heat. I expect some will continue to argue that the Revenue Bill is the wrong place to make such a change. I expect others will say a jump from $450 to $5,000 is too much for commercial vehicle owners in these poor economic times. If I am ever going to get this proposal through, I would have to drag everyone screaming and kicking till the very last minute of the vote in LegCo. And, I am going to need your help if I am going to have a chance to succeed.

Let us look at the economic and public health side of the equation. Government studies confirm that the annual health costs associated with air pollution are equivalent to some half a percent of Hong Kong's GDP, that is, $5.5 billion at 1996 figures. Friends of the Earth suggested that if 10% of visitors get put off by air pollution here and don't come, then the loss in tourism revenue could be as high as $4.5 billion a year. In proposing an increase of the smoky vehicle penalty to $5,000 - am I really so crazy? No, I don't think so. And, remember, if an owner maintains his vehicle well, he will not be penalized.

You will also hear some say, including some in the transport trade, that they agree with the fine but it should not be imposed now. They will argue that the Environmental Protection

Department is only bringing out advanced emission testing equipment for light diesel vehicles in September and that it would be more fair to only impose a heavier fine when a new testing scheme has been put in place.

Well, that is really no problem. The Revenue Bill is only set to come into effect on 1 August. If the Government is serious about the environment, they can enable my proposed $5,000 penalty to only come into effect say in November. Then there would be 3 months to put the testing system in place. Hong Kong always claims itself to be quick to adapt to economic change - surely, we can adapt to a heavier penalty in a relatively short period of time. With some commitment, Hong Kong can do it.

As I said, I am going to need your help. If you agree with a much heavier penalty for smoky vehicle offenders, could you make your views known? Interest groups have a voice in LegCo. For example, there is a functional representative member representing the transport sector. But ordinary folks do not always find it easy to voice their concerns. As your directly elected representative, I believe I do represent the views of many who want to see real change. It would help if you can also voice your concerns directly.

Please take a few moments, ask your friend, family and colleagues, to write to the Legislative Council Bill's Committee for the Revenue Bill. Tell the Committee what you think about worsening air pollution. Say that you want to see a much heavier penalty for smoky vehicles, and I hope you will even agree with increasing the fine to $5,000.

8.5 Interview Questions

Interview with Environmental Specialist:

Introduction:

- Introduce ourselves
- Introduce and explain our project, sponsor, and how our results will be used

Questions:

1) How long have you been working in the field of environmental studies?

2) What is your exact field of expertise?

3a) Do you feel Hong Kong currently has a problem with air pollution?
3b) Could you describe what you feel are the most predominant air pollution issues currently facing Hong Kong?

4a) Can you describe the causes and effects of air pollution?
4b) What environmental affects do you think are the result of the pollution in Hong Kong?
4c) What health effects do you think are the result of the air pollution in Hong Kong?

5a) What environmental effects do you think the HKIA and other airports in the area have on the Hong Kong environment?
5b) What health effects do you think the HKIA and other airports in the area have on the population of Hong Kong.

6) What do you feel are the most significant types and effects of aircraft air pollution?

7) Do you know of any studies that have been done to measure the air pollution levels and effects of airports?

8a) Can you describe the methods for determining the levels of air pollution that come as a result of different aspects of air traffic?
8b) Specifically related to Taxiing?
8c) Take off and landing cycles?
8d) Aircraft Movements?

9a) Which of these factors is the most significant contributor and why?
9b) What do you feel is the best method for reducing each of these contributors?

10) What sort of effect do you feel weather conditions and patterns have on aircraft pollution?

11) Do you have any recommendations for anyone else that we could speak to in order to gather more information?

Interview with Airport Specialist:

Introduction:

- Introduce ourselves
- Introduce and explain our project, sponsor, and how our results will be used

Questions:

1) How long have you been working for this airport?

2) What is your exact field of expertise or job title?

3) Do you feel Hong Kong currently has a problem with air pollution?

4a) Currently how many aircraft are there at your airport?
4b) What are the numbers of planes based on Make and Model?
4c) Do you have a lot of connecting flights?
4d) What are the different airlines that make connections through your airport?

5a) How many flights usually takeoff and land from this airport on a daily basis?
5b) Do you know the annual numbers for aircraft movements, passengers, and cargo?

6a) Can you describe the takeoff and landing procedures usually employed at this airport?
6b) How often and how far do planes usually taxi?
6c) Is full thrust usually used during takeoff?
6d) How close to weight capacity are most flights leaving the airport?
6e) Can you describe some of the general flight paths used for takeoffs and landings?

7a) Are you familiar with the Stage 1 and Stage 2 fueling systems?
7b) Does your airport use Stage 1 or Stage 2 fueling systems?
7c) How many planes employ stage 1 and how many employ stage 2?

8a) What are the general weather patterns surrounding your airport?
8b) Are there prevailing winds during different seasons?

9) Has your airport done any studies to measure the air pollution levels and effects of airports?

10) Does your airport have any regulations or guidelines concerning air pollution?

11) Do you have any recommendations for anyone else that we could speak to in order to gather more information?

Interview with Health Care Specialist:

Introduction:

- Introduce ourselves
- Introduce and explain our project, sponsor, and how our results will be used

Questions:

1) How long have you been working in the field of Health Care?

2) What is your exact field of expertise, and job title?

3a) Do you feel Hong Kong currently has a problem with air pollution?
3b) Could you describe what you feel are the most predominant health issues related to air pollution in Hong Kong?
3c) How many hospitalizations are there annually for respiration illnesses or complications?
3d) How many deaths are there annually related to respiration illnesses or complications?

5a) Could you describe some of the health effects related to Suspended Respirable Particles?
5b) Do you think this is a large problem in the Hong Kong population?

6a) Could you describe some of the health effects related to Ozone?
6b) Do you think this is a large problem in the Hong Kong population?

7a) Could you describe some of the health effects related to NO_X (compounds containing a combination of Nitrogen and Oxygen)?
7b) Do you think this is a large problem in the Hong Kong population?

8a) Could you describe some of the health effects related to HAPs (Hazardous Air Pollutants such as lead and other metallic toxins)?
8b) Do you think this is a large problem in the Hong Kong population?

9) Are there any other health problems related to aircraft air pollution (or general air pollution)?

10) Do you have any recommendations for anyone else that we could speak to in order to gather more information?

Interview with Aircraft Specialist:

Introduction:

- Introduce ourselves
- Introduce and explain our project, sponsor, and how our results will be used

Questions:

1) How long have you been working for this airport?

2) What is your exact field of expertise or job title?

3) Do you feel Hong Kong currently has a problem with air pollution?

4a) Can you describe some of the causes and effects of air pollution?
4b) What health effects do you think are resultant of the air pollution in Hong Kong?

5a) What environmental affects do you think the HKIA and other airports in the area have on the Hong Kong environment?
5b) What health effects do you think the HKIA and other airports in the area have on the population of Hong Kong.

6a) What types of aircraft models or engines produce the largest amounts of pollution?
6b) What are the types of pollution are produced by each aircraft model or engine type.
6c) How many planes employ stage 1 fueling and how many employ stage 2?

7a) What do you feel are the most significant of these types of aircraft air pollution?
7b) What do you feel is the best method for reducing each of these contributors?

8a) Can you describe the methods for determining the levels of air pollution that come as a result of different aspects of aircraft use?
8b) What levels and types of pollution do engines produce while the aircraft is taxiing?
8c) What levels and types of pollution do engines produce while the aircraft is in take off and landing cycles?
8d) What levels and types of pollution do engines produce while the aircraft is in flight?

9a) Does the weight or capacity of the aircraft affect the levels of air pollution produced?
9b) Does the amount of thrust used during takeoff affect the levels of air pollution produced??
9c) Do different flight paths affect the levels of air pollution produced?

10) Are there any regulations or guidelines concerning air pollution for aircraft or engines?

11) Do you know of any studies that have been done to measure the air pollution levels and
effects of different aircraft models and engine types?

11) Do you have any recommendations for anyone else that we could speak to in order to gather more information?

8.6 Flight traffic Data at Hong Kong International Airport

(HK Civil Aviation Department, 2001)

8.6.1 Number of Aircraft

Period	*Number of Aicraft* *Landing*	*Takeoff*	*Total*	*% change*
1.Calendar Year (Jan - Dec)				
1993	67 548	67 544	135 092	11.7
1994	71 609	71 642	143 251	6
1995	75 053	75 065	150 118	4.8
1996	79 401	79 396	158 797	5.8
1997	82 573	82 581	165 154	4
1998	81 616	81 607	163 223	-1.2
1999	83 686	83 683	167 369	2.5
2000	90 953	90 974	181 927	8.7
2. Financial Year (Apr - Mar)				
1993/ 94	69 080	69 072	138 152	11.5
1994/ 95	72 521	72 564	145 085	5
1995/ 96	75 862	75 869	151 731	4.6
1996/ 97	80 618	80 608	161 226	6.3
1997/ 98	82 033	82 039	164 072	1.8
1998/ 99	82 248	82 262	164 510	0.3
1999/ 2000	84 584	84 586	169 170	2.8
2000/ 2001	93 222	93 228	186 450	10.2
3. Monthly Air Traffic				
Jan-99	6 803	6 809	13 612	-3.2
Feb-99	6 619	6 615	13 234	8.9
Mar-99	6 904	6 919	13 823	5
Apr-99	6 994	6 995	13 989	4.4
May-99	6 960	6 935	13 895	2.4
Jun-99	6 626	6 651	13 277	1.4
Jul-99	7 144	7 145	14 289	2.9
Aug-99	7 174	7 169	14 343	-0.3
Sep-99	6 803	6 805	13 608	-0.3
Oct-99	7 266	7 264	14 530	2
Nov-99	7 078	7 081	14 159	5.1
Dec-99	7 315	7 295	14 610	3.5
Jan-00	6 908	6 926	13 834	1.6
Feb-00	7 010	7 014	14 024	6
Mar-00	7 306	7 306	14 612	5.7
Apr-00	7 445	7 446	14 891	6.4
May-00	7 531	7 538	15 069	8.4
Jun-00	7 318	7 321	14 639	10.3

Jul-00	7 758	7 737	15 495	8.4
Aug-00	7 928	7 938	15 866	10.6
Sep-00	7 761	7 765	15 526	14.1
Oct-00	8 116	8 087	16 203	11.5
Nov-00	7 803	7 816	15 619	10.3
Dec-00	8 069	8 080	16 149	10.5
Jan-01	8 229	8 230	16 459	19
Feb-01	7 092	7 099	14 191	1.2
Mar-01	8 172	8 171	16 343	11.8
Apr-01	8 328	8 323	16 651	11.8
May-01	8 410	8 402	16 812	11.6
Jun-01	8 228	8 234	16 462	12.5
Jul-01	8 379	8 368	16 747	8.1
Aug-01	8 602	8 607	17 209	8.5
Sep 2001 #	8 295	8 295	16 590	6.9
Oct 2001 #	8 467	8 468	16 935	4.5

8.6.2 Number Of Passengers

Period	*Arriving*	***Number of Passengers*** *Departing*	*Total*	*%Change*	*Arrival Transit*
1. Calendar Year (Jan - Dec)					
1993	12 118 651	12 301 995	24 420 646	10.7	708 424
1994	12 540 515	12 707 683	25 248 198	3.4	700 591
1995	13 640 899	13 782 845	27 423 744	8.6	619 594
1996	14 705 612	14 836 978	29 542 590	7.7	669 737
1997	14 101 694	14 216 144	28 317 838	-4.1	688 727
1998	13 634 989	13 573 803	27 208 792	-3.9	711 143
1999	14 552 270	14 510 300	29 062 570	6.8	665 747
2000	16 112 065	16 018 647	32 130 712	10.6	621 647
2. Financial Year (Apr - Mar)					
1993/ 1994	12 369 987	12 600 459	24 970 446	10.9	712 099
1994/ 1995	12 719 902	12 834 989	25 554 891	2.3	689 440
1995/ 1996	13 920 347	14 058 222	27 978 569	9.5	630 698
1996/ 1997	14 950 858	15 130 855	30 081 713	7.5	651 311
1997/ 1998	13 627 648	13 661 234	27 288 882	-9.3	689 732
1998/ 1999	13 822 830	13 777 740	27 600 570	1.1	722 388
1999/ 2000	14 855 492	14 754 165	29 609 657	7.3	653 450
2000/ 2001	16 352 260	16 284 058	32 636 318	10.2	603 551
3. Monthly Air Traffic					
Jan-99	1 072 733	1 080 788	2 153 521	-3.4	65 063
Feb-99	1 165 738	1 177 213	2 342 951	16.9	50 514
Mar-99	1 141 608	1 158 939	2 300 547	6	60 225
Apr-99	1 266 402	1 222 643	2 489 045	6.5	51 244
May-99	1 156 803	1 163 977	2 320 780	9	57 921
Jun-99	1 110 030	1 135 203	2 245 233	3.4	54 764
Jul-99	1 330 977	1 369 445	2 700 422	10.6	58 516

Aug-99	1 408 157	1 339 286	2 747 443	5.5	58 610
Sep-99	1 113 918	1 153 682	2 267 600	7	47 641
Oct-99	1 316 375	1 277 962	2 594 337	7.2	49 156
Nov-99	1 235 095	1 217 614	2 452 709	13.7	56 373
Dec-99	1 234 434	1 213 548	2 447 982	1	55 720
Jan-00	1 125 875	1 166 816	2 292 691	6.5	54 709
Feb-00	1 305 123	1 233 741	2 538 864	8.4	51 882
Mar-00	1 252 303	1 260 248	2 512 551	9.2	56 914
Apr-00	1 433 209	1 445 557	2 878 766	15.7	43 615
May-00	1 330 375	1 322 463	2 652 838	14.3	53 357
Jun-00	1 310 638	1 320 560	2 631 198	17.2	57 198
Jul-00	1 450 450	1 484 304	2 934 754	8.7	56 573
Aug-00	1 525 680	1 452 082	2 977 762	8.4	51 975
Sep-00	1 315 969	1 376 089	2 692 058	18.7	50 289
Oct-00	1 429 783	1 379 342	2 809 125	8.3	44 053
Nov-00	1 274 250	1 247 394	2 251 644	2.8	51 240
Dec-00	1 358 410	1 330 051	2 688 461	9.8	49 842
Jan-01	1 331 381	1 419 393	2 750 774	20	53 358
Feb-01	1 175 217	1 090 521	2 265 738	-10.8	48 024
Mar-01	1 416 898	1 416 302	2 833 200	12.8	44 027
Apr-01	1 425 368	1 473 037	2 898 405	0.7	42 183
May-01	1 356 892	1 323 266	2 680 158	1	45 773
Jun-01	1 358 268	1 393 481	2 751 749	4.6	52 850
Jul-01	1 389 075	1 408 658	2 797 733	-4.7	50 879
Aug-01	1 540 111	1 487 073	3 027 184	1.7	53 636
Sep 2001 #	1 222 000	1 296 000	2 518 000	-6.5	37 000
Oct 2001 #	1 289 000	1 206 000	2 495 000	-11.2	27 000

8.6.3 Amount of Freight

	Frieght (tons)			
Period	Unload	Load	Total	% Change
1.Calendar Year (Jan - Dec)				
1993	512 534	626 556	1 139 090	19
1994	605 782	686 724	1 292 504	13.5
1995	685 450	772 230	1 457 680	12.8
1996	733 907	829 586	1 563 493	7.3
1997	839 872	946 615	1 786 487	14.3
1998	774 544	854 198	1 628 742	-8.8
1999	841 161	1 133 130	1 974 291	21.2
2000	952 514	1 288 071	2 240 586	13.5
2. Financial Year (Apr - Mar)				
1993/ 1994	535 611	639 250	1 174 861	18.7
1994/ 1995	628 548	703 638	1 332 186	13.4
1995/ 1996	696 750	780 334	1 477 084	10.9
1996/ 1997	757 599	864 635	1 622 234	9.8
1997/ 1998	853 367	942 373	1 795 740	10.7
1998/ 1999	765 600	877 988	1 643 588	-8.5

1999/ 2000	865 639	1 194 349	2 059 989	25.3
2000/ 2001	956 469	1 273 076	2 229 545	8.2
3. Monthly Air Traffic				
Jan-99	62 389	71 177	133 566	6.5
Feb-99	56 367	60 932	117 299	3.7
Mar-99	70 664	86 221	156 885	1.6
Apr-99	67 720	88 335	156 055	11.9
May-99	71 316	87 789	159 105	11.3
Jun-99	66 394	85 257	151 651	9.8
Jul-99	70 096	95 223	165 319	73.6
Aug-99	65 910	96 744	162 654	34.9
Sep-99	69 492	104 617	174 108	24.8
Oct-99	80 596	119 429	200 025	29.5
Nov-99	77 657	125 220	202 877	28.8
Dec-99	82 560	112 188	194 749	31.5
Jan-00	71 559	90 464	162 022	21.3
Feb-00	61 923	74 265	136 187	16.1
Mar-00	80 416	114 821	195 237	24.5
Apr-00	79 007	107 336	186 342	19.4
May-00	77 890	103 515	181 405	14
Jun-00	79 055	101 523	180 578	19.1
Jul-00	81 179	107 739	188 918	14.3
Aug-00	79 036	109 116	188 152	15.7
Sep-00	85 060	117 433	202 494	16.3
Oct-00	84 840	125 315	210 155	5.1
Nov-00	85 296	129 237	214 533	5.7
Dec-00	87 253	107 309	194 562	-0.1
Jan-01	65 479	77 491	142 970	-11.8
Feb-01	70 601	80 263	150 864	10.8
Mar-01	81 772	106 799	188 571	-3.4
Apr-01	74 299	90 546	164 845	-11.5
May-01	73 159	85 913	159 071	-12.3
June-01	75 419	88 867	164 286	-9
July-01	72 311	89 937	162 248	-14.1
August-01	70 463	97 253	167 716	-10.9
Sep 2001 #	77 000	105 000	182 000	-10.1
Oct 2001 #	76 000	121 000	197 000	-6.3

8.7 1999 Air Pollution Statistics

(Hong Kong Environmental Department 2000)

HONG KONG AIR POLLUTANTS EMISSION INVENTORY

CO Emissions (tonnes)

Source/Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Fuel Combustion (Ind., Comm. & Dom.)	12,675	10,264	11,365	9,210	8,821	8,998	8,799	4,519	3,532	3,456
Power Generation	2,597	2,902	3,150	3,246	2,387	2,543	4,008	3,784	3,351	3,024
Aircraft	1,627	1,708	1,848	2,065	2,186	2,265	2,379	2,432	2,299	2,165
Marine Vessel	1,887	1,965	1,990	2,327	2,422	2,531	2,485	2,586	2,515	2,562
Motor Vehicle	74,213	87,179	91,573	95,979	98,426	91,767	87,117	90,236	84,134	81,113
TOTAL	**93,000**	**104,017**	**109,925**	**112,826**	**114,242**	**108,103**	**104,788**	**103,558**	**95,833**	**92,320**

Remarks :

1. Data subject to revision as and when more appropriate information becomes available.
2. Individual values may not sum to total due to rounding.
3. For marine emissions, the part concerning ocean-going vessels are derived from auxiliary power generation only.
4. Last Updated : December, 2000

HONG KONG AIR POLLUTANTS EMISSION INVENTORY

NOx Emissions (tonnes)

Source/Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Fuel Combustion (Ind., Comm. & Dom.)	8,961	6,164	9,214	10,332	11,062	10,540	9,864	9,513	6,767	6,566
Power Generation	136,100	149,400	163,000	113,300	93,600	97,475	69,204	56,084	55,230	41,744
Aircraft	2,843	3,014	3,306	3,771	4,052	4,162	4,337	4,424	4,218	4,096
Marine Vessel	7,604	7,904	7,988	9,282	9,679	10,130	9,954	10,268	9,920	10,129
Motor Vehicle	39,259	36,142	36,733	39,555	40,387	37,773	37,171	38,541	36,370	37,020
TOTAL	**194,766**	**202,624**	**220,241**	**176,241**	**158,780**	**160,080**	**130,530**	**118,831**	**112,506**	**99,556**

Remarks :

1. Data subject to revision as and when more appropriate information becomes available.
2. Individual values may not sum to total due to rounding.
3. For marine emissions, the part concerning ocean-going vessels are derived from auxiliary power generation only.
4. Last Updated : December, 2000

HONG KONG AIR POLLUTANTS EMISSION INVENTORY

Particulate Matters Emissions (tonnes)

Source/Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Fuel Combustion (Ind., Comm. & Dom.)	1,188	743	1,006	1,068	1,130	1,034	965	819	547	512
Power Generation	7,657	8,395	8,675	8,739	5,207	5,765	4,078	3,747	3,845	2,790
Aircraft	27	29	31	34	36	37	39	41	39	40
Marine Vessel	581	605	614	722	750	783	768	806	788	801
Motor Vehicle	5,707	6,454	6,462	6,984	7,122	6,821	6,759	6,807	5,867	5,736
TOTAL	**15,159**	**16,227**	**16,789**	**17,547**	**14,246**	**14,440**	**12,609**	**12,220**	**11,086**	**9,879**

Remarks :

1. Data subject to revision as and when more appropriate information becomes available.
2. Individual values may not sum to total due to rounding.
3. For marine emissions, the part concerning ocean-going vessels are derived from auxiliary power generation only.
4. Last Updated : December, 2000

HONG KONG AIR POLLUTANTS EMISSION INVENTORY

SO_2 Emissions (tonnes)

Source/Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Fuel Combustion (Ind., Comm. & Dom.)	28,710	12,004	18,500	22,380	24,126	20,544	18,229	16,992	9,793	8,835
Power Generation	118,300	131,600	145,200	162,600	116,600	103,967	72,799	54,434	60,961	47,750
Aircraft	254	272	301	346	378	391	404	409	384	363
Marine Vessel	912	948	959	1,114	1,161	1,216	1,194	1,232	1,190	1,216
Motor Vehicle	10,251	11,432	11,602	11,124	11,332	6,070	6,199	1,620	1,538	1,629
TOTAL	**158,427**	**156,257**	**176,562**	**197,564**	**153,597**	**132,187**	**98,826**	**74,688**	**73,866**	**59,792**

Remarks :

1. Data subject to revision as and when more appropriate information becomes available.
2. Individual values may not sum to total due to rounding.
3. For marine emissions, the part concerning ocean-going vessels are derived from auxiliary power generation only.
4. Last Updated : December, 2000

Non-Methane VOC Emissions (tonnes)

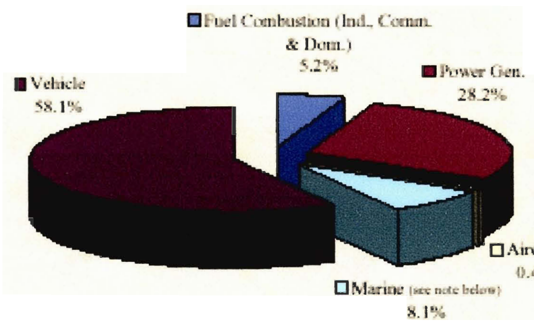
Source/Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Fuel Combustion (Ind., Comm. & Dom.)	603	493	537	452	442	452	437	250	204	205
Power Generation	216	248	272	280	198	213	296	296	278	258
Aircraft	545	573	611	670	704	712	739	741	690	628
Marine Vessel	752	781	790	917	956	1,001	984	1,014	979	1,000
Motor Vehicle	11,850	14,053	14,477	15,467	15,858	15,184	15,186	15,715	14,820	14,861
TOTAL	**13,966**	**16,147**	**16,687**	**17,785**	**18,159**	**17,563**	**17,641**	**18,016**	**16,972**	**16,953**

Remarks :

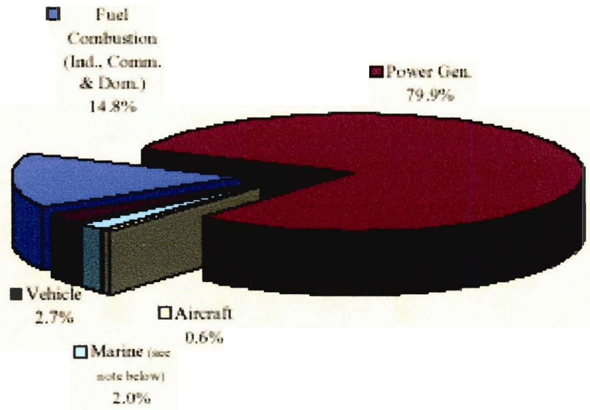
1. Data subject to revision as and when more appropriate information becomes available.
2. Individual values may not sum to total due to rounding.
3. For marine emissions, the part concerning ocean-going vessels are derived from auxiliary power generation only.
4. Last Updated : December, 2000

HONG KONG AIR POLLUTANTS EMISSION INVENTORY 1999

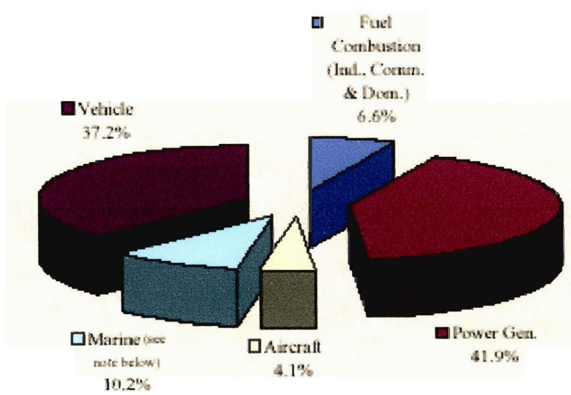
Particulate Matters Emissions



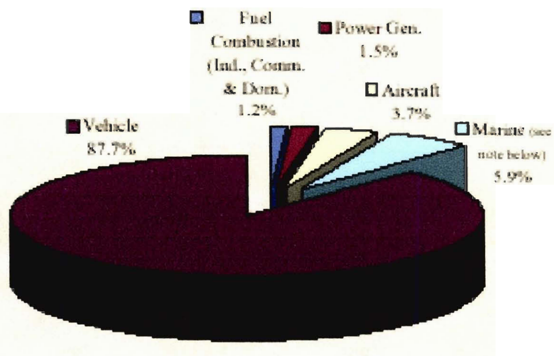
SO_2 Emissions



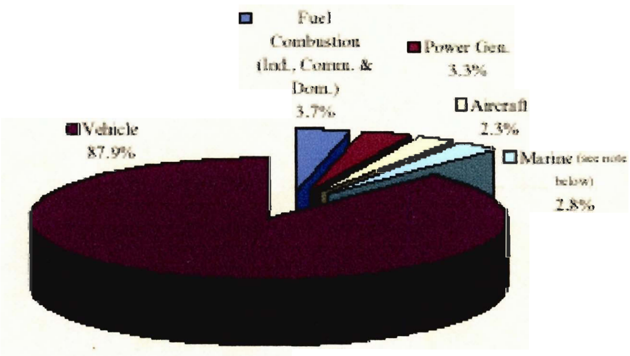
NOx Emissions



Non-Methane VOC Emissions



CO Emissions



Note :

Please refer to the "Remarks" in the data tables.

8.8 2001 Aircraft Pollution Inventory

…endix 8… …issions … Take-C…

Aircraft Make	Model	# of Departure	Avg Take Off Time	THCef lb/min	total lb per aircraft	COef lb/min	total lb per aircraft	NOXef lb/min	total lb per aircraft	SO2ef lb/min	total lb per aircraft
Fokker	100	5	0.70	0.16085	0.56298	0.14074	0.49259	4.24240	14.84840	0.10857	0.38000
Airbus Industrie	a310	298	0.70	0.04480	9.34528	0.31826	66.38904	15.65280	3265.17408	0.30000	62.58000
Airbus Industrie	a310 Freighter	7	0.70	0.04480	0.21952	0.31826	1.55947	15.65280	76.69872	0.30000	1.47000
Airbus Industrie	a310-200	67	0.70	0.08965	4.20459	0.31939	14.97939	23.30959	1093.21977	0.30258	14.19100
Airbus Industrie	a310-300	356	0.70	0.07487	18.65760	0.06911	17.22221	15.49267	3860.77336	0.31101	77.50369
Airbus Industrie	a319	428	0.70	0.02655	7.95438	0.14520	43.50102	9.85464	2952.45014	0.27000	80.89200
Airbrus Industrie	a320	9251	0.70	0.02950	191.03315	0.16133	1044.72468	10.94960	70906.32472	0.30000	1942.71000
Airbus Industrie	a321	2051	0.70	0.03540	50.82378	0.19360	277.94578	13.13952	18864.40886	0.36000	516.85200
Airbus Industrie	a330	11033	0.70	0.27480	2122.30788	0.14960	1155.37576	36.30280	280370.15468	0.30000	2316.93000
Airbus Industrie	a330-200	130	0.70	0.27480	25.00680	0.14960	13.61360	36.30280	3303.55480	0.30000	27.30000
Airbus Industrie	a330-300	1470	0.70	0.27480	282.76920	0.14960	153.93840	36.30280	37355.58120	0.30000	308.70000
Airbus Industrie	a340	6419	0.70	0.00580	26.06114	0.70986	3189.61394	25.27970	113589.27601	0.30000	1347.99000
Airbus Industrie	a340-200	26	0.70	0.00580	0.10556	0.70986	12.91945	25.27970	460.09054	0.30000	5.46000
Airbus Industrie	a340-300	1394	0.70	0.00580	5.65964	0.70986	692.68139	25.27970	24667.93126	0.30000	292.74000
Boeing	727 Freighter	114	0.70	0.15549	12.40810	0.58469	46.65826	6.74443	538.20551	0.21230	16.94154
Boeing	737-200 Passenger	9	0.70	0.07816	0.49241	0.30391	1.91463	5.29978	33.38861	0.15398	0.97007
Boeing	737-300 Passenger	2784	0.70	0.01006	19.60493	0.25143	489.98678	5.41977	10562.04778	0.15086	293.99597
Boeing	737-400 Passenger	459	0.70	0.01006	3.23228	0.25143	80.78446	5.41977	1741.37210	0.15086	48.47132
Boeing	737-500 Passenger	1137	0.70	0.00916	7.29044	0.27477	218.68944	6.31963	5029.79352	0.16486	131.21207
Boeing	737 Passenger	261	0.70	0.01006	1.83796	0.25143	45.93626	5.41977	990.19198	0.15086	27.56212
Boeing	737-800 Passenger	2505	0.70	0.01157	20.28624	0.28914	507.01488	6.23274	10929.10170	0.17349	304.21296
Boeing	747-100 Passenger	7	0.70	0.25841	1.26621	0.25841	1.26621	40.82822	200.05828	0.69770	3.41873
Boeing	747-200 Passenger	1323	0.70	0.27517	254.83494	0.29706	275.10727	42.00930	38904.81273	0.69302	641.80582
Boeing	747-300 Passenger	165	0.70	0.02423	2.79857	0.37270	43.04685	31.95942	3691.31301	0.50315	58.11383
Boeing	747-400 Passenger	15572	0.70	0.02423	264.11669	0.37270	4062.57908	31.95942	348370.46177	0.50315	5484.53626
Boeing	747 Passenger	264	0.70	0.25841	47.75417	0.25841	47.75417	40.82822	7545.05506	0.69770	128.93496
Boeing	747-200 Mixed Configuration	471	0.70	0.27517	90.72355	0.29706	97.94068	42.00930	13850.46621	0.69302	228.48869
Boeing	747-300 Mixed Configuration	13	0.70	0.02423	0.22049	0.37270	3.39157	31.95942	290.83072	0.50315	4.57867
Boeing	747-300 Mixed Configuration	3370	0.70	0.02423	57.15857	0.37270	879.19930	31.95942	75392.27178	0.50316	1186.93085
Boeing	747 Freighter	3192	0.70	0.34401	768.65594	0.45867	1024.85225	52.74756	117859.14806	0.61921	1383.56282
Boeing	747SP Passenger	1	0.70	0.33117	0.23182	0.42863	0.30004	50.95966	35.67176	0.63098	0.44169
Boeing	747 Mixed Configuration	12	0.70	0.25841	2.17064	0.25841	2.17064	40.82822	342.95705	0.69770	5.86068
Boeing	747SR Passenger	1	0.70	0.33117	0.23182	0.42863	0.30004	50.95966	35.67176	0.63098	0.44169
Boeing	747-100/200/747SR Freighter	1960	0.70	0.34401	471.98172	0.45867	629.29524	52.74756	72369.65232	0.61921	849.55612
Boeing	747-400 Frieghter	1199	0.70	0.02423	20.33624	0.37270	312.80711	31.95942	26823.54121	0.50315	422.29380
Boeing	757-200 Passenger	3560	0.70	0.01976	49.24192	0.16775	418.03300	13.01970	32445.09240	0.22241	554.24572
Boeing	757 Passenger	279	0.70	0.01976	3.85913	0.16775	32.76158	13.01970	2542.74741	0.22241	43.43667
Boeing	757 Freighter	202	0.70	0.01771	2.50419	0.41623	58.85492	23.34454	3300.91796	0.26204	37.05246
Boeing	767-200 Passenger	353	0.70	0.13461	33.26213	0.46921	115.94179	18.10006	4472.52483	0.31166	77.00872
Boeing	767-300 Passenger	2858	0.70	0.04776	95.54866	0.35479	709.79287	21.02125	42055.11275	0.36843	737.08106
Boeing	767 Passenger	515	0.70	0.09119	32.87219	0.41200	148.52600	19.56066	7051.61613	0.34004	122.58442
Boeing	767 Freighter	20	0.70	0.04776	0.66864	0.35479	4.96706	21.02125	294.29750	0.36843	5.15802
Boeing	777-200	4653	0.70	0.04776	155.55910	0.70986	2312.08501	25.27000	82306.91700	0.36843	1200.01335
Boeing	777-300	4031	0.70	0.04776	134.76439	0.70986	2003.01196	25.27000	71304.35900	0.36843	1039.59893
Boeing	777	947	0.70	0.04776	31.66010	0.70986	470.56619	25.27000	16751.48300	0.36843	244.23225
Airbus Industrie	a300	84	0.70	0.38112	22.40986	0.27223	16.00712	16.87806	992.42993	0.29400	17.28720
Airbus Industrie	a300-600 Passenger	6487	0.70	0.04780	217.05502	0.35506	1612.29195	23.47520	106598.53568	0.36872	1674.32065
Airbus Industrie	a300 Freighter	283	0.70	0.38112	75.49987	0.27223	53.92876	16.87806	3343.54369	0.29400	58.24140
Airbus Industrie	a300b4/c4/f40 freighter	36	0.70	0.38112	9.60422	0.27223	6.86020	16.87806	425.32711	0.29400	7.40880
Beechcraft	(light Aircraft)	1	0.70	0.16626	0.11638	0.38810	0.27167	22.90599	16.03419	0.38000	0.26600
Canadair	Challenger	74	0.70	0.16626	8.61227	0.38810	20.10358	22.90599	1186.53028	0.38000	19.68400
Cessna	Citation	8	0.70	0.16626	0.93106	0.38810	2.17336	22.90599	128.27354	0.38000	2.12800
Canadair	Regional Jet 100/200	11	0.70	0.16626	1.28020	0.38810	2.98837	22.90599	176.37612	0.38000	2.92600
McDonnell Douglas	DC-10 Passenger	159	0.70	0.20667	23.00237	0.34445	38.33729	27.55602	3066.98503	0.37201	41.40471
McDonnell Douglas	DC-10-30/40 Passenger	379	0.70	0.25516	67.69395	1.32685	352.01331	2.39853	636.33001	0.13779	36.55569
McDonnell Douglas	DC-10 Freighter	10	0.70	0.20667	1.44669	0.34445	2.41115	27.55602	192.89214	0.37201	2.60407
McDonnell Douglas	DC-8-50 Passenger	3	0.70	2.48470	5.21787	0.93176	1.95670	7.51621	15.78404	0.33543	0.70440
McDonnell Douglas	DC-9-30 Passenger	18	0.70	0.09052	1.14055	0.36122	4.55137	4.72992	59.59699	0.14416	1.81642
Dassault (Breguet Mystere)	Falcon 50/900	55	0.70	0.16626	6.40101	0.38810	14.94185	22.90599	881.88062	0.38000	14.63000
Grumman	4 Seater	8	0.70	0.16626	0.93106	0.38810	2.17336	22.90599	128.27354	0.38000	2.12800
Gulfstream Aerospace (Grumman)	G-1159 Gulfstream II/III/V	150	0.70	0.16626	17.45730	0.38810	40.75050	22.90599	2405.12895	0.38000	39.90000
British Aerospace (Hawker Siddeley)	125	121	0.70	0.16626	14.08222	0.38810	32.87207	22.90599	1940.13735	0.38000	32.18600
Lockheed	L-1011-100/150 Tristar	117	0.70	0.11130	9.11547	0.57970	47.47743	27.77820	2275.03458	0.00042	0.03422
Lockheed	L-382(L-100) Hercules	3	0.70	0.16626	0.34915	0.38810	0.81501	22.90599	48.10258	0.38000	0.79800
Learjet		14	0.70	0.16626	1.62935	0.38810	3.80338	22.90599	224.47870	0.38000	3.72400
McDonnell Douglas	MD-11 Passenger	1280	0.70	0.07211	64.61056	0.53569	479.97824	33.63525	30137.18400	0.55630	498.44480
McDonnell Douglas	MD-11 Freighter	1591	0.70	0.07211	80.30891	0.53569	596.59795	33.63525	37459.57793	0.55630	619.55131
McDonnell Douglas	MD-82	404	0.70	0.09770	27.62956	0.27867	78.80693	0.00014	0.03908	0.89655	253.54434
McDonnell Douglas	MD-83	27	0.70	0.09770	1.84653	0.27867	5.26680	0.00014	0.00261	0.89655	16.94480
McDonnell Douglas	MD-90	1465	0.70	0.09770	100.19135	0.27867	285.77267	0.00014	0.14172	0.89655	919.41203
Pilats	PC-6 Turbo Porter	5	0.70	0.16626	0.58191	0.38810	1.35835	22.90599	80.17097	0.38000	1.33000
Other (Private)		26	0.7	0.16626	3.02593	0.38810	7.06342	22.90599	416.88902	0.38000	6.91600
		Toal Emissions for All Aircraft (Tons)			3.04723		12.72103		875.83862		13.27667

A[illegible] 3.8.2 T[illegible] nission[illegible] Idle/Ta[illegible]

Make	Model	Total # of flights	Avg Taxi time (min)	THCef (lb/min)	total lb per aircraft	COef (lb/min)	total lb per aircraft	NOxef (lb/min)	total lb per aircraft	SO2ef (lb/min)	total lb per aircraft
Fokker	100	9	10.00	0.09894	8.90460	0.70133	63.11970	0.07275	6.54750	0.01571	1.41390
Airbus Industrie	a310	596	10.00	0.52400	3123.04000	2.29533	13680.16680	0.19770	1178.29200	0.03400	202.64000
Airbus Industrie	a310 Freighter	14	10.00	0.52400	73.36000	2.29533	321.34620	0.19770	27.67800	0.03400	4.76000
Airbus Industrie	a310-200	133	10.00	0.06490	86.31700	0.48352	643.08160	0.23971	318.81430	0.03400	45.22000
Airbus Industrie	a310-300	712	10.00	0.03465	246.70800	0.59750	4254.20000	0.22945	1633.68400	0.03400	242.08000
Airbus Industrie	a319	856	10.00	0.00648	55.46880	0.22836	1954.75903	0.17460	1494.57600	0.03060	261.93600
Airbrus Industrie	a320	18512	10.00	0.00720	1332.86400	0.25373	46971.05296	0.19400	35913.28000	0.03400	6294.08000
Airbus Industrie	a321	4102	10.00	0.00864	354.41280	0.30448	12489.75319	0.23280	9549.45600	0.04080	1673.61600
Airbus Industrie	a330	22070	10.00	0.06930	15294.51000	0.66733	147279.73100	0.41010	90509.07000	0.03400	7503.80000
Airbus Industrie	a330-200	260	10.00	0.06930	180.18000	0.66733	1735.05800	0.41010	1066.26000	0.03400	88.40000
Airbus Industrie	a330-300	2941	10.00	0.06930	2038.11300	0.66733	19626.17530	0.41010	12061.04100	0.03400	999.94000
Airbus Industrie	a340	12836	10.00	0.34100	43770.76000	2.06800	265448.48000	0.27040	34708.54400	0.03400	4364.24000
Airbus Industrie	a340-200	52	10.00	0.34100	177.32000	2.06800	1075.36000	0.27040	140.60800	0.03400	17.68000
Airbus Industrie	a340-300	2788	10.00	0.34100	9507.08000	2.06800	57655.84000	0.27040	7538.75200	0.03400	947.92000
Boeing	727 Freighter	228	10.00	0.53526	1220.39280	1.79702	4097.20560	0.13873	316.30440	0.02768	63.11040
Boeing	737-200 Passenger	18	10.00	0.20068	36.12240	0.76370	137.46600	0.10591	19.06380	0.01934	3.48120
Boeing	737-300 Passenger	5567	10.00	0.05509	3066.86030	0.94761	52753.44870	0.12908	7185.88360	0.01700	946.39000
Boeing	737-400 Passenger	918	10.00	0.05509	505.72620	0.94761	8699.05980	0.12908	1184.95440	0.01700	156.06000
Boeing	737-500 Passenger	2274	10.00	0.04658	1059.22920	0.87917	19992.32580	0.14106	3207.70440	0.01771	402.72540
Boeing	737 Passenger	522	10.00	0.05509	287.56980	0.94761	4946.52420	0.12908	673.79760	0.01700	88.74000
Boeing	737-800 Passenger	5009	10.00	0.06335	3173.37682	1.08975	54585.65264	0.14844	7435.45978	0.01955	979.25950
Boeing	747-100 Passenger	14	10.00	1.50479	210.67060	6.64614	930.45960	0.37620	52.66800	0.06772	9.48080
Boeing	747-200 Passenger	2644	10.00	1.59531	42179.99640	6.50782	172066.76080	0.37825	10000.93000	0.06708	1773.59520
Boeing	747-300 Passenger	332	10.00	0.18453	612.63960	2.05850	6834.22000	0.34445	1143.57400	0.04429	147.04280
Boeing	747-400 Passenger	31137	10.00	0.18453	57457.10610	2.05850	640955.14500	0.34445	107251.39650	0.04429	13790.57730
Boeing	747 Passenger	529	10.00	1.50479	7960.33910	6.64614	35158.08060	0.37620	1990.09800	0.06772	358.23880
Boeing	747-200 Mixed Configuration	942	10.00	1.59531	15027.82020	6.50782	61303.66440	0.37825	3563.11500	0.06708	631.89360
Boeing	747-300 Mixed Configuration	26	10.00	0.18453	47.97780	2.05850	535.21000	0.34445	89.55700	0.04429	11.51540
Boeing	747-300 Mixed Configuration	6741	10.00	0.18453	12439.16730	2.05850	138763.48500	0.34445	23219.37450	0.04429	2985.58890
Boeing	747 Freighter	6386	10.00	3.01274	192393.57640	6.25724	399587.34640	0.35921	22939.15060	0.06257	3995.72020
Boeing	747SP Passenger	2	10.00	2.78655	55.73100	6.31557	126.31140	0.36176	7.23520	0.06334	1.26680
Boeing	747 Mixed Configuration	24	10.00	1.50479	361.14960	6.64614	1595.07360	0.37620	90.28800	0.06772	16.25280
Boeing	747SR Passenger	2	10.00	2.78655	55.73100	6.31557	126.31140	0.36176	7.23520	0.06334	1.26680
Boeing	747-100/200/747SR Freighter	3916	10.00	3.01274	117978.89840	6.25724	245033.51840	0.35921	14066.66360	0.06257	2450.24120
Boeing	747-400 Frieghter	2399	10.00	0.18453	4426.87470	2.05850	49383.41500	0.34445	8263.35550	0.04429	1062.51710
Boeing	757-200 Passenger	7120	10.00	0.08452	6017.82400	0.87255	62125.56000	0.16522	11763.66400	0.02035	1448.92000
Boeing	757 Passenger	558	10.00	0.08452	471.62160	0.87255	4868.82900	0.16522	921.92760	0.02035	113.55300
Boeing	757 Freighter	404	10.00	0.06118	247.16720	0.84192	3401.35680	0.20472	827.06880	0.02584	104.39360
Boeing	767-200 Passenger	707	10.00	0.23482	1660.17740	1.09225	7722.20750	0.16677	1179.06390	0.02444	172.79080
Boeing	767-300 Passenger	5714	10.00	0.49232	28131.16480	2.28142	130360.33880	0.20755	11859.40700	0.02957	1689.62980
Boeing	767 Passenger	1032	10.00	0.36357	3752.04240	1.68684	17408.13720	0.18716	1931.49120	0.02701	278.69160
Boeing	767 Freighter	260	10.00	0.49232	1280.03200	2.28142	5931.69200	0.20755	539.63000	0.02957	76.88200
Boeing	777-200	9305	10.00	0.49232	45810.37600	2.28142	212286.13100	0.27000	25123.50000	0.02957	2751.48850
Boeing	777-300	8067	10.00	0.49232	39715.45440	2.28142	184042.15140	0.27000	21780.90000	0.02957	2385.41190
Boeing	777	1894	10.00	0.49232	9324.54080	2.28142	43210.09480	0.27000	5113.80000	0.02957	560.05580
Airbus Industrie	a300	168	10.00	1.37569	2311.15920	3.49213	5866.77840	0.17461	293.34480	0.02857	47.99760
Airbus Industrie	a300-600 Passenger	12974	10.00	0.49232	63873.59680	2.28087	295920.07380	0.20755	26927.53700	0.02957	3836.41180
Airbus Industrie	a300 Freighter	566	10.00	1.37569	7786.40540	3.49213	19765.45580	0.17461	988.29260	0.02857	161.70620
Airbus Industrie	a300b4/c4/f40 freighter	39	10.00	1.37569	536.51910	3.49213	1361.93070	0.17461	68.09790	0.02857	11.14230
Beechcraft	(light Aircraft)	1	10.00	0.86751	8.67510	2.58118	25.81180	0.63716	6.37160	0.03496	0.34960
Canadair	Challenger	150	10.00	0.86751	1301.26500	2.58118	3871.77000	0.63716	955.74000	0.03496	52.44000
Cessna	Citation	18	10.00	0.86751	156.15180	2.58118	464.61240	0.63716	114.68880	0.03496	6.29280
Canadair	Regional Jet 100/200	22	10.00	0.86751	190.85220	2.58118	567.85960	0.63716	140.17520	0.03496	7.69120
McDonnell Douglas	DC-10 Passenger	318	10.00	1.44002	4579.26360	3.71663	11818.88340	0.30858	981.28440	0.03703	117.75540
McDonnell Douglas	DC-10-30/40 Passenger	758	10.00	0.53196	4032.18100	0.37997	2880.17260	22.03807	167048.57060	0.41036	3110.52880
McDonnell Douglas	DC-10 Freighter	20	10.00	1.44002	288.00400	3.71663	743.32600	0.30858	61.71600	0.03703	7.40600
McDonnell Douglas	DC-8-50 Passenger	6	10.00	8.00012	480.00720	7.00010	420.00600	1.78574	107.14440	0.03857	2.31420
McDonnell Douglas	DC-9-30 Passenger	36	10.00	0.30620	110.23200	1.05246	378.88560	0.09541	34.34760	0.01864	6.71040
Dassault	Falcon 50/900	110	10.00	0.86751	954.26100	2.58118	2839.29800	0.63716	700.87600	0.03496	38.45600
Grumman	4 Seater	17	10.00	0.86751	147.47670	2.58118	438.80060	0.63716	108.31720	0.03496	5.94320
Gulfstream Aerospace	G-1159 Gulfstream II/III/V	298	10.00	0.86751	2585.17980	2.58118	7691.91640	0.63716	1898.73680	0.03496	104.18080
British Aerospace	125	242	10.00	0.86751	2099.37420	2.58118	6246.45560	0.63716	1541.92720	0.03496	84.60320
Lockheed	L-1011-100/150 Tristar	235	10.00	6.05170	14221.49500	7.93100	18637.85000	0.25570	600.89500	0.00001	0.01293
Lockheed	L-382(L-100) Hercules	6	10.00	0.86751	52.05060	2.58118	154.87080	0.63716	38.22960	0.03496	2.09760
Learjet		28	10.00	0.86751	242.90280	2.58118	722.73040	0.63716	178.40480	0.03496	9.78880
McDonnell Douglas	MD-11 Passenger	2561	10.00	0.70235	17987.18350	3.24961	83222.51210	0.29556	7569.29160	0.04200	1075.62000
McDonnell Douglas	MD-11 Freighter	3179	10.00	0.70235	22327.70650	3.24961	103305.10190	0.29556	9395.85240	0.04200	1335.18000
McDonnell Douglas	MD-82	808	10.00	0.12050	973.64000	0.44440	3590.75200	0.00000	0.01212	0.01245	100.59600
McDonnell Douglas	MD-83	54	10.00	0.12050	65.07000	0.44440	239.97600	0.00000	0.00081	0.01245	6.72300
McDonnell Douglas	MD-90	2929	10.00	0.12050	3529.44500	0.44440	13016.47600	0.00000	0.04394	0.01245	364.66050
Pilats	PC-6 Turbo Porter	10	10.00	0.86751	86.75100	2.58118	258.11800	0.63716	63.71600	0.03496	3.49600
Other (Private)		52	10.00	0.86751	451.10520	2.58118	1342.21360	0.63716	331.32320	0.03496	18.17920
		Total Emmisions for all aircraft (tons)			412.29717		1863.97897		355.02490		36.31140

Aircraft Make	Model	# of Movements Arrival	Approach	THCef lb/min	total lb per aircraft	COef lb/min	total lb per aircraft	NOXef lb/min	total lb per aircraft	SO2ef lb/min	total lb per aircraft
Fokker	100	4	5.00	0.05476	1.09520	0.23731	4.74620	0.34683	6.93660	0.03286	0.65720
Airbus Industrie	a310	298	5.00	0.03530	52.59700	0.45027	670.89634	1.44770	2157.07300	0.09000	134.10000
Airbus Industrie	a310 Freighter	7	5.00	0.03530	1.23550	0.45027	15.75931	1.44770	50.66950	0.09000	3.15000
Airbus Industrie	a310-200	66	5.00	0.02245	7.40850	0.21246	70.11180	1.79637	592.80210	0.09327	30.77910
Airbus Industrie	a310-300	356	5.00	0.02353	41.88340	0.17100	304.38000	1.74138	3099.65640	0.08472	150.80160
Airbus Industrie	a319	428	5.00	0.01188	25.42320	0.06112	130.78811	1.07145	2292.90300	0.08100	173.34000
Airbrus Industrie	a320	9261	5.00	0.01320	611.22600	0.06791	3144.41511	1.19050	55126.10250	0.09000	4167.45000
Airbus Industrie	a321	2051	5.00	0.01584	162.43920	0.08149	835.65862	1.42860	14650.29300	0.10800	1107.54000
Airbus Industrie	a330	11037	5.00	0.18000	9933.30000	0.17307	9550.64721	2.37360	130987.11600	0.09000	4966.65000
Airbus Industrie	a330-200	130	5.00	0.18000	117.00000	0.17307	112.49290	2.37360	1542.84000	0.09000	58.50000
Airbus Industrie	a330-300	1471	5.00	0.18000	1323.90000	0.17307	1272.90043	2.37360	17457.82800	0.09000	661.95000
Airbus Industrie	a340	6417	5.00	0.01450	465.23250	0.30653	9835.11131	2.04300	65549.65500	0.09000	2887.65000
Airbus Industrie	a340-200	26	5.00	0.01450	1.88500	0.30653	39.84929	2.04300	265.59000	0.09000	11.70000
Airbus Industrie	a340-300	1394	5.00	0.01450	101.06500	0.30653	2136.53501	2.04300	14239.71000	0.09000	627.30000
Boeing	727 Freighter	114	5.00	0.17967	102.41190	1.17252	668.33640	0.62656	357.13920	0.06138	34.98660
Boeing	737-200 Passenger	9	5.00	0.08260	3.71700	0.41891	18.85095	0.49328	22.19760	0.04394	1.97730
Boeing	737-300 Passenger	2783	5.00	0.00606	84.32490	0.28244	3930.15260	0.72271	10056.50965	0.04486	624.22690
Boeing	737-400 Passenger	459	5.00	0.00606	13.90770	0.28244	648.19980	0.72271	1658.61945	0.04486	102.95370
Boeing	737-500 Passenger	1137	5.00	0.00622	35.36070	0.27556	1566.55860	0.80890	4598.59650	0.04800	272.88000
Boeing	737 Passenger	261	5.00	0.00606	7.90830	0.28244	368.58420	0.72271	943.13655	0.04486	58.54230
Boeing	737-800 Passenger	2504	5.00	0.00697	87.25188	0.32481	4066.57112	0.83112	10405.57858	0.05159	645.89428
Boeing	747-100 Passenger	7	5.00	0.10800	3.78000	0.61201	21.42035	2.80805	98.28175	0.19440	6.80400
Boeing	747-200 Passenger	1321	5.00	0.11984	791.54320	0.67125	4433.60625	2.81585	18598.68925	0.19303	1274.96315
Boeing	747-300 Passenger	167	5.00	0.04695	39.20325	0.52170	435.61950	2.76502	2308.79170	0.14086	117.61810
Boeing	747-400 Passenger	15565	5.00	0.04695	3653.88375	0.52170	40601.30250	2.76502	215187.68150	0.14086	10962.42950
Boeing	747 Passenger	265	5.00	0.57132	756.99900	0.61201	810.91325	2.80805	3720.66625	0.19440	257.58000
Boeing	747-200 Mixed Configuration	471	5.00	0.11984	282.22320	0.67125	1580.79375	2.81585	6631.32675	0.19303	454.58565
Boeing	747-300 Mixed Configuration	13	5.00	0.04695	3.05175	0.52170	33.91050	2.76502	179.72630	0.14086	9.15590
Boeing	747-300 Mixed Configuration	3371	5.00	0.04695	791.34225	0.52170	8793.25350	2.76502	46604.41210	0.14086	2374.19530
Boeing	747 Freighter	3194	5.00	0.16500	2635.05000	0.95702	15283.60940	2.57404	41107.41880	0.17820	2845.85400
Boeing	747SP Passenger	1	5.00	0.15645	0.78225	0.90527	4.52635	2.60914	13.04570	0.18063	0.90315
Boeing	747 Mixed Configuration	12	5.00	0.57132	34.27920	0.61201	36.72060	2.80805	168.48300	0.19440	11.66400
Boeing	747SR Passenger	1	5.00	0.15645	0.78225	0.90527	4.52635	2.60914	13.04570	0.18063	0.90315
Boeing	747-100/200/747SR Freighter	1956	5.00	0.16500	1613.70000	0.95702	9359.65560	2.57404	25174.11120	0.17820	1742.79600
Boeing	747-400 Frieghter	1200	5.00	0.04695	281.70000	0.52170	3130.20000	2.76502	16590.12000	0.14086	845.16000
Boeing	757-200 Passenger	3560	5.00	0.02210	393.38000	0.24420	4346.76000	1.10835	19728.63000	0.05819	1035.78200
Boeing	757 Passenger	279	5.00	0.02210	30.82950	0.24420	340.65900	1.10835	1546.14825	0.05819	81.17505
Boeing	757 Freighter	202	5.00	0.01057	10.67570	0.25864	261.22640	1.19637	1208.33370	0.07857	79.35570
Boeing	767-200 Passenger	354	5.00	0.05663	100.23510	0.41024	726.12480	1.81210	3207.41700	0.09538	168.82260
Boeing	767-300 Passenger	2856	5.00	0.03630	518.36400	0.35027	5001.85560	1.65332	23609.40960	0.09800	1399.44000
Boeing	767 Passenger	517	5.00	0.04647	120.11203	0.38026	982.95918	1.73271	4479.05535	0.09669	249.94365
Boeing	767 Freighter	240	5.00	0.03630	43.56000	0.03630	43.56000	0.03630	43.56000	0.03630	43.56000
Boeing	777-200	4652	5.00	0.03630	844.33800	0.30600	7117.56000	2.04000	47450.40000	0.03630	844.33800
Boeing	777-300	4036	5.00	0.03630	732.53400	0.30600	6175.08000	2.04000	41167.20000	0.03630	732.53400
Boeing	777	947	5.00	0.03630	171.88050	0.30600	1448.91000	2.04000	9659.40000	0.03630	171.88050
Airbus Industrie	a300	84	5.00	0.16966	71.25720	1.15677	485.84340	1.29558	544.14360	0.08329	34.98180
Airbus Industrie	a300-600 Passenger	6487	5.00	0.03635	1179.01225	0.35078	11377.54930	1.65573	53703.60255	0.09814	3183.17090
Airbus Industrie	a300 Freighter	283	5.00	0.16966	240.06890	1.15677	1636.82955	1.29558	1833.24570	0.08329	117.85535
Airbus Industrie	a300b4/c4/f40 freighter	3	5.00	0.16966	2.54490	1.15677	17.35155	1.29558	19.43370	0.08329	1.24935
Beechcraft	(light Aircraft)	0	5.00	0.13458	0.00000	0.62016	0.00000	2.14484	0.00000	0.09046	0.00000
Canadair	Challenger	76	5.00	0.13458	51.14040	0.62016	235.66080	2.14484	815.03920	0.09046	34.37480
Cessna	Citation	10	5.00	0.13458	6.72900	0.62016	31.00800	2.14484	107.24200	0.09046	4.52300
Canadair	Regional Jet 100/200	11	5.00	0.13458	7.40190	0.62016	34.10880	2.14484	117.96620	0.09046	4.97530
McDonnell Douglas	DC-10 Passenger	159	5.00	0.13442	106.86390	1.24818	992.30310	2.18911	1740.34245	0.10369	82.43355
McDonnell Douglas	DC-10-30/40 Passenger	379	5.00	0.56644	1073.40380	0.47203	894.49685	33.04222	62615.00690	0.50979	966.05205
McDonnell Douglas	DC-10 Freighter	10	5.00	0.13442	6.72100	1.24818	62.40900	2.18911	109.45550	0.10369	5.18450
McDonnell Douglas	DC-8-50 Passenger	3	5.00	0.73229	10.98435	4.48526	67.27890	0.87875	13.18125	0.09886	1.48290
McDonnell Douglas	DC-9-30 Passenger	18	5.00	0.10558	9.50220	0.65285	58.75650	0.43434	39.09060	0.04159	3.74310
Dassault (Breguet Mystere)	Falcon 50/900	55	5.00	0.13458	37.00950	0.62016	170.54400	2.14484	589.83100	0.09046	24.87650
Grumman	4 Seater	9	5.00	0.13458	6.05610	0.62016	27.90720	2.14484	96.51780	0.09046	4.07070
Gulfstream Aerospace (Grumman)	G-1159 Gulfstream II/III/V	148	5.00	0.13458	99.58920	0.62016	458.91840	2.14484	1587.18160	0.09046	66.94040
British Aerospace (Hawker Siddeley)	125	121	5.00	0.13458	81.42090	0.62016	375.19680	2.14484	1297.62820	0.09046	54.72830
Lockheed	L-1011-100/150 Tristar	118	5.00	1.33380	786.94200	4.63100	2732.29000	1.84090	1086.13100	0.00004	0.02213
Lockheed	L-382(L-100) Hercules	3	5.00	0.13458	2.01870	0.62016	9.30240	2.14484	32.17260	0.09046	1.35690
Learjet		14	5.00	0.13458	9.42060	0.62016	43.41120	2.14484	150.13880	0.09046	6.33220
McDonnell Douglas	MD-11 Passenger	1281	5.00	0.05214	333.95670	0.50579	3239.58495	2.38818	15296.29290	0.14079	901.75995
McDonnell Douglas	MD-11 Freighter	1588	5.00	0.05214	413.99160	0.50579	4015.97260	2.38818	18962.14920	0.14079	1117.87260
McDonnell Douglas	MD-82	404	5.00	0.16240	328.04800	0.42167	851.76667	0.00001	0.02384	0.09259	187.03180
McDonnell Douglas	MD-83	27	5.00	0.16240	21.92400	0.42167	56.92500	0.00001	0.00159	0.09259	12.49965
McDonnell Douglas	MD-90	1464	5.00	0.16240	1188.76800	0.42167	3086.60000	0.00001	0.08638	0.09259	677.75880
Pilats	PC-6 Turbo Porter	5	5.00	0.13458	3.36450	0.62016	15.50400	2.14484	53.62100	0.09046	2.26150
Other (Private)		26	5.00	0.13458	17.49540	0.62016	80.62080	2.14484	278.82920	0.09046	11.75980
		Total Emmisions for all Aircraft (tons)			16.56522		90.71222		512.82233		24.97189

Appendix 8.8.4				Total Emissions During Climbout							
Aircraft Make	Model	# of Departure	Climbout	THCef lb/min	total lb per aircraft	COef lb/min	total lb per aircraft	NOXef lb/min	total lb per aircraft	SO2ef lb/min	total lb per aircraft
Fokker	100	5	2.86	0	0.71500	0	1.90676	3	40.04072	0	1.28700
Airbus Industrie	a310	298	2.86	0.04620	39.37534	0.25373	216.25156	9.55340	8142.17175	0.40000	340.91200
Airbus Industrie	a310 Freighter	7	2.86	0.04620	0.92492	0.25373	5.07973	9.55340	191.25907	0.40000	8.00800
Airbus Industrie	a310-200	67	2.86	0.05929	11.36115	0.24173	46.32030	15.59836	2988.95774	0.40000	76.64800
Airbus Industrie	a310-300	356	2.86	0.07556	76.93217	0.08028	81.73788	10.71963	10914.29848	0.40000	407.26400
Airbus Industrie	a319	428	2.86	0.02421	29.63498	0.12078	147.84438	6.81228	8338.77570	0.36000	440.66880
Airbrus Industrie	a320	9251	2.86	0.02690	711.71643	0.13420	3550.64481	7.56920	200264.83391	0.40000	10583.14400
Airbus Industrie	a321	2051	2.86	0.03228	189.34996	0.16104	944.63809	9.08304	53279.84101	0.48000	2815.61280
Airbus Industrie	a330	11033	2.86	0.23880	7535.18594	0.10193	3216.33795	22.26670	702611.91315	0.40000	12621.75200
Airbus Industrie	a330-200	130	2.86	0.23880	88.78584	0.10193	37.89757	22.26670	8278.75906	0.40000	148.72000
Airbus Industrie	a330-300	1470	2.86	0.23880	1003.96296	0.10193	428.53411	22.26670	93613.66014	0.40000	1681.68000
Airbus Industrie	a340	6419	2.86	0.00480	88.12003	0.48986	8993.01643	16.16720	296802.95445	0.40000	7343.33600
Airbus Industrie	a340-200	26	2.86	0.00480	0.35693	0.48986	36.42599	16.16720	1202.19299	0.40000	29.74400
Airbus Industrie	a340-300	1394	2.86	0.00480	19.13683	0.48986	1952.99344	16.16720	64456.03965	0.40000	1594.73600
Boeing	727 Freighter	114	2.86	0.15893	51.81754	0.63774	207.92875	4.36100	1421.86044	0.17408	56.75704
Boeing	737-200 Passenger	9	2.86	0.07644	1.96757	0.29301	7.54208	3.29808	84.89258	0.12467	3.20901
Boeing	737-300 Passenger	2784	2.86	0.01092	86.94766	0.20905	1664.50627	3.87906	30886.00669	0.12543	998.70376
Boeing	737-400 Passenger	459	2.86	0.01092	14.33512	0.20905	274.42830	3.87906	5092.19722	0.12543	164.65698
Boeing	737-500 Passenger	1137	2.86	0.01010	32.84338	0.22715	738.65091	4.49246	14608.67128	0.13629	443.19055
Boeing	737 Passenger	261	2.86	0.01092	8.15134	0.20905	156.04746	3.87906	2895.56313	0.12543	93.62848
Boeing	737-800 Passenger	2505	2.86	0.01256	89.96928	0.24041	1722.35145	4.46092	31959.36199	0.14424	1033.41087
Boeing	747-100 Passenger	7	2.86	0.21160	4.23623	0.21160	4.23623	27.08498	542.24130	0.57132	11.43783
Boeing	747-200 Passenger	1323	2.86	0.22722	859.75049	0.23841	902.09099	27.58135	104361.76050	0.56592	2141.31678
Boeing	747-300 Passenger	165	2.86	0.02682	12.65636	0.30646	144.61847	20.91591	9870.21793	0.41372	195.23447
Boeing	747-400 Passenger	15572	2.86	0.02682	1194.45337	0.30646	13648.47804	20.91591	931509.29449	0.41372	18425.40082
Boeing	747 Passenger	264	2.86	0.21160	159.76646	0.21160	159.76646	0.21160	159.76646	27.08498	20450.24330
Boeing	747-200 Mixed Configuration	471	2.86	0.22722	306.07897	0.23841	321.15257	27.58135	37153.73333	0.56592	762.32820
Boeing	747-300 Mixed Configuration	13	2.86	0.02682	0.99717	0.30646	11.39418	20.91591	777.65353	0.41372	15.38211
Boeing	747-300 Mixed Configuration	3370	2.86	0.02682	258.49652	0.30646	2953.72277	20.91591	201591.72376	0.41372	3987.51610
Boeing	747 Freighter	3192	2.86	0.28000	2556.15360	0.37334	3408.26566	32.10720	293110.48166	0.50401	4601.16777
Boeing	747SP Passenger	1	2.86	0.26974	0.77146	0.34908	0.99837	31.35387	89.67207	0.51411	1.47035
Boeing	747 Mixed Configuration	12	2.86	0.21160	7.26211	0.21160	7.26211	0.21160	7.26211	27.08498	929.55651
Boeing	747SR Passenger	1	2.86	0.26974	0.77146	0.34908	0.99837	31.35387	89.67207	0.51411	1.47035
Boeing	747-100/200/747SR Freighter	1960	2.86	0.28000	1569.56800	0.37334	2092.79470	32.10720	179980.12032	0.50401	2825.27846
Boeing	747-400 Frieghter	1199	2.86	0.02682	91.96953	0.30646	1050.89424	20.91591	71723.58362	0.41372	1418.70380
Boeing	757-200 Passenger	3560	2.86	0.01947	198.23575	0.13889	1414.12242	8.51834	86730.33054	0.18303	1863.53825
Boeing	757 Passenger	279	2.86	0.01947	15.53589	0.13889	110.82589	9.51834	7595.06422	0.18303	146.04696
Boeing	757 Freighter	202	2.86	0.00644	3.72052	0.40344	233.07536	13.42027	7753.15838	0.21342	123.29700
Boeing	767-200 Passenger	353	2.86	0.12990	131.14444	0.41876	422.77172	12.98862	13113.05098	0.25859	261.06729
Boeing	767-300 Passenger	2858	2.86	0.04404	359.97768	0.28628	2340.01837	12.62935	103230.79138	0.29729	2430.01279
Boeing	767 Passenger	515	2.86	0.08697	128.09811	0.35252	519.22671	12.80899	18866.35401	0.27794	409.37783
Boeing	767 Freighter	20	2.86	0.04404	2.51909	0.04404	2.51909	0.04404	2.51909	0.04404	2.51909
Boeing	777-200	4653	2.86	0.04404	586.06582	0.49000	6520.71420	16.60000	220905.82800	0.04404	586.06582
Boeing	777-300	4031	2.86	0.04404	507.72219	0.49000	5649.04340	16.60000	191375.75600	0.04404	507.72219
Boeing	777	947	2.86	0.04404	119.27882	0.49000	1327.12580	16.60000	44959.77200	0.04404	119.27882
Airbus Industrie	a300	84	2.86	0.31778	76.34347	0.22699	54.53208	11.89417	2857.45540	0.24515	58.89484
Airbus Industrie	a300-600 Passenger	6487	2.86	0.04406	817.43725	0.28642	5313.89870	12.59135	233605.05011	0.29743	5518.16525
Airbus Industrie	a300 Freighter	283	2.86	0.31778	257.20478	0.22699	183.72117	11.89417	9626.90331	0.24515	198.41951
Airbus Industrie	a300b4/c4/f40 freighter	36	2.86	0.31778	32.71863	0.22699	23.37089	11.89417	1224.62374	0.24515	25.24064
Beechcraft	(light Aircraft)	1	2.86	0.15378	0.43981	0.38392	1.09801	12.69262	36.30089	0.40000	1.14400
Canadair	Challenger	74	2.86	0.15378	32.54600	0.38392	81.25283	12.69262	2686.26610	0.40000	84.65600
Cessna	Citation	8	2.86	0.15378	3.51849	0.38392	8.78409	12.69262	290.40715	0.40000	9.15200
Canadair	Regional Jet 100/200	11	2.86	0.15378	4.83792	0.38392	12.07812	12.69262	399.30983	0.40000	12.58400
McDonnell Douglas	DC-10 Passenger	159	2.86	0.17036	77.46951	0.28393	129.11433	18.51245	8418.35151	0.30665	139.44602
McDonnell Douglas	DC-10-30/40 Passenger	379	2.86	1.93495	2097.36970	5.24120	5681.14633	0.29445	319.16613	0.04543	49.24339
McDonnell Douglas	DC-10 Freighter	10	2.86	0.17036	4.87230	0.28393	8.12040	18.51245	529.45607	0.30665	8.77019
McDonnell Douglas	DC-8-50 Passenger	3	2.86	0.98626	8.46211	1.38076	11.84692	4.88199	41.88747	0.26629	2.28477
McDonnell Douglas	DC-9-30 Passenger	18	2.86	0.09157	4.71402	0.38064	19.59535	3.01430	155.17616	0.11788	6.06846
Dassault (Breguet Mystere)	Falcon 50/900	55	2.86	0.15378	24.18959	0.38392	60.39062	12.69262	1996.54913	0.40000	62.92000
Grumman	4 Seater	8	2.86	0.15378	3.51849	0.38392	8.78409	12.69262	290.40715	0.40000	9.15200
Gulfstream Aerospace (Grumman)	G-1159 Gulfstream II/III/V	150	2.86	0.15378	65.97162	0.38392	164.70168	12.69262	5445.13398	0.40000	171.60000
British Aerospace (Hawker Siddeley)	125	121	2.86	0.15378	53.21711	0.38392	132.85936	12.69262	4392.40808	0.40000	138.42400
Lockheed	L-1011-100/150 Tristar	117	2.86	0.15320	51.26378	1.02850	344.15667	16.53470	5532.84131	0.00028	0.09480
Lockheed	L-382(L-100) Hercules	3	2.86	0.15378	1.31943	0.38392	3.29403	12.69262	108.90268	0.40000	3.43200
Learjet		14	2.86	0.15378	6.15735	0.38392	15.37216	12.69262	508.21250	0.40000	16.01600
McDonnell Douglas	MD-11 Passenger	1280	2.86	0.06556	240.00205	0.42612	1559.94010	19.68338	72056.91750	0.44251	1619.94061
McDonnell Douglas	MD-11 Freighter	1591	2.86	0.06556	298.31505	0.42612	1938.95679	19.68338	89564.49668	0.44251	2013.53555
McDonnell Douglas	MD-82	404	2.86	0.12270	141.77249	0.34980	404.17291	0.00009	0.10699	0.58716	678.42815
McDonnell Douglas	MD-83	27	2.86	0.12270	9.47489	0.34980	27.01156	0.00009	0.00715	0.58716	45.34050
McDonnell Douglas	MD-90	1465	2.86	0.12270	514.10073	0.34980	1465.62702	0.00009	0.38798	0.58716	2460.14168
Pilats	PC-6 Turbo Porter	5	2.86	0.15378	2.19905	0.38392	5.49006	12.69262	181.50447	0.40000	5.72000
Other (Private)		26	2.86	0.15378	11.43508	0.38392	28.54829	12.69262	943.82322	0.40000	29.74400
		Total Emmisions from all aircraft (tons)			11.99885		42.68253		2252.39306		58.23553

Aircraft Model	ID Number	Number of Movements Arrival	Departure	Total	comments on approximations
100	100	4	5	9	EPA
a310	310	298	298	596	EPD
a310 Freighter	31F*	7	7	14	EPD
a310-200	312	66	67	133	EPA
a310-300	313	356	356	712	EPA
a319	319	428	428	856	EPD 320 + 10%
a320	320	9261	9251	18512	EPD
a321	321	2051	2051	4102	EPD 320 + 20%
a330	330	11037	11033	22070	EPD
a330-200	332	130	130	260	EPD 330
a330-300	333	1471	1470	2941	EPD 330
a340	340	6417	6419	12836	EPD
a340-200	342	26	26	52	EPD340
a340-300	343	1394	1394	2788	EPD340
727 Freighter	72F	114	114	228	EPA
737-200 Passenger	732	9	9	18	EPA
737-300 Passenger	733	2783	2784	5567	EPA
737-400 Passenger	734	459	459	918	EPA747-300
737-500 Passenger	735	1137	1137	2274	EPD
737 Passenger	737	261	261	522	EPA 747-300
737-800 Passenger	738	2504	2505	5009	EPA373 + 15%
747-100 Passenger	741	7	7	14	EPA
747-200 Passenger	742	1321	1323	2644	EPA
747-300 Passenger	743	167	165	332	EPA
747-400 Passenger	744	15565	15572	31137	EPA
747 Passenger	747	265	264	529	EPA747-100
747-200 Mixed Configuration	74C	471	471	942	EPA 747-200
747-300 Mixed Configuration	74D	13	13	26	EPA 747-300
747-300 Mixed Configuration	74E	3371	3370	6741	EPA747-400
747 Freighter	74F	3194	3192	6386	EPA
747SP Passenger	74L	1	1	2	EPA
747 Mixed Configuration	74M	12	12	24	EPA pass
747SR Passenger	74R	1	1	2	EPA 747sr
747-100/200/747SR Freighter	74X	1956	1960	3916	EPA 747F
747-400 Frieghter	74Y	1200	1199	2399	EPA
757-200 Passenger	752	3560	3560	7120	EPA
757 Passenger	757	279	279	558	EPA 757-200
757 Freighter	75F	202	202	404	EPA757-200c
767-200 Passenger	762	354	353	707	EPA
767-300 Passenger	763	2856	2858	5714	EPA
767 Passenger	767	517	515	1032	EPA 767 avg
767 Freighter	76F	240	20	260	EPA 767-300
777-200	772	4652	4653	9305	EPA a340
777-300	773	4036	4031	8067	EPA a340
777	777	947	947	1894	EPA a340
a300	AB3	84	84	168	EPA a300-B4
a300-600 Passenger	AB6	6487	6487	12974	EPA
a300 Freighter	ABF	283	283	566	EPA a300-B4
a300b4/c4/f40 freighter	ABX	3	36	39	avg
(light Aircraft)	BEC	-	1	1	avg
Challenger	CCJ	76	74	150	avg
Citation	CNJ	10	8	18	avg
Regional Jet 100/200	CR1	11	11	22	avg
DC-10 Passenger	D10	159	159	318	avg
DC-10-30/40 Passenger	DIC	379	379	758	EPA DC10-30
DC-10 Freighter	D1F	10	10	20	E-A DC1* -ass
DC-8-50 Passenger	D85	3	3	6	EPA DC8-51
DC-9-30 Passenger	D93	18	18	36	avg
Falcon 50/900	DF3	55	55	110	avg
4 Seater	G4*	9	8	17	avg
G-1159 Gulfstream II/III/V	GRJ	148	150	298	avg
125	H25	121	121	242	avg
L-1011-100/150 Tristar	L10	118	117	235	EPD
L-382(L-100) Hercules	LOH	3	3	6	avg
	LRG	14	14	28	avg
MD-11 Passenger	M11	1281	1280	2561	EPA
MD-11 Freighter	M1F	1588	1591	3179	EPA MD11 pass
MD-82	M82	404	404	808	EPA MD-80
MD-83	M83	27	27	54	EPA MD-80
MD-90	M90	1464	1465	2929	EPA MD-80
PC-6 Turbo Porter	PL6	5	5	10	avg
Other		26	26	52	avg

Note on approximations: EPA: EPA data for that specific aircraft was a vailable

EPA## - ###: US EPA data from aircraft ### - ### was used because data was unavailable

EPD: EPD data was used for this aircraft, this data may however have been adjusted to make it more accura

AVG: This data was the result of an average of all emissions rates.

We feel this was acceptable do to the small amount number of LTO's for these aircraft

8.9 Health Data for Each 50 ug/m^3 Increase in a Pollutant

Relative risks (RR) and 95% confidence interval (95% CI) for 50 ug/m^3 increase in a pollutant for each category of hospital admission – 1995-97 (Basic Table F1)

		Respiratory disease (ICD9: 460-519)				
		Lag 0			Lag (0-n)*	
Pollutant	Age	RR (95% CI)	p-value	Lag :	RR (95% CI)	p-value
NO_2 (24-hr)	All	1.08 (1.06,1.10)	0.0000	0-0 :	1.08 (1.06,1.10)	0.0000
	<15	1.04 (1.01,1.07)	0.0055	0-3 :	1.08 (1.04,1.12)	0.0001
	15-64	1.06 (1.03,1.10)	0.0002	0-0 :	1.06 (1.03,1.10)	0.0002
	65-74	1.07 (1.03,1.10)	0.0002	0-1 :	1.09 (1.06,1.15)	0.0000
	75+	1.10 (1.07,1.14)	0.0000	0-0 :	1.10 (1.07,1.14)	0.0000
SO_2 (24-hr)	All	1.04 (1.02,1.07)	0.0024	0-0 :	1.04 (1.02,1.07)	0.0024
	<15	1.01 (0.96,1.05)	0.7884	0-1 :	0.99 (0.94,1.04)	0.6575
	15-64	1.04 (0.99,1.09)	0.0832	0-0 :	1.04 (0.99,1.09)	0.0832
	65-74	1.06 (1.01,1.11)	0.0239	0-0 :	1.06 (1.01,1.11)	0.0239
	75+	1.14 (1.09,1.19)	0.0000	0-0 :	1.14 (1.09,1.19)	0.0000
RSP (24-hr)	All	1.04 (1.02,1.06)	0.0000	0-3 :	1.06 (1.04,1.09)	0.0000
	<15	1.04 (1.01,1.07)	0.0019	0-3 :	1.09 (1.05,1.12)	0.0000

	15-64	1.03 (1.00,1.05)	0.0596	0-0 :	1.03 (1.00,1.05)	0.0596
	65-74	1.02 (0.99,1.05)	0.1248	0-1 :	1.05 (1.01,1.08)	0.0075
	75+	1.05 (1.03,1.08)	0.0001	0-0 :	1.05 (1.03,1.08)	0.0001
O_3 (8-hr)	All	1.03 (1.01,1.05)	0.0005	0-2 :	1.08 (1.06,1.11)	0.0000
	<15	1.03 (1.00,1.06)	0.0326	0-2 :	1.07 (1.03,1.10)	0.0001
	15-64	1.00 (0.97,1.03)	0.9632	0-2 :	1.04 (1.00,1.07)	0.0413
	65-74	1.04 (1.01,1.07)	0.0182	0-2 :	1.09 (1.05,1.14)	0.0000
	75+	1.00 (0.98,1.13)	0.7280	0-1 :	1.06 (1.06,1.10)	0.0010
FSP (24-hr)	All	1.05 (1.02,1.07)	0.0002	0-3 :	1.06 (1.03,1.10)	0.0001
	<15	1.02 (0.98,1.06)	0.3335	0-3 :	1.06 (1.01,1.11)	0.0215
	15-64	1.02 (0.98,1.06)	0.2963	0-0 :	1.02 (0.98,1.06)	0.2963
	65-74	1.04 (0.99,1.09)	0.1026	0-1 :	1.07 (1.01,1.12)	0.0125
	75+	1.08 (1.04,1.12)	0.0001	0-0 :	1.08 (1.04,1.12)	0.0001
			COPD (ICD9: 490-496 excluding 493)			
NO_2 (24-hr)	All	1.13 (1.09,1.16)	0.0000	0-1 :	1.14 (1.10,1.19)	0.0000
SO_2 (24-hr)	All	1.15 (1.10,1.20)	0.0000	0-0 :	1.15 (1.10,1.20)	0.0000
RSP (24-hr)	All	1.05 (1.02,1.08)	0.0002	0-0 :	1.05 (1.02,1.08)	0.0002

O_3 (8-hr)	All	1.01 (0.98,1.03)	0.6988	0-3 :	1.08 (1.04,1.12)	0.0001
FSP (24-hr)	All	1.06 (1.02,1.10)	0.0049	0-0 :	1.06 (1.02,1.10)	0.0049
			Asthma (ICD9 493)			
NO_2 (24-hr)	All	1.12 (1.07,1.17)	0.0000	0-3 :	1.22 (1.14,1.30)	0.0000
	<15	1.11 (1.04,1.19)	0.0014	0-3 :	1.33 (1.22,1.46)	0.0000
	15-64	1.12 (1.04,1.20)	0.0031	0-0 :	1.12 (1.04,1.20)	0.0031
SO_2 (24-hr)	All	1.04 (0.97,1.11)	0.2856	0-0 :	1.04 (0.97,1.11)	0.2856
	<15	0.96 (0.87,1.06)	0.3990	0-1 :	0.95 (0.84,1.06)	0.3547
	15-64	1.14 (1.03,1.27)	0.0116	0-0 :	1.14 (1.03,1.27)	0.0116
RSP(24-hr)	All	1.05 (1.01,1.09)	0.0108	0-3 :	1.17 (1.11,1.23)	0.0000
	<15	1.09 (1.04,1.15)	0.0011	0-3 :	1.29 (1.21,1.38)	0.0000
	15-64	0.98 (0.92,1.04)	0.5091	0-0 :	0.98 (0.92,1.04)	0.5091
O_3 (8-hr)	All	1.04 (1.00,1.09)	0.0584	0-2 :	1.17 (1.11,1.23)	0.0000
	<15	1.10 (1.04,1.17)	0.0009	0-2 :	1.24 (1.16,1.34)	0.0000
	15-64	0.98 (0.92,1.05)	0.5653	0-2 :	1.09 (1.01,1.18)	0.0356
FSP (24-hr)	All	1.00 (0.94,1.06)	0.9626	0-3 :	1.11 (1.03,1.20)	0.0066
	<15	1.03 (0.95,1.12)	0.4783	0-3 :	1.25 (1.13,1.38)	0.0000

	15-64	0.92 (0.84,1.01)	0.0804	0-0 :	0.92 (0.84,1.01)	0.0804
			Cardiac disease (ICD9: 390-429)			
NO_2 (24-hr)	All	1.06 (1.04,1.09)	0.0000	0-1 :	1.07 (1.04,1.10)	0.0000
	15-64	1.06 (1.02,1.09)	0.0029	0-0 :	1.06 (1.02,1.09)	0.0029
	65-74	1.05 (1.01,1.09)	0.0138	0-3 :	1.09 (1.03,1.15)	0.0018
	75+	1.08 (1.05,1.12)	0.0000	0-0 :	1.08 (1.05,1.12)	0.0000
SO_2 (24-hr)	All	1.07 (1.03,1.10)	0.0001	0-0 :	1.07 (1.03,1.10)	0.0001
	15-64	1.03 (0.98,1.09)	0.1775	0-2 :	1.06 (0.99,1.14)	0.0712
	65-74	1.04 (0.98,1.09)	0.1714	0-1 :	1.06 (1.00,1.13)	0.0685
	75+	1.09 (1.04,1.15)	0.0004	0-0 :	1.09 (1.04,1.15)	0.0004
RSP (24-hr)	All	1.02 (1.01,1.05)	0.0137	0-1 :	1.03 (1.01,1.05)	0.0071
	15-64	1.02 (0.99,1.05)	0.1590	0-3 :	1.03 (0.99,1.07)	0.1481
	65-74	1.02 (0.99,1.05)	0.2054	0-1 :	1.03 (1.00,1.07)	0.0767
	75+	1.04 (1.01,1.07)	0.0132	0-1 :	1.05 (1.01,1.08)	0.0000
O_3 (8-hr)	All	1.00 (0.98,1.02)	0.8749	0-5 :	1.04 (1.01,1.08)	0.0058
	15-64	1.01 (0.98,1.04)	0.4747	0-5 :	1.03 (0.98,1.08)	0.2297
	65	1.00	0.8842	0-5 :	1.08	0.0023

	74	(0.97,1.04)			(1.03,1.14)	
	75+	0.99 (0.96,1.03)	0.7021	0-3 :	1.07 (1.03,1.11)	0.0016
FSP (24-hr)	All	1.02 (0.99,1.05)	0.1452	0-3 :	1.05 (1.01,1.09)	0.0023
	15-64	1.01 (0.97,1.06)	0.6339	0-3 :	1.02 (0.96,1.08)	0.4812
	65-74	1.01 (0.96,1.06)	0.6678	0-3 :	1.03 (1.07,1.10)	0.2732
	75+	1.05 (1.00,1.10)	0.0309	0-3 :	1.08 (1.03,1.14)	0.0044
			IHD (ICD9: 410-414)			
NO_2 (24-hr)	All	1.04 (1.00,1.07)	0.0552	0-0 :	1.04 (1.00,1.07)	0.0552
	15-64	0.99 (0.93,1.04)	0.6226	0-0 :	0.99 (0.93,1.04)	0.6226
	65-74	1.07 (1.01,1.13)	0.0273	0-3 :	1.11 (1.06,1.11)	0.0116
	75+	1.07 (1.01,1.14)	0.0222	0-0 :	1.07 (1.01,1.14)	0.0222
SO_2 (24-hr)	All	1.01 (0.96,1.06)	0.6082	0-1 :	1.02 (0.96,1.08)	0.5635
	15-64	0.96 (0.89,1.04)	0.3536	0-0 :	0.96 (0.89,1.04)	0.3536
	65-74	1.09 (1.07,1.12)	0.0000	0-1 :	1.04 (0.95,1.14)	0.3964
	75+	1.08 (1.05,1.10)	0.0000	0-3 :	0.93 (0.81,1.05)	0.2366
RSP (24-hr)	All	1.03 (1.00,1.06)	0.0982	0-0 :	1.03 (1.00,1.06)	0.0982
	15-64	0.99 (0.95,1.04)	0.7484	0-1 :	0.98 (0.93,1.03)	0.4713

	65-74	1.05 (1.00,1.09)	0.0593	0-1 :	1.07 (1.03,1.12)	0.0161
	75+	1.05 (1.00,1.10)	0.0478	0-0 :	1.05 (1.00,1.10)	0.0478
O_3 (8-hr)	All	1.00 (0.97,1.03)	0.9800	0-3 :	1.02 (0.98,1.07)	0.2944
	15-64	1.01 (0.96,1.06)	0.7614	0-1 :	1.01 (0.95,1.07)	0.7592
	65-74	1.01 (0.96,1.06)	0.8053	0-2 :	1.05 (0.99,1.12)	0.1246
	75+	0.99 (0.94,1.04)	0.7276	0-3 :	1.04 (0.97,1.11)	0.3225
FSP (24-hr)	All	0.99 (0.95,1.04)	0.6478	0-0 :	0.99 (0.95,1.04)	0.6478
	15-64	0.95 (0.89,1.02)	0.1785	0-0 :	0.95 (0.89,1.02)	0.1785
	65-74	1.00 (0.93,1.07)	0.9873	0-1 :	1.03 (0.95,1.11)	0.4381
	75+	1.04 (0.96,1.12)	0.3375	0-1 :	1.05 (0.97,1.14)	0.2437

* Note: 1) Lag 0-n denotes the cumulative effects of the mean pollutant concentration of lag from day 0 (same day) to day 1 up to day n

2) using up to Lag 0-5 for ozone and up to Lag 0-3 for other pollutants

8.10 Hong Kong Interview Notes

Interview With Moira Chan

She explained to us that there are a lot of problems with obtaining health information in China, because if there are any negative effects shown during the study, then the company involved will have to pay liability to its workers, therefore, it is more profitable for them to not allow any studies.

She also advised us to look at cardiovascular and respiratory diseases along with mortality rates as an indication of how air pollution was affecting the general population and that although not many studies had been done recently, the raw data was still somewhat available. She advised us to look at www.who.int/environmental_information/air/guidelines/chapter02.htm and see what articles we were interested in. If we were unable to obtain them ourselves, she would get them for us.

She also provided us with a very sound methodology for studying the effects of aircraft air pollution, however stated that it would be impossible to actually obtain these results. If we were to take a survey (preferably a diagnosis) of health for indoor and outdoor crews at the HKIA at both the beginning and ends of their shifts, we would be able to obtain a measurement of how much air pollution from the aircraft were affecting the people who worked there. We would also have to take in external factors such as smoking, as well, but given this data, we would be able to make some estimates and extrapolate more information.

Interview with Alexis Lau

He informed us that the API was determined at the HK UST, and that there were two main factors in determining the API: Wind and Sources. While the emission sources stay the same on a day-to-day basis, the winds change dramatically. Water and land temperatures also affect the winds around Hong Kong a great deal.

The API in China is extremely high (some parts around 200, 97% above 50), with Hong Kong being around 70. In Vancouver, the API is around 6, while in Worcester (although not measured) is probably around 20. Most pollution is particulate matter, not SO_2 or NOx.

Pollution in Hong Kong isn't necessarily ALL from Hong Kong, some of it comes from the PRD (Pearl River Delta), but very little of it comes from Northern China. The Nan Lang mountain range blocks a great deal of the pollution from coming south, thereby creating a separate air shed.

Also, severe weather patterns such as typhoons and northern cold fronts can transfer a lot of pollution to a different area. Northern cold fronts will occur 4-5 times a year, bring pollution from the north down to the south. A typhoon will push down the mixing height, terribly increasing the API in only a few hours.

The typical mixing height can range quite a bit:

Summer: 1500-2000 m day
~900 m night

Winter: ~300 m
Typhoon: 100-150 m

Another major problem is visibility, with hazy days being defined as visibility less than 8 km with humidity level less than 80%. In 1990, 4% of days were declared hazy; whiles in 2000, 10% of days were hazy. In 2001, 15% of the days were declared hazy. Macau experienced an even greater increase in hazy days, jumping from 3% in 1990 to 30% in 2000. Hazy days are created by particulate matter suspended in the air, which then attach themselves to water vapor forming clouds. These droplets are still to small to fall, however and stay suspended for quite a long time, resulting in less rainfall.

EPD Interview with Chris Fung and Lau Hin-chung

The HK EPD is ahead in the air quality monitoring system in the region. They have combined several different systems that monitor emissions, meteorological data, and chemistry, and transport systems to gain a more complete view of the pollution situation. Clients are typically the government organizations that want to know the future of Hong Kong.

Industry sources are reducing as textile mills move to the mainland because of cheaper building and labor costs. This pollution is blowing back into the mainland during the winter because the winds blow from north to south, and in the summer, the winds blow the opposite.

Air pollution can react in many different ways than you would initially think. When all NO_X emissions are removed, O_3 levels will increase because of the lack of chemical bonding that takes place.

There is also a lot of information that will be useful for our methodology. They gave us a spreadsheet that will help us calculate the emissions data from the aircraft given all the specifics, such as plane information, engine types (one of the most important characteristics), and number of flights. They were also interested in performing some simulations for us concerning the airport emissions and the effect that it would have on Hong Kong, but were unable to do so at this time because of the classified nature of the data.

Interview with the Hong Kong Observatory

- Hong Kong has a predominant Easterly wind, while in the winter there is a cold northerly breeze. The summer brings warm air from the South.
- There is a cyclonic vortex effect caused by the sea breezes and the warming of the land masses that traps the air over Hong Kong island.
- Also provided us with information concerning the mixing heights of the Hong Kong area.

Interview with the Civil Aviation Department

Received:

- Jet fuel specifications from the AFSC (Air Fuel Supply Company)
- Summary times for runway occupancy at the HKIA
- Aircraft statistics including movements and passengers

- Table of aircraft registered in Hong Kong

Also learned that there is no fuel recovery system in place because jet fuel is very stable and rarely evaporates

Interview with Cathay Pacific

Learned more about the airports practices concerning:
- Derated takeoffs – Because the runway is so long, derated takeoffs are very common
- Reduced energy taxiing – Because it can cause problems for the engines, it is not done
  - Engines need a proper amount of cooling time
  - Little fuel is used during the taxi time
- Reduced reverse thrust is used:
  - When carbon breaks are are used, only idle engine power is used for reverse thrust
  - Cannot use reverse thrust when the plane is moving too slowly
  - Open reverse for only 10-15 seconds after landing
- Pilots use the APU until the aircraft is parked because the ground power quality is poor

Interview with the Hong Kong Airport Authority

Fixed Ground Power is provided by the airport but the airlines choose not to use it because their turnaround time is fast.
Over the next few years, there will be a 4-5% increase in traffic until 2004 and then a 2% increase for the next 6 years.
Currently 96.5% of the aircraft come into the front gate.
Received:
- Flight Paths
- MP2020
- NAMP-EIA
- Number of movements per hour

8.11 Project Plan

Project	**Air Pollution In Hong Kong**
Starting Date	07-Jan
Completion Date	04-Mar
Present Date	11-Dec

Task Description	**Starting Date**	**Ending Date**	**No. of Days**
			1
Data Collection			
Setting up on site interviews	07-Jan	16-Jan	10
Interviews: Environmental Sci	09-Jan	23-Jan	15
Interviews: Health Care Officials	10-Jan	24-Jan	15
Interviews: Airport Officials	11-Jan	25-Jan	15
Observations of Pollution	07-Jan	03-Feb	28
Observations of Airport	07-Jan	03-Feb	28
Determine Usefulness of Proposal	07-Jan	15-Jan	9
Discuss and Write Project Particulars			
Data Analysis	23-Jan	05-Feb	14
Pattern Matching	25-Jan	07-Feb	14
Discuss Possible Trends	05-Feb	10-Feb	6
Propose Possible Solutions	07-Feb	13-Feb	7
Begin Writing	18-Jan	18-Jan	0
Draft 1	28-Jan	28-Jan	0
Refine Project	30-Jan	08-Feb	10
Draft 2	19-Feb	19-Feb	0
Project Presentation			
Determine Usefulnes of Previous Presentation	16-Feb	18-Feb	3
Design and Plan New Present.	18-Feb	20-Feb	3
Start Present. Slides	19-Feb	19-Feb	0
Refine Present	19-Feb	28-Feb	10
Practice Present	26-Feb	03-Mar	6
Give Final Presentation	04-Mar	04-Mar	0