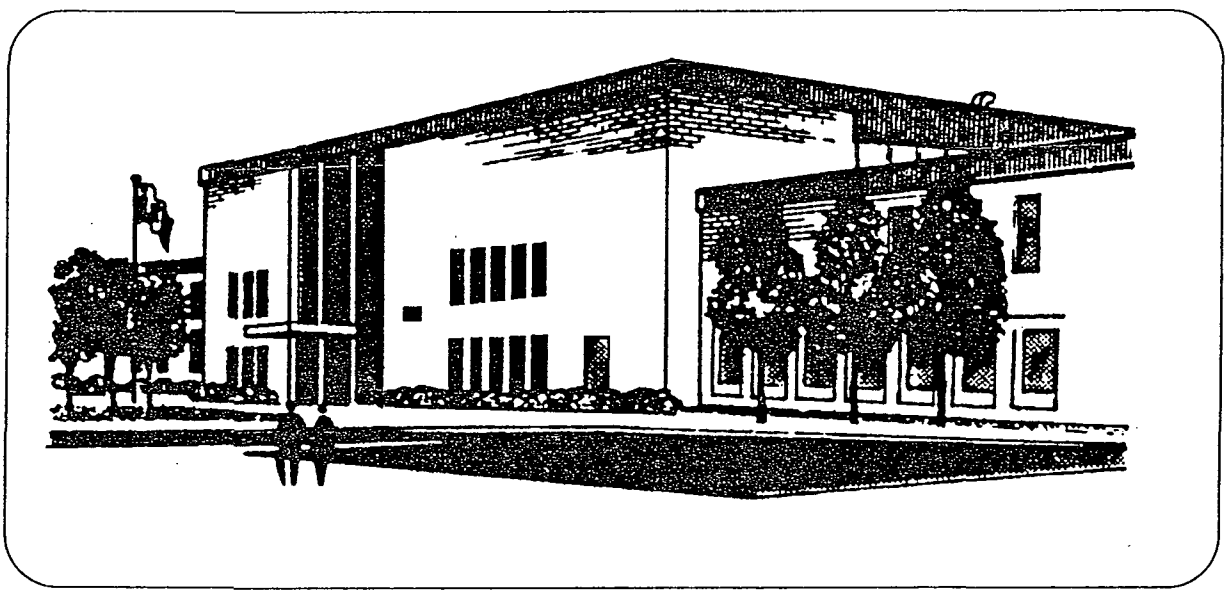
Study of Mobile Source Emissions: Macdonald-Cartier International Airport

Final Report



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EXECUTIVE SUMMARY

The Mobile Sources Emissions Division of Environment Canada and the Airports Group of Transport Canada collaborated on a study to evaluate exhaust emissions generated by airport mobile sources. The objective of this study was to determine the emissions contribution of the various forms of mobile sources operating at the airport to the air quality pollution burden. The field testing, conducted at the Macdonald-Cartier International airport in Ottawa, between September 1993 and December 1994, concentrated on passenger taxis, airport service vehicles and equipment, and aircraft engines. Testing was performed during the fall, winter, and summer seasons under different traffic conditions.

Testing indicated differences in the pollutant concentration levels detected between the varying test temperatures and traffic conditions. Continuous monitoring of CO at the passenger taxi loading area and the apron, indicated peak levels that exceeded the National Ambient Air Quality Objectives. Volatile organic compound concentrations, detected at the ambient air test sites, were highest at the passenger taxi loading area and the apron.

Engine exhaust stream measurements were collected during simulated operational cycles for the service vehicles and aircraft. The resulting data indicated emission level differences between service vehicles and equipment and aircraft engine configurations. Differences in emission levels provided the preliminary information that could be used for predicting apron air quality when the operational activities of the engines and the climatic conditions are known.

Suggestions were made in order to reduce the emissions contribution at the Macdonald-Cartier International airport. The recommendations included changes to the type of fuel used in service vehicles, idle time for these vehicles and regular inspection and maintenance of passenger taxis.

This study was based on a joint project involving the Mobile Sources Emissions Division of Environment Canada and the Airports Group of Transport Canada. The above mentioned parties would like to express their gratitude to the management and staff of the following, without whom this project would not have been possible:

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1.0 BACKGROUND

Concern for the contribution from aircraft to local, regional and global inventories of air contaminants first developed in the late 1950's. Since then numerous studies have investigated the impact of airport operations on the air quality in the areas surrounding these facilities. [1,2,3,4,5,6,7]

The stimulus for the earlier studies was the public concern regarding the visible exhaust plumes from the engines and the increased levels of noxious odours at airports. These concerns lead to various investigations into the composition and quantity of aircraft emissions. This early work recommended that a reduction of particulates from jet aircraft was both required and feasible. Subsequent studies conducted in the 1970's, led to the conclusion that aircraft emissions were significant contributors to the regional air pollution burden, in comparison to other sources regulated by National Ambient Air Quality Standards.[4,8,9] At this time all mobile sources were being scrutinized to determine their relative contributions to air pollution. This scrutiny lead to the development of emission standards for a variety of sources. Over the past twenty years these standards have become increasingly stringent, particularly for on-road vehicles.

More recently, there has been renewed interest in identifying the contribution of non-road sources to the urban air pollution burden. The motive for this work has been the significant number of urban areas which continue to have excessive ambient air levels of ozone and nitrogen oxides. Ozone, as an ambient ground level pollutant, represents a significant health concern. This pollutant is formed through a complex series of photochemical reactions involving a class of non-methane hydrocarbons referred to as volatile organic compounds (VOCs), nitrogen oxides (NO_X) and actinic radiation in the lower atmosphere. The direct health effect of this pollution is reduced respiratory capacity, manifested through several processes such as reduced lung permeability and constricted tissue. Since only a small number of non-road engines have emission regulations, very few have adapted emission control technologies. Therefore these non-road engines have been identified as a potentially significant source of the ambient ozone levels.[10]

The Canadian government has initiated the development of a national Nitrogen Oxides and Volatile Organic Compound management plan. A key consideration of this activity has been to develop a database or emissions inventory which can be used to determine the relative contribution to ambient air levels of these pollutants. With respect to the contribution from aircraft or airports, they could be considered as a concentrated source in urban areas. The activity of the aircraft and the airport service equipment combine to form a single focused source of VOCs, NO_X, and a number of other pollutants which may be detrimental to human health.

The study reported herein represents a joint effort by the Airports Group of Transport Canada and the Mobile Sources Emissions Division of Environment Canada to develop an understanding of the emissions which are a result of normal airport activities.

2.0 OBJECTIVE

The purpose of this collaborative effort was to determine the impact of exhaust emissions from various mobile sources operating during normal daily airport activities on the surrounding air quality during varying climatic conditions. This was to be accomplished by conducting air quality sampling at specific points during various periods of the day. In addition, the study was to identify potential emission reduction opportunities. It should be emphasized that the objective of the study was to determine the cumulative effect of emissions from a variety of mobile sources and not to provide data for the purpose of developing regulations.

3.0 INTRODUCTION

3.1 Description of Pollutants and Their Effects

The combustion of fossil fuels results in the creation of a large number of chemical compounds that have a negative impact on the environment and many of these compounds are hazardous to human health. Ground level ozone (smog), global warming, air toxics, and acid rain are global environmental issues that are contributed to by the emissions from mobile sources. In the urban environment mobile sources have been identified as the major contributor to the formation of photochemical smog or ground level ozone.[1] The ozone is produced by a series of atmospheric reactions involving volatile organic compounds and nitrogen oxides each of which is found in the exhaust of motor vehicles. A general overview of the compounds identified in mobile source exhaust and their impacts on the environment is provided in the following paragraphs.

- Ground level ozone, commonly referred to as smog, is formed through a series of chemical reactions involving volatile organic compounds and oxides of nitrogen. The volatile organic compounds are also referred to as non-methane hydrocarbons since methane does not react to form smog and is therefore not included in the grouping. Several compounds within the VOC grouping can have a direct effect upon health and the environment such as the carbonyls (formaldehyde, acrolein, etc.) and the aromatics (benzene, toluene, xylene, etc.). Mobile sources are major contributors of both of these compounds in urban areas where smog is most prevalent. There are a number of health concerns related to the long term exposure to smog including respiratory disorders, eye and skin irritations, and other physiological problems.

- Global warming, or the Greenhouse effect is an increase in the temperature of the earth generated by trapping radiated solar heat within a layer of atmospheric gases. Twenty-one compounds which have been identified as having this effect are emitted by mobile sources. An increase in the global temperature has the potential for devastating geographical effects such as changes in wind patterns, rainfall distribution, and the melting of the polar ice caps.

- Acid rain, or acid deposition, is the formation of acidic precipitation or solids from SO_X and NO_X gases. These substances can be transported over long distances and

deposited on the soil or in bodies of water. The result of this acidic deposition is the elimination of aquatic life and the decline of forests and plant life. This form of pollution is also being investigated as a link to respiratory disorders. Mobile sources contribute to this environmental problem through the emissions of NO_x. In Canada, two thirds of NO_x is generated from internal combustion engines of transportation vehicles. [11]

- Air toxics are compounds that are suspected of causing a number of health problems including skin and eye irritations, organ and blood disorders, and cancer. Mobile sources emit a number of toxic compounds to the environment through a variety of processes, starting with the handling and transportation of the fuel to the final combustion of the fuel in the engine.

Known toxic compounds emitted by mobile sources include: benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, oxides of nitrogen, carbon monoxide, total suspended particulate matter (PM), polyaromatic hydrocarbons (PAHs), etc.

PAHs are polycyclic aromatic hydrocarbon structures which are emitted in both solid and vapour phases in the exhaust. To date more than one hundred PAH compounds have been identified in vehicle exhaust and ninety percent of the mass of the heavier PAHs, such as the highly toxic benzo(a)pyrenes, are found on particulate matter with a diameter of less than one micrometer. This material, because of its size, is easily respirable which results in deposition of this material in the pulmonary region of the lungs. Nitrated or oxygenated PAHs, which are formed from a chemical reaction between the NO_x and PAH in the exhaust, are also known to be toxic.

3.2 Pollutant Regulation, Inventories, Ambient Air Quality Objectives

In the following section pollutant regulations, emission inventories and the ambient air quality objectives are reviewed. Current policies and regulations are examined as they apply to the objectives of this study.

Pollutant Regulation

As the pollution burden began to take its toll on the environment and consequently on human health, public concern prompted governments and industry to investigate the nature of pollution and its sources. As a result, governments initiated programs to prohibit the release of harmful substances to the air, water, and soil. This process has been evolving and ongoing as the number of chemicals used or produced by modern society increases. Scientific research must be conducted to identify, quantify, and qualify the effects of these compounds on the environment. In addition, emissions of pollutants that have been determined to be detrimental must be controlled in a manner which is both technologically and economically feasible.

With respect to mobile sources, the knowledge of the toxicity of the exhaust emissions has been increasing for several decades. This eventually lead to the implementation of emission standards for on-road sources such as light duty cars and trucks, heavy duty truck and bus engines,

motorcycles and some non-road sources such as aircraft engines. The emissions of concern were total hydrocarbons, carbon monoxide, oxides of nitrogen and particulate mass. For on-road vehicles, exhaust emission standards were first introduced for new vehicles/engines in the early nineteen seventies and have continually evolved as the technology to further reduce the emissions was developed. Recently, consideration has been given to expand these limited regulated exhaust emissions to include specific hydrocarbons such as formaldehyde and other non-methane compounds.

Emission Inventories

In order to assess the significance of emissions generated by a specific source, these emissions must first be identified and quantified under a variety of operating conditions. A result of this process is the formation of emission factors, which are normally emission rates in terms of mass of pollutant per work conducted or energy consumed. The emission factors may then be combined with source activity information, such as fuel consumed, number of sources, etc., to estimate the relative contribution of the specific source to the inventory of ambient pollutants. The emission estimates determined through these models may then be compared to other sources and the National Ambient Air Quality Objectives (NAAQO).

In this study there are a number of sources of air contaminants within a concentrated area which are related by the primary activity of the region. Typically, the specific sources at an airport would be considered as separate entities in most inventory reviews using the following categories:

- service vehicles
- service equipment (industrial and utility)
- aircraft (landing, takeoff, inflight)

An Environment Canada report compared the contribution of a number of emission sources including aircraft.[12] From the classifications used in this study, it was not possible to segregate the airport service vehicle and aircraft emissions from the non-road and on-road fleet emissions derived from mobile sources in the airport vicinity. Therefore the emissions contribution from the airport as a source cannot be estimated from this data.

Another study, conducted by the US Environmental Protection Service considered airport service as an equipment category, which included aircraft and baggage towing tractors and airport service vehicles, but did not include the aircraft engine or refueling emissions.[10]

Both of these studies consider segments of the sources which contribute to airport emissions, but not as a cumulative source.

The objective of this study was to combine the airport service vehicles/equipment and aircraft operations to estimate the localized emission levels on the airport site. These measurements may then be compared to ambient air quality objectives to determine the significance of the concentration levels. Similar work was conducted by the Los Angeles County Air Pollution

Control District. [5,6] Several studies of emissions and air quality of Canadian airports have been undertaken, including studies of the Vancouver International Airport and the Toronto Island Airport. [2,3]

Ambient Air Quality Objectives

Under the Canadian Environmental Protection Act, national ambient air quality objectives (NAAQO) were established in order to protect human health, vegetation, and materials. These objectives are listed in *Table 1.*[13]

The maximum tolerable level of an air pollutant was defined as the concentrations beyond which appropriate action is required to protect the health of the general population. The maximum acceptable level was intended to provide adequate protection against adverse effects on soil, water, vegetation, materials, animals, visibility, and personal well being. The maximum desirable level defines the long-term goals for air quality and provides a basis for the continuing development of pollution control technology.

TABLE 1. National Ambient Air Quality Objectives

Pollutant	Averaging Time	Maximum Desirable Level	Maximum Acceptable Level	Maximum Tolerable Level
Carbon Monoxide	8-hr 1-hr	5 ppm 13 ppm	9 ppm 31 ppm	17 ppm
Nitrogen Dioxide	annual 24-hr 1-hr	0.03 ppm	0.05 ppm 0.11 ppm 0.21 ppm	 0.16 ppm 0.53 ppm
Particulate Matter	annual 24-hr	60 $\mu g/m^3$	70 $\mu g/m^3$ 120 $\mu g/m^3$	 400 $\mu g/m^3$

In the absence of other guidelines, the NAAQO were used to determine the significance of the pollutants detected at the Macdonald-Cartier Airport.

3.3 Future Technological Developments

Current research in the areas discussed in the previous section has identified specific compounds that are harmful to both the environment and/or human health. To expand the knowledge base of chemicals and chemical sources which occur in the environment, government agencies are broadening their measurement studies to include a number of previously uncontrolled emission sources. These studies are incorporating varying degrees of emission characterization data which is used to confirm emission models, enhance the emission inventories, and provide background information for developing alternatives to current technologies. As an example of this last point, various airports in the US are presently replacing gasoline and diesel fueled aircraft service vehicles with natural gas powered units. One incentive for this action is the lower reactivity of the exhaust hydrocarbons from natural gas powered vehicles.

Transport Canada, the department responsible for environmental protection at airport facilities, has programs in place to determine the impact of normal operational activities on the air quality. This report discusses the project in which Transport Canada collaborated with Environment Canada to conduct a study to identify the exhaust emissions generated by airport mobile sources.

4.0 PROGRAM DESCRIPTION

This study examined the effect of emissions generated from airport mobile source operations on the ambient air, at various geographical locations, at the Macdonald-Cartier International Airport in Ottawa. The test sites were selected to best represent the contribution of mobile source activities, within the airport, to the degradation of ambient air quality. The areas of concern included the passenger taxi loading area, airside vehicular traffic and aircraft traffic. The airside mobile sources consisted of ground service and support vehicles and aircraft.

The sampling was conducted at each location under different traffic and weather conditions. Repeats at each location under the different conditions were conducted. This resulted in a multi-phased project in which pollutant concentrations, determined from the test locations, were compared based on these differing traffic and weather conditions.

The specific emissions measured were as follows: carbon monoxide (CO), carbon dioxide (CO_2), oxides of nitrogen (NO_x), hydrocarbons including volatile organic compounds (VOCs), carbonyls (aldehydes and ketones), polycyclic aromatic hydrocarbons (PAHs), and total suspended particulate matter (PM).

The testing plan was designed to conduct air quality sampling at a number of locations at the airport designated as points of high mobile source activity. In addition, airport mobile sources using these routes as part of the regular airport operation, were to have their exhaust streams sampled under simulated operational conditions. Following is a summary of the selected sites for air quality sampling of the mobile sources and the other airport activities that were evaluated.

A. Ambient Air Sites

- the passenger taxi loading area at the terminal
- the thresholds of runway 07/25 and 14/32
- the apron

B. Aircraft Refueling

C. Mobile Sources

- ground service and support vehicles
- aircraft and helicopters

Air quality sampling was performed during three test phases in order to determine the effect of varying ambient air temperatures and other weather conditions on exhaust emissions and pollutants at the airport site. Sampling was performed during three seasons. *Table 2* lists the sampling test dates.

TABLE 2. Airport Air Quality Field Sampling Test Dates

PHASE	SEASON	TEST DATES
I	Fall	October-December 1993
II	Winter	January-March 1994
III	Summer	July-August 1994

Testing of the ground service and support vehicles, aircraft and helicopters was repeated once. The initial testing was performed in the fall and repeated during the next fall and early winter season. It is recognized that the colder ambient air temperatures normally seen in the winter months will have an effect on engine startup and the emissions generated during startup.

5.0 SAMPLING AND ANALYTICAL TECHNIQUES

The sampling procedures employed for all sites and sources were similar and involved using common sampling techniques, sample media, and analytical methods. However, there were some modifications in the sampling procedures for the different sites due to the targeted source. These modifications are discussed in Section 6.0. The following sections describe the sampling train used for sample collection, the sample media, and the analytical procedures.

As the emission sources for this study were diverse, it was necessary to design and fabricate a system which could be readily modified for the various sources. In general, the process involved drawing the sample through a probe and either a Teflon™ line or a heated sample line, by vacuum pumps, to the sample media. The sample flow rates were maintained by mass flow controllers which were calibrated prior to each test run using a Gilibrator™. The high volume flow samplers were also calibrated using the Gilibrator although they were also equipped with internal flow controllers. The complete sampling train consisted of the following instrumentation:

- sample probe of varying dimensions and configurations
- Teflon tubing line
- heated line equipped with a temperature controller
- metal bellows sample pumps
- Gilian AirCon2™ High Volume Air Samplers
- Tylan mass flow controllers
- Gilian Gilibrator primary flow controller

The types of sample media and analytical methods varied slightly for sampling at each different site and between the phases. Prior to conducting the initial test phase, a pre-test sampling

procedure was undertaken to perform some development work and establish sampling and analysis methods. However, due to the magnitude and the varying test locations and test conditions, modifications were made to the test procedures and sampling systems between test phases. A summary of the sample media and analytical techniques that were used for this study are found in *Table 3*. A detailed description of these techniques is provided in the following sections.

TABLE 3. Sample Media and Analytical Methods

Compound	Sample Media	Analytical Method
Carbon Monoxide, Carbon Dioxide, Oxides of Nitrogen	Tedlar™ Bags, Summa Canisters	Fourier-Transform Infrared Spectrometer (FTIR)
Volatile Organic Compounds	Tedlar Bags, Summa Canisters	Gas Chromatography, FTIR
Aldehydes and Ketones	2,4-DNPH coated - Silica gel cartridges Tedlar Bags	High Performance Liquid Chromatography FTIR
Total Suspended Particulate Matter	47 mm Filters	Gravimetric Procedure
Polycyclic Aromatic Hydrocarbons	Polyurethane Foams	Gas Chromatography, Mass spectrometry

TM-registered trademarks

5.1 Carbon Monoxide, Carbon Dioxide, and Oxides of Nitrogen Analysis

Ambient air samples samples were collected in Tedlar bags and transported to the MSED laboratory for analysis by Fourier-Transform Infrared Spectroscopy. During transport, the bags were kept warm and out of direct sunlight to prevent decomposition of the sample. When the laboratory analysis could not be performed immediately the samples were transferred to 6L and 15L Summa canisters for storage, until analysis was possible.

Fourier-Transform Infrared Spectroscopy is a method of spectroscopy involving sample analysis by infrared radiation, modulating infrared frequencies and fourier transform computations. The features of this spectrometer allow for the measurement of gaseous species at concentration levels in the parts per million (ppm) range. The characteristics of the spectrometers used in this study are listed in Appendix A.

For samples that were considered to have high concentrations of exhaust components, an analysis bench consisting of specialized vehicle emission analyzers was used for the sample analysis. The test bench was equipped with CO and CO_2 analyzers using Non-Dispersive Infrared detectors, a NO_X instrument using a Chemiluminescence detector and a hydrocarbon analyzer using a Flame Ionization detector.

5.2 Volatile Organic Compound (VOC) Analysis

The determination of individual VOCs was accomplished using gas chromatography. A Hewlett Packard 5890 gas chromatograph using cryogenic concentration followed by high resolution GC-FID (Flame Ionization Detector) separation and detection was used for the detailed hydrocarbon speciation. The target compound list of VOCs selected for evaluation for this part of the study is listed below. These compounds were selected because either they are on the Environment Canada's Priorities Substances List, they have a high maximum ozone reactivity or are highly toxic. The specific details of the analysis can be found in Appendix A.

- 1,3-butadiene
- 2-methylbutane
- benzene
- toluene
- m & p-xylene
- o-xylene
- 1,2,4-trimethylbenzene

5.3 Carbonyl Analysis

Samples for carbonyl collection and analysis were directed through silica gel cartridges which had been pretreated with 2,4-dinitrilphenylhydrazine (DNPH) solution. These cartridges were coated with an acidic solution of DNPH in acetonitrile (ACN). The cartridges were dried and the excess ACN was removed by blowing nitrogen through the cartridges. The aldehydes and ketones in the air and exhaust samples were trapped as hydrazone derivatives of the DNPH solution on the cartridges. After sample collection, the cartridges were eluted with 5 ml of ACN and analyzed by High Performance Liquid Chromatography (HPLC). A Hewlett-Packard model 1090 Series II liquid chromatograph with a Hewlett Packard Pascal Series ChemStation was used to perform this analysis. The target species for the carbonyl analysis are listed:

- formaldehyde
- acetaldehyde
- acetone

5.4 Particulate Matter Analysis

Samples of the exhaust or ambient air were directed through 47 millimeter (mm) diameter filters (Teflon coated glass fiber), which were used to extract particulate mass from the sample stream. The filters were preconditioned in a dry chamber and their initial weight was measured. After sample collection the filters were placed in the dry chamber in order to stabilize. The filters were then re-weighed and the total particulate mass was calculated.

5.5 Polycyclic Aromatic Hydrocarbon Analysis

Pre-cleaned polyurethane foams (PUF) contained within glass lined aluminum canisters were used for the trapping of PAHs from the sample stream. Sample analysis was performed by the Chemistry Division of Environment Canada. The quantification of the individual PAH compounds was performed by gas chromatography and mass spectrometry. The detailed analysis methodology is contained in Appendix A, along with the list of individual PAH compounds..

6.0 DESCRIPTION OF TEST SITES AND TEST CONDITIONS

The Macdonald-Cartier International Airport in Ottawa is classed as a small international airport. The close proximity of the airport to the MSED test facility was considered ideal for a study of this nature. *Table 4* lists the types of mobile/exhaust sources which operate on the airfield on a daily basis.

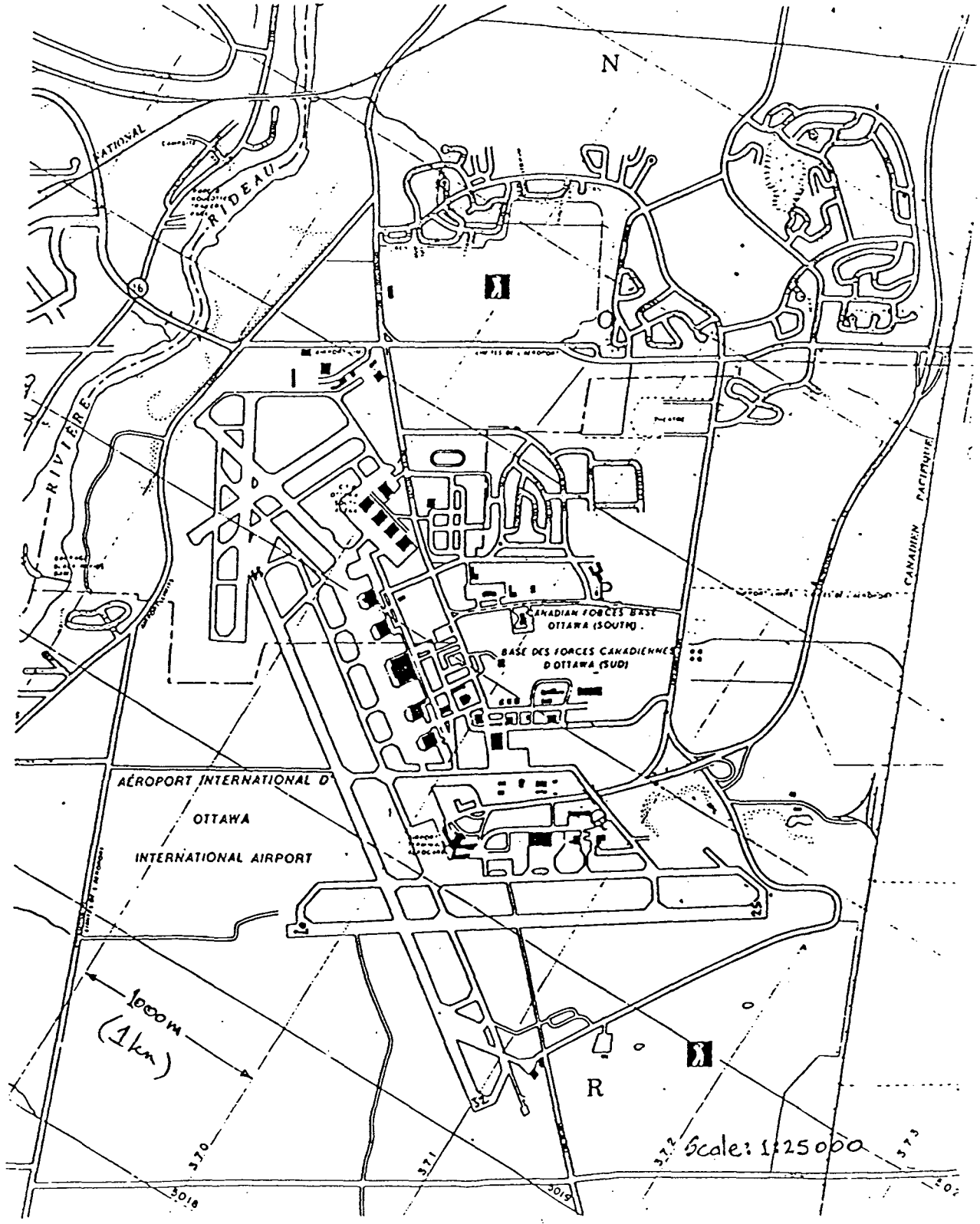
TABLE 4. Mobile/Exhaust Sources Operating at the Airport

General Sources	Specific Examples
Aircraft	Wide Body Jets
	Commuter Traffic
	Turbo-props
	Helicopters
Service Vehicles/Equipment	Heavy Diesels
	Ground Power Units
	Ramp Service Vehicles
Passenger Taxis	Gasoline, Propane, Natural Gas

Geographic Location

The Macdonald-Cartier Airport is located at the south end of the city of Ottawa. The area to the north and east of the airport consists of housing developments and light industry. To the west and south are satellite communities approximately eight kilometres from the airport with open land in between. The most common prevailing winds are the westerly winds, which result in runway 07/25 having the most aircraft activity. A layout of the airport is detailed in *Figure 1.* The absence of heavy industry and traffic in the vicinity of the airport was considered to be beneficial to the study as outside influences could be assumed to be minimal.

FIGURE 1. Macdonald-Cartier International Airport Layout



6.1 Ambient Air Sites

6.1.1 Passenger Taxi Loading Area

Site Description

The ground side location designated for passenger taxi loading is located at the east end of the terminal building. The area bounded by the terminal, the main entrance to the terminal building and the roadway is triangular in shape and covered by a roof which results in minimal air movement in relation to the area on the other side of the entrance route.

During regular airport operation there are taxis parked in this location waiting to pick up passengers. Depending upon the number of aircraft arrivals, the number of taxis in this area can range from four to ten. The fleet of taxis licensed to operate in this area consists of 128 vehicles of which approximately 50% are gasoline powered, 45% on propane and 5% natural gas.[14] The average vehicle is a medium to large size four-door sedan powered by a large displacement six cylinder engine. The weather conditions and the volume of passenger traffic dictates the length of time the taxi engines are left idling. In addition to the taxis, there are diesel powered airporters, similar to small buses, which park in the area and leave their engines idling.

Adding to the commercial traffic is a constant flow of traffic on the roadway beside the area. This traffic is comprised mainly of light duty, gasoline powered passenger vehicles.

Test Conditions

The terminal location for passenger taxi pickup is an area which becomes highly congested during peak hours of operation. Typically, elevated traffic levels occurred in the early morning, midday, and late afternoon. Traffic counts were taken on several dates (during Phase I) in order to establish the peak periods and the volume of traffic during these periods. *Table 5* lists the average of the traffic counts. Based upon these counts, the time period from 15:30hrs to 17:00hrs was designated as heavy conditions, 11:00hrs to 12:45hrs and 14:45hrs to 15:30hrs as moderate conditions, and the remaining time as light conditions.

During the summer season an overall decreased traffic flow was noted in the passenger taxi loading area. Differences between the heavy, moderate, and light traffic conditions were not apparent due to the decreased volume of traffic. Therefore, pollutant emissions are not presented with respect to the different traffic periods.

TABLE 5. Record of the Vehicle Traffic During Sampling at the Passenger Taxi Area-Phase I

	Traffic Condition	
	Heavy	Moderate
Time (minutes)	30	30
Total Number of Vehicles	378	125
Specific Vehicle:		
Taxis	115	39
Non-commercial vehicles	251	79
Trucks	6	4
OC Transpo Buses	2	3

The criteria for the sample selection period was based on similar weather conditions. *Table 6* provides a summary of the range of the weather conditions while sampling during the Phase I through III.

TABLE 6. Range of Weather Conditions During Sampling at the Passenger Taxi Area

Weather Condition	Phase I		Phase II		Phase III	
	High	Low	High	Low	High	Low
Temperature(°C)	19	17	-1	-5	21	18
Humidity (%)	77	68	73	50	94	57
Barometric Pressure (kpa)	100.8	100	101.2	99.6	101.3	101.1
Winds (km/hr)	S-SW @ 15	S-SW @ 7	W @ 18	W @ 15	S-SW @ 15	S @ 9

Sampling Methodology

To determine the impact of the vehicle exhaust on the air quality in this location, a sampling train was set up to collect samples over the duration of the designated sampling period. A multi-orificed probe was positioned at the five foot level in order to capture the average emissions being inhaled by the pedestrians in the area. The probe system consisted of a horizontal six foot long, 3/8 inch diameter, stainless steel tube, with four sampling ports machined into the tube. The probe was connected to a Teflon line or a heated line which was directed to sample pumps and filters located just prior to the sample media. On average, samples were collected for a 1-hr time period.

To quantify the impact of the taxi exhaust emissions on the air quality in this location, average and continuous CO measurements were collected during both heavy and light traffic volume periods. Carbon monoxide emissions are nearly entirely attributable to motor vehicle activity, since CO is produced as a product of the incomplete combustion of fossil fuels.

In Phase I and III, continuous CO measurements were monitored by drawing an air sample from the multi-orificed probe through a 3/8 inch Teflon tube to either a Non-Dispersive Infrared detector or the FTIR. Continuous analysis measurements are not available for Phase II passenger taxi loading area sampling.

During the continuous sampling of the taxi stand in Phase I, a hand-held CO monitor was used to indicated the CO levels in this area at a specific point in time. In an attempt to target or specify certain types of activities which may be contributing to the air quality in this area samples were collected when the CO levels were increased, as detected by the CO monitor. These point source samples were collected using the following procedure. When an increase in CO was noted on the monitror, the valve on a canister was opened and a sample of the air was collected. Two point source samples were collected during a heavy traffic period. The first near the curbside and the second at the stop sign at the entrance to the terminal.

6.1.2 Thresholds of Runway 07/25 and 14/32

Site Description

The Macdonald-Cartier Airport consists of four runways, two servicing large aircraft and two servicing small aircraft. Runways 14/32 and 07/25 are the major runways used for larger aircraft. These runways run north-south and east-west respectively. Runway 07/25 is the preferred runway because of the westerly prevailing winds and because the glide path bypasses most housing developments during takeoff and landing. The thresholds of these runways were selected as sampling sites so that emissions from the aircraft could be obtained during takeoff and landing.

As a function of the aircraft take off process, it is often necessary for aircraft to wait on a taxiway with their engines idling until given clearance, by the control tower, to proceed. The engines will remain in this mode until increasing power to move on to the runway and into position for full thrust and takeoff. The air quality was sampled in proximity to these aircraft during the holding pattern as this operation also contributes to the dispersion of exhaust emissions on the airport site.

Test Conditions

In order to evaluate the impact of the emissions from aircraft in the takeoff and landing modes on the air quality, the sampling was conducted during periods of varying volumes of aircraft traffic. The periods of highest aircraft traffic (determined during Phase I) during the average weekday were considered to be between 0700hrs and 0900hrs and between 1530hrs and 1730hrs. The hours in between the heavy traffic period were designated as light traffic conditions. *Table 7* differentiates between the traffic conditions at the threshold sampling site.

TABLE 7. Average Traffic Conditions During 2-hr Sampling at the Thresholds of Runway 07/25-Phase I

Traffic Condition	Heavy	Light
Number of Takeoffs	25	13
Number of Landings	23	3

Depending upon weather conditions, one runway, either 07/25 or 14/32 is selected as the 'in use' runway. Under certain circumstances, i.e. the aircraft being low on fuel or the aircraft coming from a specific direction, the pilots may request that the air traffic controllers allow the aircraft to land on the 'not in use' runway. During the Phase III sampling period, runway 07/25 was closed due to construction and the latter procedure was not an option. As a result all aircraft were rerouted to runway 14/32. The 'normal' peak hours of aircraft activity seen in Phase I and II were not apparent because there was an increased number of aircraft using one runway. The flow of traffic in Phase III was not comparable to the flow of traffic in Phase I and II when both runway 07/25 and 14/32 were operational. Therefore, the results, for Phase III, are not presented with respect to the different traffic periods.

Table 8 provides a summary of the weather conditions for each sampling period for all of the test Phases.

TABLE 8. Range of Weather Conditions During Sampling at the Thresholds of Runway 07/25 and 14/32

Weather Condition	Phase I		Phase II		Phase III	
	High	Low	High	Low	High	Low
Temperature(^{o}C)	18	5	-1	-17	29	20
Humidity (%)	100	34	97	73	89	86
Barometric Pressure (kpa)	103	101.9	103.7	99.6	101.6	101.1
Winds (km/hr)	W @ 9	NE @ 16	W @ 18	NE @ 5	SW @ 13	SW @ 9

Sampling Methodology

During Phase I, several samples were collected at different sites on the threshold in order to determine the optimum location for collection of a representative sample of the previously discussed operational activities. A site 400 feet parallel to the threshold lights was chosen as an optimum location for sample collection, as fallout could be collected from the aircraft and factors of dispersion could be taken into account. The air samples were collected through a probe, mounted on a steel plate, which stood twelve inches off the ground. The sample was directed through Teflon tubing to the sample media vacuum pumps which were maintained at a constant flow rate by mass flow controllers.

In Phase I, samples of emissions from specific aircraft were collected at the threshold lights at the centre line. The sample collection period included a specified time from aircraft taxiing/turning to the runway, powering up to full thrust and takeoff, until the aircraft was approximately 150

feet down the runway. This sample period was approximately 90 seconds in duration. A DC-9 and DASH-8 were the aircraft surveyed in this operating situation.

Also, in Phase I, air quality measurements were taken from the aircraft engine exhaust plumes as the aircraft were started prior to departing from the apron. It is normal practice for the larger passenger aircraft to conduct their final warm-up (inspections) and/or start up after being pushed back from the terminal by a service vehicle. The exhaust from the engines is directed away from the apron toward the runways. During this sampling period, the field sampling system was located directly behind the terminal on the grass covered space between the apron and the runways. Each time an aircraft was pushed back for start-up, the probe was located in the exhaust plume of one of the engines, a minimum of 25 feet from the exit nozzle. Samples were collected during the period of time that the engine was operated in this position.

For an evaluation of emissions during aircraft takeoff, the air quality was also sampled midrunway, during Phase II. The sample probe was placed at the 2500 foot mark of runway 07/25.

Continuous monitoring of the thresholds of the runways was performed during the fall season.

6.1.3 Apron

Description of the Area

The apron at the Ottawa Macdonald-Cartier Airport terminal consists of several gates which connect directly to the terminal departure area. These gates, or fingers, consist of loading bridges which protrude from the terminal building thus allowing passengers to board the aircraft without going outside. Air samples were collected at these gates while aircraft were being loaded and unloaded. This loading process could last up to one hour and includes numerous activities which involve mobile source activity such as, aircraft refueling, unloading and loading baggage, catering services, auxiliary power units and aircraft heaters, deicing equipment and towing trucks.

Test conditions

Samples were collected at light load and heavy load conditions. A record of vehicular traffic was kept during the sample periods. *Table 9* summarizes the average number of vehicles present during the sampling periods for Phase I. In the winter season the number of service vehicles on the apron increased due to an increased demand for certain services. Deicing trucks, glycol sweepers and glycol recovery trucks ,and snow blowing and snow ploughing trucks are some examples of service vehicles which are operating on the apron during the winter season and not during the summer season.

TABLE 9. Traffic Conditions During Sampling on the Apron-Phase I

Traffic Condition	Number of Vehicles in the Immediate Vicinity During Aircraft Loading	
	Lower Limit	Upper Limit
Heavy	3	15
Light	1	7

Table 10 presents the test weather conditions during all test Phases.

TABLE 10. Range of Weather Conditions During Sampling on the Apron

Weather Condition	Phase I		Phase II		Phase III	
	High	Low	High	Low	High	Low
Temperature(^{o}C)	-1	-11	-17	-22	24	20
Humidity (%)	64	87	97	32	86	63
Barometric Pressure (kpa)	103	102.1	103.7	103.3	101.6	101.1
Winds (km/hr)	E @ 34	SW @ 7	NW @ 28	NE @ 11	NW @ 24	SW @ 9

Sampling Methodology

A four foot stainless steel probe was placed near the nose of the aircraft, under the loading bridge during the loading and unloading procedure. This site was selected as it allowed for the measurement of pollutants on the apron, without interfering with normal apron activities. Vacuum pumps were used to draw air samples from the probe through Teflon lines to the sample media for the compounds of interest.

Continuous monitoring of selected compounds was performed on the apron during the winter and summer phases.

In the winter phase a heated sample line was used to direct the ambient air to the portable test bench analyzer. This transportable test bench was used to monitor HC, NO_X, CO and CO_2 using a Flame Ionizing Detector, a Chemiluminescence Detector, and Nondispersive Infrared Detectors, respectively.

The test bench was installed in a van so it could be transported to all of the test locations on and around the airfield. While housed in the van, the test bench was shielded from the weather conditions and maintained at a constant temperature. The individual instruments were calibrated before each test was initiated and on a regular basis during testing. The calibration included zeroing and spanning the instruments with calibration gases. The instrument output and calibrated response curves were used to calculate the gas concentrations. The emission levels were measured and recorded every three seconds.

Due to the cold ambient temperatures during testing, a heated sample line was used to transport the sample to the test bench via sample pumps. This procedure was undertaken to minimize condensation in the sample line.

The heated line was alternately quick connected to the test bench, or to a Tedlar bag for sample collection. The bag, filled with sample, was then brought back to the MSED for VOC analysis. As with Phase 1, sample pumps and high volume air samplers were used to collect carbonyl compounds with DNPH cartridges, and particulate matter with filters.

As with the testing on the threshold during Phase III, the effect of the closed runway during the summer had an impact on the air quality monitoring. There was an increased amount of traffic on the apron throughout the day. Therefore, for Phase III, the sample probe was placed downwind of the loading bridges adjacent to a garage door that enters into a covered service road, which in turn runs alongside a section of the terminal building. This service road is mainly used for service vehicles used to transfer passenger baggage and cargo between the aircraft and the terminal building. This site was chosen in order to monitor the emissions from the service vehicles traveling in and out of the garage, the emissions from vehicles servicing the aircraft during loading and unloading, and the emissions from the aircraft as the aircraft were pushed back and their engines were being started. During the summer, continuous monitoring was achieved with the FTIR.

6.2 Aircraft Refueling

Description

Air samples were collected while commercial passenger aircraft were being refueled. The refueling process is performed using a closed system designed to prevent the release of fuel vapors to the atmosphere. The sampling was accomplished with assistance of ESSO.

Test Conditions

Table 11 summarizes the test refueling conditions.

TABLE 11. Weather Conditions During Aircraft Refueling Sampling

Weather Condition	Phase I	Phase II
Temperature (°C)	3.7	-17
Humidity (%)	87	97
Barometric Pressure (kpa)	103	103.7
Winds (km/hr)	SW @ 6	NW @ 28

Sampling Methodology

On all test dates, the aircraft were loaded with jet fuel into the bottom-wing tank. During Phase I testing, the sample probe was placed three feet from the wing of the aircraft directly under the refueling nozzle. During Phase II, the sample probe was placed under the vent of the wing. The purpose of sample collection at these sites was to measure hydrocarbon emissions that may be vented or that may enter the atmosphere through spillage during the refueling procedure. Therefore, only VOCs were measured.

Due to the closed runway during Phase III, it was not possible to collect refueling samples. Increased traffic and congestion on the apron were a result of the closed runway. Sample collection might have interfered with the strict timing schedules of aircraft takeoff. Unfortunately, this occurred during the summer season when the ambient air temperatures are highest, and the potential for increased hydrocarbons escaping into the atmosphere was the highest.

6.3 Mobile Sources

6.3.1 Ground Support and Service Vehicles/Equipment

Test Fleet Description

For the exhaust stream measurements, fleet owners and operators of aircraft and service equipment were approached to request their assistance by providing and operating their vehicles for the measurement of emissions in the exhaust. With respect to service equipment, Hudson General, First Air and Transport Canada complied with the request. First Air and Transport Canada provided aircraft in support of the project.

The service vehicles/equipment were defined as those generating an exhaust stream on a regular basis on the airport property. The selected equipment included ground power units (GPU), auxiliary power units (APU), aircraft heating units, aircraft towing trucks, baggage trucks and deicing trucks.

Much of the mobile source equipment used to support the operation of the aircraft and airport is powered by diesel fueled engines. This form of engine is very fuel efficient when operated at an optimum constant speed, which is the case for stationary equipment such as aircraft heaters, APUs and GPUs. The majority of the time, the service equipment is running at high idle, between 1800 and 2600 rpm. The conveyors and loaders remain at idle until engaged when their engine speed becomes dependent on the load placed upon them. Under certain conditions, specific equipment such as aircraft heaters, fuel trucks and deicing trucks could operate 24 hours a day. The range of engines and configurations varied from the small displacement diesel engine in the Transport Canada Kubota tractor, used for moving helicopters, to a large eight cylinder Detroit Diesel in a Hudson General ground power unit. *Table 12* lists the vehicles tested, the fuel used and the type of engine powering the vehicle.

TABLE 12. Ground Service and Support Vehicles/Equipment Description

Company	Equipment	Fuel	Engine
Hudson General	Heater	Gasoline	Ford 300 in^3
	GPU #1	Diesel	Detroit 471N
	Deicing Truck	Gasoline	Ford 300 in^3
First Air	APU Hobart	Diesel	John Deer 6359TL
	Paymover Tow Truck	Diesel	Cummins 5.9L
Transport Canada	Clark Tow Truck	Diesel	--
	GPU #2	Diesel	--
	Tractor	Diesel	Kubota

Repeat testing of Transport Canada service vehicles was performed in the winter of 1994. This testing will be referred to as Phase IV. Clark Tow trucks and GPUs were tested in Phase IV.

Service Vehicle/Equipment Operating Conditions During Sampling

The test procedure consisted of operating each specific unit at the normal steady state speed for ten minutes. During this period the probe was located at the outlet of the exhaust pipe. At the completion of the sampling, the engine was again operated at the same speed while the intake air velocity and temperature were measured. When the engine was shutdown, the inlet nozzle configuration was measured and recorded. This information provided for the determination of the dry gas exhaust volume over the sampling period which was necessary to calculate mass emission rates of the various exhaust emissions. This procedure was performed with Transport Canada service vehicles only. The operating conditions during sampling of the service vehicles and equipment are shown in *Table 13*.

For the Hudson General and First Air vehicles, estimated dry gas volumes were used in this phase in order to determine mass emission rates. The sample operating conditions were unattainable due to time constraints during the testing.

TABLE 13. Service Vehicle/Equipment Operating Conditions During the Test Sampling Period

Company	Equipment	Air flow (fpm)	Temperature (°F)	Shape of Inlet Nozzle	Diameter of Inlet Nozzle (inches)	Power (rpm)
Transport Canada	Clark Tow Truck	4400	40	Circle	2 1/8	--
	GPU	75% (750) 25% (1500)	40	Square	2 X1 (40 slots)	--
	Tractor	1200	40	Circle	3	2500

Sampling Methodology

The exhaust emissions were to be collected from a high velocity, high volume, high temperature exhaust stream with a high concentration of water vapour. Therefore the sampling system incorporated the use of a 3/8 inch diameter stainless steel probe and heated sampling train. The exhaust flow was directed into the probe, which was connected to a heated double filter box before the heated sample line. The double 47 mm, in series, filter system was used to collect the diesel particulate for analysis and to prevent the contamination of the 25 foot heated sample line and the downstream sample media.

The sample probe was reconfigured for each vehicle's exhaust system to ensure that the sample was drawn in a direction which was slightly offset to the axial flow of the exhaust stream. The above procedures were necessary as raw exhaust, especially from diesel engines, contains large quantities of water vapor and particulate matter.

Due to the difficulties experienced during the initial testing of the service vehicles, the sampling procedure was modified to remedy these difficulties before the repeat testing of the service vehicle exhaust emissions in Phase IV. The purpose of the modifications was to dilute the exhaust air with a known constant volume of ambient air, so as to decrease the concentrations being measured, and to significantly reduce the condensation of water vapour in the exhaust stream. This would ensure concentration levels which could be measured by sensitive analytical instruments and prevent sample breakthrough.

The sampling system was a modified dilution tunnel similar to those used in the laboratory studies of engine and vehicle exhaust. A sample pump was used to draw the exhaust into the dilution tunnel. As with the initial testing the sample probe was reconfigured for each vehicle's exhaust system and the sample exhaust was drawn through a 25 foot heated sample line. A blower, placed at the opposite end of the tunnel, was used to draw ambient air into the sampling system.

The dilution tunnel was configured in such a way to achieve adequate mixing of the raw sample exhaust and the ambient air. Factors influencing adequate mixing include; the properties of the materials used to fabricate the tunnel, the length and diameter of the tunnel, the shape and size of the sample inlets and outlets, the temperatures of the samples and the velocity of air movement through the tunnel, etc.

Five sample ports were machined into the tunnel and sample was drawn from the ports to the sample media via sample pumps. The flow rates of the sample pumps were monitored before and after sampling. One port was used to direct sample to the FTIR, the others were used to collect VOC, carbonyl, particulate matter, and PAH samples.

The ambient air flow into the system and the flow of exhaust was monitored with mass flow sensors. The output of these sensors was connected to a data acquisition computer used to record the sensor's output at timed intervals. Temperatures at these two locations were also monitored.

A sample of the ambient air used to dilute the sample was collected during testing and the concentrations determined were subtracted from the sample concentrations in order to arrive at the raw exhaust sample concentrations.

Propane injections were performed prior to testing in order to validate the tunnel. The sample injection concentration, the ambient air concentration, and the final mixed sample concentration together with the flow rates were used to calculate a dilution rate. Finally, the exhaust sample concentration and the dilution rate were used to calculate the raw exhaust sample concentration.

6.3.2 Test Aircraft

Aircraft Test Fleet Description

To obtain operation emissions data from aircraft, a request was made of all the commercial operators to participate in this study. The request was made to allow for the sampling of the exhaust streams from the aircraft engines during ramp operations including engine startup, warm-up, idling, taxiing and takeoff. First Air and Transport Canada were the only two fleet operators willing to participate in this program. Due to the demands of the various schedules for the aircraft, it was difficult to coordinate periods of time for the exhaust emissions testing. However, with the support of First Air and Transport Canada's Aircraft Maintenance groups, emissions measurements were completed on three different propulsion engines as detailed in *Table 14.*

TABLE 14. Test Aircraft Engine Specifications

Aircraft	Classification	Engine Type	Engine Model	Engines/ Aircraft
Boeing 727	Medium Range Transport Jet	Turbofan	Pratt and Whitney JT8D	3
DeHavilland DASH-8	General Aviation Business Jet	Turboprop	Pratt and Whitney PW 120	2
Jet Ranger 206	Helicopter	Turboshaft	Allison C-20 Series	1

Aircraft Operating Conditions During Sampling

For each engine that was tested, the engine conditions during sampling were based upon the limitations of operating the engine while on the ground. The various test sequences that were conducted were based on the request for engine startup, a ten minute idle period, increases in power or thrust to normal cruise speed for a ten minute sample period and then full power. The last operational phase was used to simulate takeoff power and was conducted on only one occasion for a three minute period. For the engines that were tested, the operating conditions were recorded and are listed in *Table 15.*

The operating conditions were used to calculate mass emission rates of exhaust compounds. When the operating conditions were not available, estimates based upon similar engine tests conducted during previous sampling periods were used.

TABLE 15. Aircraft Engine Operating Conditions During Sampling

	Boeing 727				DeHavilland DASH-8		Jet Ranger	
	Start Up & Idle	N1	N2	Cruise	Idle	Cruise	Idle	Flight Idle
Power (%)	--	56.3	74.2	80	19	70	--	--
Exhaust Temperature (°C)	300	360	325	410	--	550	--	--
Fuel Flow (lbs/hr)	1100	1100	2600	5500	307	650	10 (gal/hr)	21 (gal/hr)

Sampling Methodology

A degree of development work was required for the sampling of the exhaust from aircraft engines. This was done to ensure that the probe system would withstand the force and the temperature of the turbine exhaust stream, while maintaining the desired sample flow rates at the appropriate probe location. To understand the effects of these parameters on the sampling system, trial runs were conducted on a mockup system with the assistance of First Air and an engine on an in-use Boeing 727. The sampling system design for this section of the work was based upon the results obtained from these trial runs. The setup and trial runs described below were based on information that was obtained during a literature search. [15,16,17]

The sampling train consisted of a single 18 inch, 3/8 inch diameter stainless steel probe directed into parallel flow of the exhaust through a 90 degree bend. The probe was connected to a three foot length of 3/8 inch stainless steel tubing which was attached to a 25 foot length of insulated and heated sample line. The initial test engine, a JT8D First Air 727 engine, was approximately 12 feet off the ground. The probe and heated line were held in place by a steel support structure weighted down to counteract the force of the exhaust stream. The sample was drawn through the line using a heated pump and filter system. Attached to the output of the pump was a CO analyzer and/or a quick connect for connections to other forms of sample media. In the initial runs, the CO monitor was the only instrument connected to the system as the data was only required to determine concentration levels in the exhaust stream and the integrity of the system.

The first trial run was conducted with the 727 engine operating at idle. The probe was located in the centre of the exhaust stream less than one exit nozzle diameter from the engine cowling. The probe location was then varied vertically by two inch increments to map the exhaust concentrations across the stream. A CO analysis monitor connected to the sample line was operated on a continuous basis for the emissions measurement. When the concentration points had been determined, a Tedlar sampling bag was connected to the exhaust of the sample pump for the collection of a VOC sample. This sample was for analysis verification purposes by the

organic chemistry laboratory at the MSED. At the conclusion of the ten minute VOC sampling period, the engine power was to be increased to between 70% and 75% thrust to simulate a cruise condition. However, prior to reaching cruise power the support stand was toppled by the force of the exhaust stream. The support stand and probe configuration were then modified to withstand the force of the exhaust stream and subsequent engine testing was conducted on another First Air 727 engine. This system verification testing was duplicated to ensure repeatability. Based upon this experience the sampling train was modified to have the capability and adaptability to be used for the measurement of exhaust emissions from a wide variety of aircraft configurations. Further testing used the sampling train connected to a FTIR which provided continuous monitoring of the emissions during the various cycles tested.

7.0 RESULTS

The field testing for this study was conducted in temperatures which reflect typical Canadian fall, winter, and summer weather conditions. During these periods, the MSED conducted measurements on the following:

- air quality in the location designated as the passenger taxi loading area
- air quality from the airside locations-the runway and the apron
- exhaust emissions from the service vehicles used on the apron
- exhaust stream measurements from three aircraft

When available, the field data was compared to known standards and/or previously measured values. The maximum concentrations of pollutants detected from the ambient air sites, during each traffic condition, are listed in tabular format. Due to the limited number of data collection periods at each traffic condition, statistical analysis was not undertaken.

7.1 Ambient Air Sites

7.1.1 Taxi Loading Area

Field measurements were conducted at heavy and light traffic periods for: CO, CO_2, NO_X, volatile organic compounds, carbonyls, and total suspended particulate matter. *Table 16* provides a summary of the data, for each traffic condition, as concentrations in parts per million (ppm) or micrograms per cubic meter ($\mu g/m^3$). These values represent the maximum pollutant concentration detected in the air in this specific location, during the sampling period. The average of the temperatures detected during each test Phase is also listed in *Table 16.*

During Phase I and II samples were collected during heavy, moderate, and light traffic periods. In condensing the data from all three test phases it was noted that the results from the moderate traffic condition data showed no significant difference from the heavy data. When possible the moderate data was compiled into the heavy traffic data and therefore results from a moderate traffic condition are not reported.

As explained in Section 6.1.1 the results for Phase III are not listed according to each traffic condition.

TABLE 16. Maximum Pollutant Concentrations at the Passenger Taxi Area

	Phase I		Phase II		Phase III
Average Temperature (°C)	**18**		**-3**		**20**
Traffic Condition	**Heavy**	**Light**	**Heavy**	**Light**	*
CO (ppm)	28	6	12	7	20
CO_2 (ppm)	402	348	353	329	362
NO_X (ppm)	*	*	*	*	*
Particulate Matter ($\mu g/m^3$)	540	460	188	67	39
1,3-butadiene($\mu g/m^3$)	10	4	24	16	*
2-methylbutane($\mu g/m^3$)	198	121	132	105	94
benzene($\mu g/m^3$)	55	34	98	99	36
toluene($\mu g/m^3$)	127	69	196	153	53
m & p-xylene($\mu g/m^3$)	93	28	96	100	41
o-xylene($\mu g/m^3$)	37	10	39	46	13
1,2,4-trimethylbenzene($\mu g/m^3$)	42	19	28	53	16
formaldehyde ($\mu g/m^3$)	77	5	46	33	10
acetaldehyde ($\mu g/m^3$)	131	2	12	10	3
acetone($\mu g/m^3$)	56	4	10	5	3

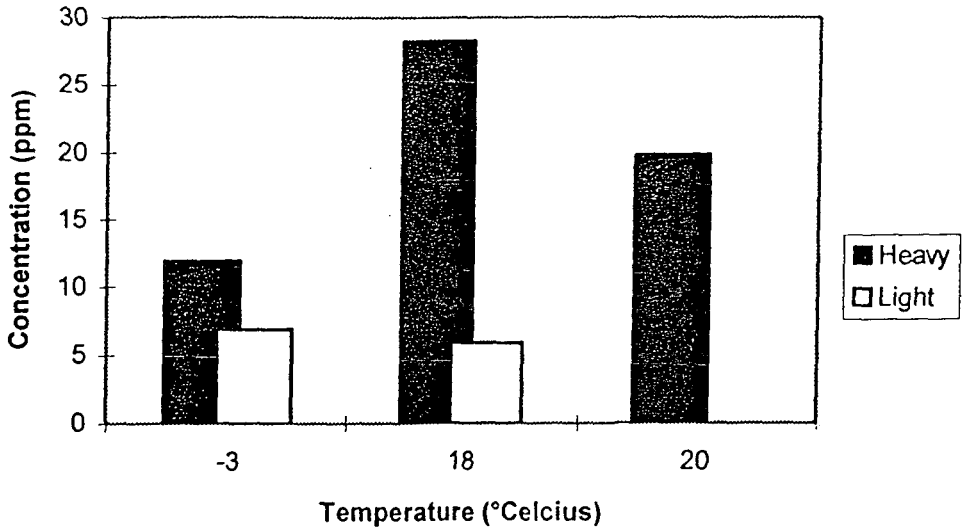
** not reportable*

Carbon Monoxide

The results indicate the CO levels measured at the passenger taxi loading area were below the NAAQO maximum acceptable level of 31 ppm for a 1-hr averaging time period. However, during the heavy traffic period in Phase I and Phase III concentrations were detected which exceeded the NAAQO maximum desirable level of 13 ppm for a 1-hr averaging time period.

Figure 2 illustrates the CO concentrations listed in the above table. These concentrations are displayed versus an increase in temperature. Heavy period CO concentration levels exceeded the light period levels for Phase I and II. The concentration detected in Phase III was comparable to the heavy traffic period concentrations noted in the other two Phases.

FIGURE 2. CO Concentrations (ppm) Detected at the Passenger Taxi Loading Area



Continuous monitoring of CO, performed at the passenger taxi loading, showed several peaks which exceeded the NAAQO. *Figures 3* and *4* illustrate the continuous monitoring results for CO collected at the passenger taxi loading area.

Figure 3 displays the CO levels detected during a heavy traffic period collected during the fall weather conditions. Over 20 peaks were detected which exceeded the NAAQO maximum acceptable level. *Figure* 4 displays the continuous monitoring of CO on two separate test dates during Phase III. Again, there were peaks which exceed the NAAQO value.

Though CO does not have an odour, it is a major product in the exhaust stream from internal combustion engines which has a pungent odour. During the periods of time that the sampling was being conducted in this location, this pungent odour was prevalent on a number of occasions, especially during the heavy traffic conditions.

Oxides of Nitrogen

The concentrations of NO_x were not reported because they were below the detection limits of the analytical instrument. A Nicolet REGA 740 spectrometer was used to analyze NO_x. The detection limit of the instrument for NO_x was 0.2 ppm.

FIGURE 3. Continuous Monitoring of CO (ppm) at the Taxi Stand During a Heavy Traffic Condition in the Fall Season- Phase I

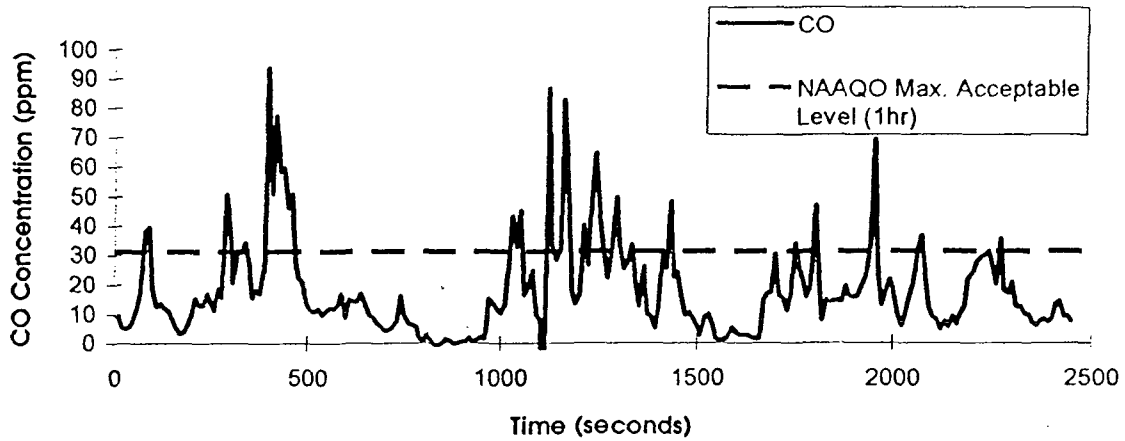
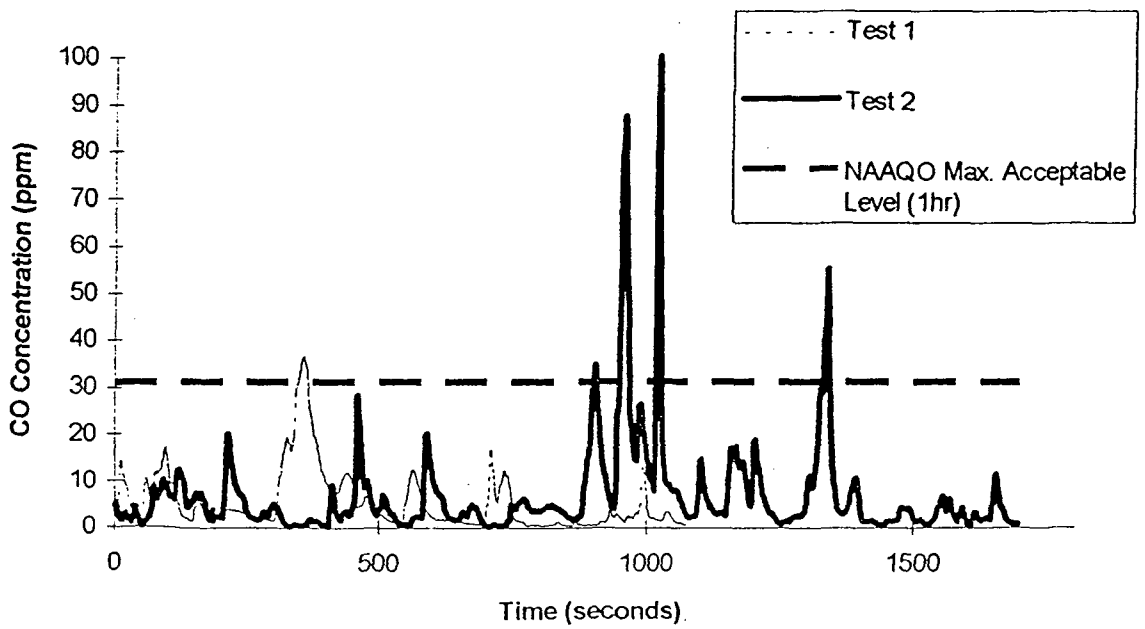


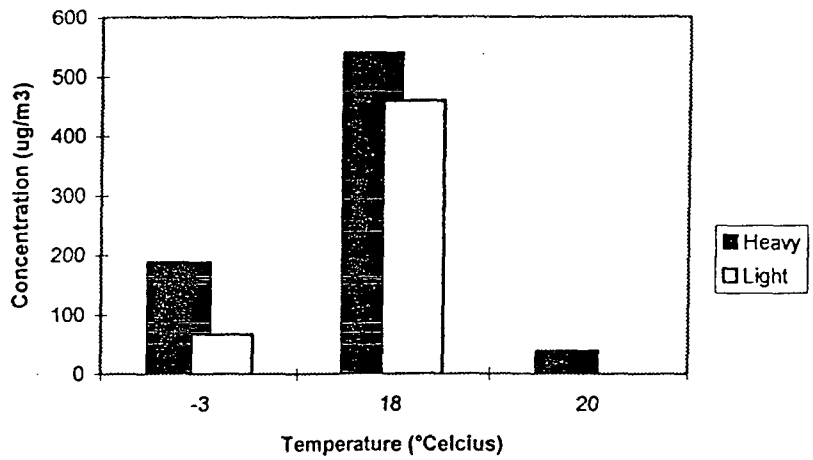
FIGURE 4. *Continuous Monitoring of CO (ppm) at the Taxi Stand During the Summer-Phase III*



Total Suspended Particulate Matter

The particulate matter collected was not measured over a 24-hr time period and therefore could not be compared to the NAAQO. *Figure 5* displays the results of the particulate matter sampling. The highest levels of particulate matter collected were detected in the fall season.

FIGURE 5. Total Suspended Particulate Matter (µg/m³) Detected at the Passenger Taxi Loading Area



Hydrocarbons

Figure 6 graphically illustrates the results of the VOC analysis listed in *Table 16.*

The highest concentrations of VOCs, with the exception of 2-methylbutane, were noted in the winter test phase. 2-methylbutane concentrations were highest in the fall season.

All volatile organic target compounds showed an increase in concentration with the increase in traffic condition during the fall season (Phase I). There was however, no correlation between VOC concentration and traffic condition in the winter season (Phase II).

The VOC concentrations detected during the summer (Phase III) and the light traffic condition in the fall (Phase I) are quite similar. A possible explanation for this is that the average temperature difference between these two Phases was only 2°C. Also, as previously discussed, the total volume of traffic at the passenger taxi loading area, during the summer, was decreased compared to the other test Phases and may have been similar to a light traffic condition in the fall (Phase I).

FIGURE 6. VOC Speciation at the Passenger Taxi Loading Area during all test Phases at Heavy and Light Traffic Conditions (μg/m³)

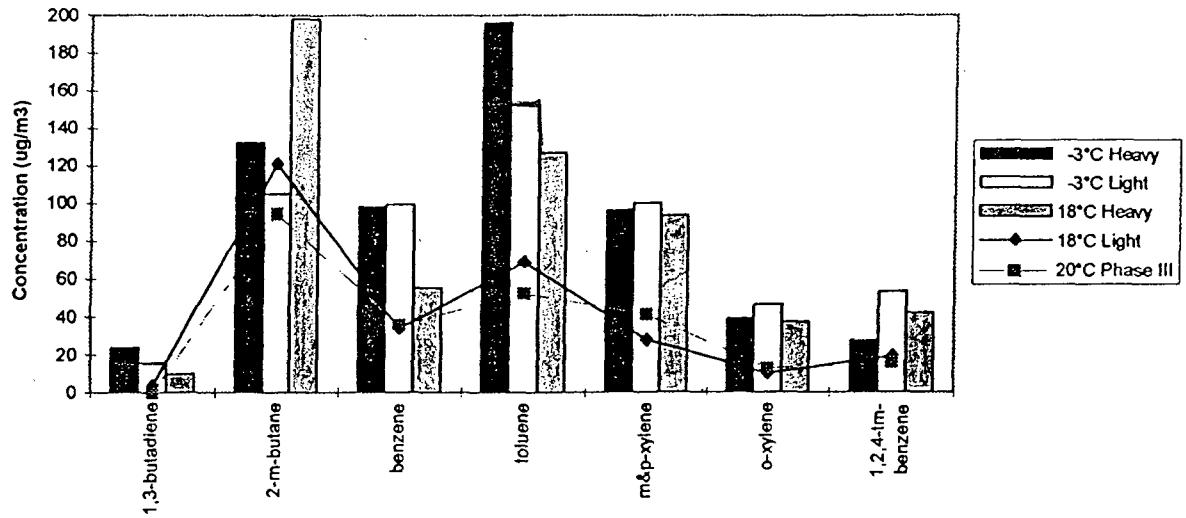
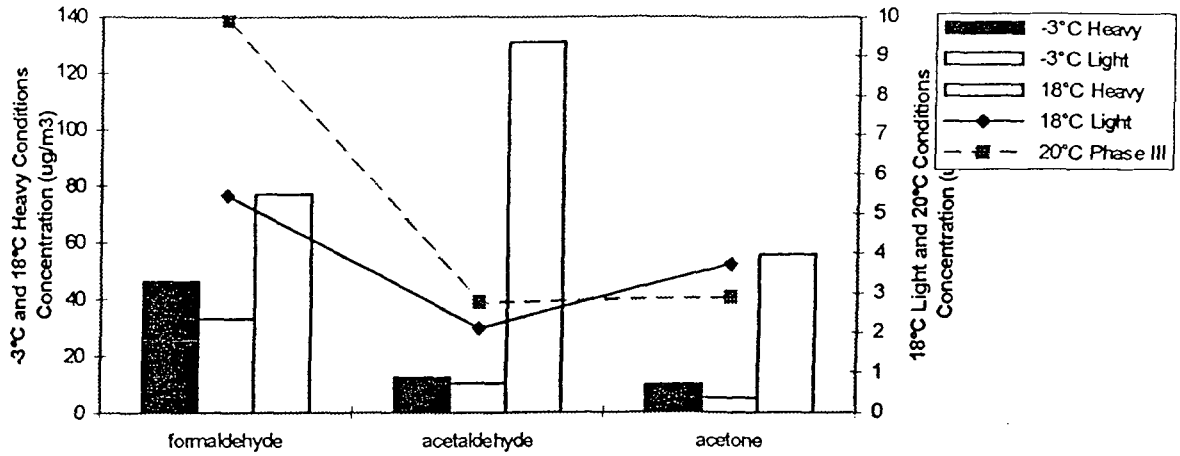


Figure 7 displays the concentrations of the target carbonyl compounds during all traffic conditions for all test Phases.

The highest levels of formaldehyde, acetaldehyde, and acetone were detected in the fall (Phase I) heavy traffic period. The levels noted in the heavy traffic winter conditions were on average four times higher than the carbonyl concentrations detected in the summer conditions.

The concentrations of acetaldehyde and acetone, as with the VOC concentrations, were similar during the fall light traffic period and the summer season (Phase III).

FIGURE 7. Target Carbonyl Concentrations (µg/m³) Detected at the Passenger Taxi Loading Area



Point Source Samples

The above concentration data represents the air quality exposure levels at the taxi stand location. Further investigation was used to isolate and quantify the sources of these emissions. As described in Section 6.1.1, one method used to accomplish this was point source sampling. *Table 17* represents the results of the point source sampling. CO, CO_2, NO_X, and VOCs were analyzed.

TABLE 17. Pollutant Concentrations Detected from Point Source Samples Collected at the Taxi Area

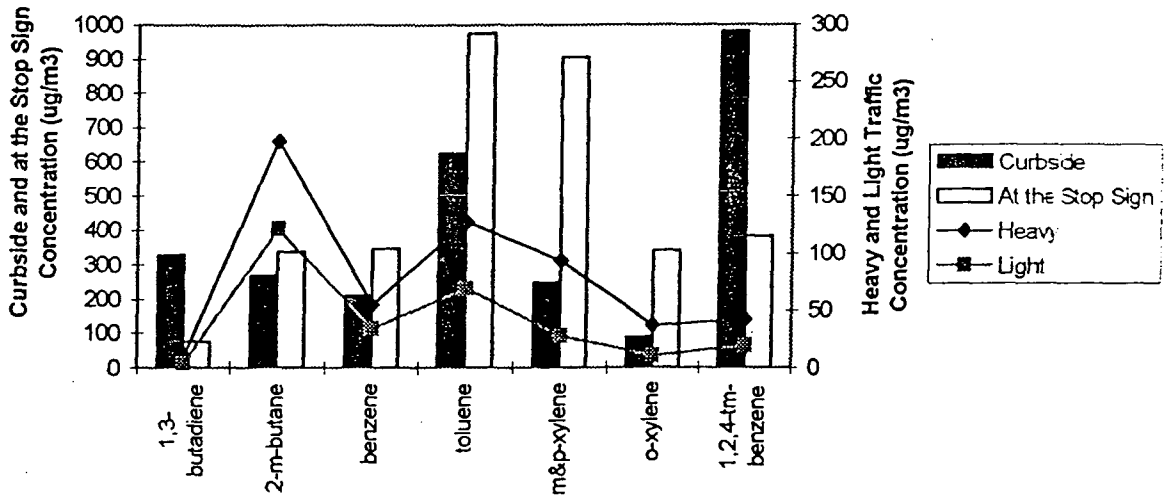
Probe Position	Curbside	At the Stop Sign
CO (ppm)	19	20
CO_2 (ppm)	614	642
NO_X (ppm)	*	*
1,3-butadiene(µg/m³)	328	75
2-methylbutane(µg/m³)	268	338
benzene(µg/m³)	209	347
toluene(µg/m³)	625	974
m & p-xylene(µg/m³)	247	905
o-xylene(µg/m³)	89	342
1,2,4-trimethylbenzene(µg/m³)	981	383

** not reportable*

As these samples were collected during Phase I, the results were compared to the timed Tedlar bag average results detected in Phase I. The CO is comparable to the heavy traffic conditions during Phase I. All VOC concentrations were significantly higher with the point source samples as illustrated in *Figure 8*.

It should be noted that these point source samples were not collected for 1-hour time period but were only collected while the concentration level on the CO monitor was increased.

FIGURE 8. VOC Speciation (µg/m³) of Point Source Samples Collected at the Passenger Taxi Loading Area



Overall, the testing at the passenger taxi loading area revealed CO concentrations which exceeded the NAAQO (at differing time periods). CO concentrations were highest in the fall season along with the particulate matter and carbonyl concentrations. Most of the target VOC concentrations were highest in the winter season. The point source samples revealed VOC concentrations significantly higher than the average bags although, the point source sample CO concentrations were similar to the heavy traffic period concentrations.

7.1.2 Thresholds of Runway 07 25 and 14/32

To determine the emissions present during takeoff and landing, air samples were collected at either threshold of runway 07/25 and 14/32. The maximum pollutant concentrations collected, under similar conditions at the thresholds during each traffic condition, are recorded in *Table 18.*

TABLE 18. Maximum Emission Concentrations Detected at the Thresholds of Runway 07/25 and 14/32

	Phase I		Phase II		Phase III
Average Temperature (°Celcius)	**12**		**-9**		**25**
Traffic Condition	**Heavy**	**Light**	**Heavy**	**Light**	
CO(ppm)	3	1	3	1	1
CO_2(ppm)	353	269	523	296	290
NO_X (ppm)	*	*	*	*	*
Particulate Mass (µg/m³)	**	**	790	133	58
1,3-butadiene(µg/m³)	6	3	1	*	2
2-methylbutane(µg/m³)	11	23	5	1	10
benzene(µg/m³)	6	6	4	5	3
toluene(µg/m³)	24	16	15	7	18
m&p-xylene(µg/m³)	25	22	11	5	8
o-xylene(µg/m³)	4	20	9	9	2
1,2,4-trimethylbenzene(µg/m³)	6	19	8	4	8
formaldehyde(µg/m³)	13	3	167	1	7
acetaldehyde(µg/m³)	17	4	113	2	6
acetone(µg/m³)	2	0	52	*	10

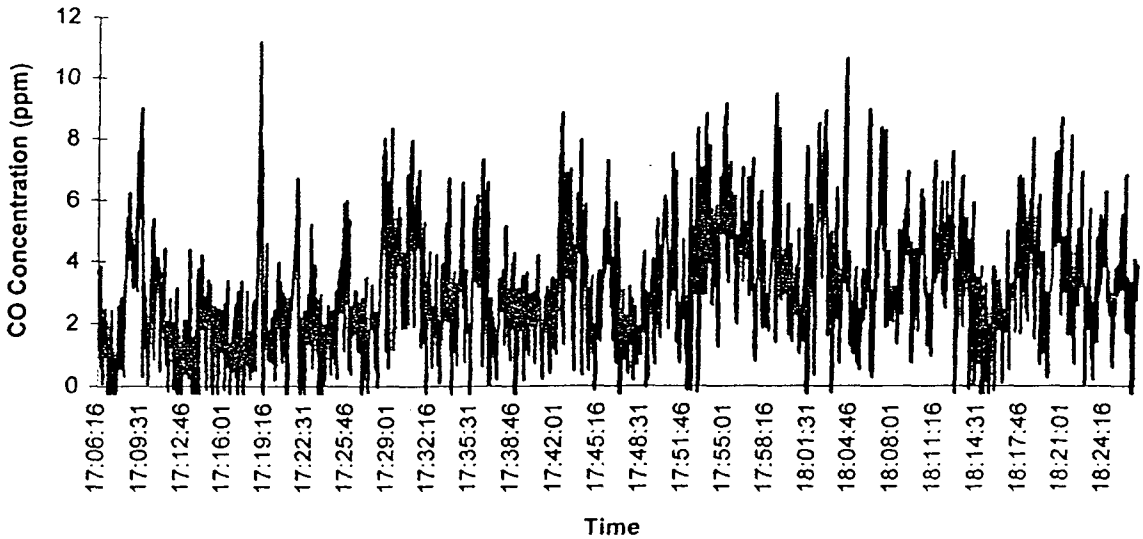
** not reportable*
*** not collected*

The results from Phase II, listed in the above table, are an average of the continuous monitoring results collected with the test bench (described in section 6.1.2), as opposed to the Tedlar bag samples collected during Phase I and Phase III.

Carbon Monoxide

The CO concentrations detected at the thresholds of the runways were minimal. The continuous monitoring of CO during Phase II, displayed in *Figure 9*, shows the maximum CO concentrations detected were well within the NAAQO.

FIGURE 9. Continuous Monitoring of CO (ppm) at the Thresholds of Runway 07/25 During a Heavy Traffic Condition in the Fall Season-Phase I



Oxides of Nitrogen

As with the taxi stand, the concentrations of NO_X collected at the thresholds of the runways (400 feet parallel from the threshold lights) were at the detection limits of the analytical instruments used.

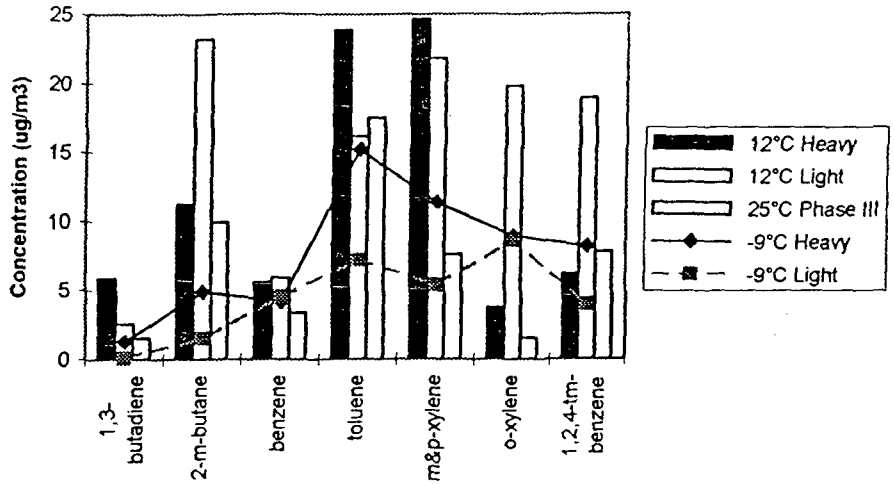
Total Suspended Particulate Matter

The concentrations of particulate matter were significantly higher in the winter season as compared to the summer season. The concentrations detected during the winter heavy traffic period were significantly higher than the winter light traffic period.

Hydrocarbons

Figure 10 displays the VOC concentrations detected at the thresholds of the runway during all test phases. All of the target VOCs showed the highest concentrations in the coldest temperatures (Phase II), for both heavy and light traffic conditions. The winter VOC concentrations were over 60 times higher than the concentrations detected in the fall and summer seasons and are therefore displayed on a different concentration scale in *Figure 10*. The lowest VOC concentrations were detected in the summer test conditions (Phase III).

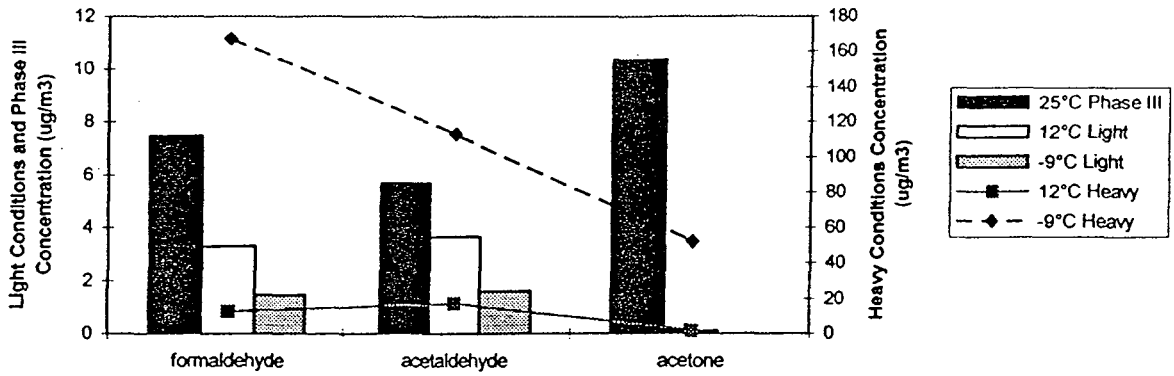
FIGURE 10. VOC Speciation at the Thresholds of the Runway during all test Phases at Heavy and Light Traffic Conditions (µg/m³)



In the winter, the VOC concentrations increased with the increase traffic condition, with the exception of benzene and o-xylene which showed similar concentrations between the heavy and light traffic period. In the fall season, there was no correlation between VOC concentration and traffic condition.

Figure 11 illustrates the carbonyl concentrations detected at the thresholds of the runway during all test Phases. The concentrations of formaldehyde, acetaldehyde, and acetone were highest in the coldest test temperatures. However, there was a direct correlation between the increased traffic volume and the increase in carbonyl concentrations, unlike the target VOCs.

FIGURE 11. Target Carbonyl Concentrations (µg/m³) Detected at the Thresholds of the Runwway



As stated in Section 6.1.2, samples were collected midrunway during Phase II. The results for this test site are listed in *Table 19*. The CO, CO_2, and NO_X concentrations were not significantly different from the concentrations detected at the thresholds of the runway (400 feet parallel from the thresholds lights). Carbonyl concentrations were significantly less compared to the Phase II heavy traffic condition but were higher than the Phase II light traffic condition concentrations. Particulate matter and VOC results are not available from the midrunway test site.

TABLE 19. Pollutant Concentrations Detected Midrunway

CO (ppm)	*
CO_2 (ppm)	424
NO_X (ppm)	*
formaldehyde (µg/m³)	11
acetaldehyde (µg/m³)	6
acetone (µg/m³)	10

* *not detected*

In Phase I, air quality measurements were taken at the threshold lights while aircraft were preparing for takeoff. *Table 20* identifies the emissions resulting from the air sample analysis after a DC-9 and a DASH-8 used the same runway for takeoff.

TABLE 20. Air Quality Emissions During Aircraft Takeoff (ppm)

Aircraft	DC-9	DASH-8
CO	17	69
CO_2	2,527	3,042
NO_X	4	9

The CO_2 concentrations, detected from the DC-9 and DASH-8, are approximately 8 times higher than those collected at the threshold of the runway, 400 feet parallel to the threshold lights. The increased CO_2 concentrations are indicative of the combustion process. In addition, CO and NO_X concentrations were also higher than the concentrations detected at the thresholds of the runways.

Also, Phase I field sampling included air quality measurements of the aircraft engine exhaust plumes as they were being warmed up prior to departing from the apron. Samples were collected during the period of time that the engine was operated in this position. *Table 21* summarizes the results from this analysis.

TABLE 21. Air Quality Emissions (ppm) Behind Aircraft During Engine Startup

Aircraft	Stretch DC-8	737-1*	737-2*	727
CO	15	1	11	1
CO_2	593	282	765	276
NO_X	1	1	2	1

** data was collected from two 737 jets*

Although the measurements indicate a significant variability between aircraft, this should not be interpreted as a controlled comparison between aircraft. Several factors influenced this exercise: varying distances from the probe to the exit nozzle of the engine, dispersion effects, wind speed and direction, and the limited sample number. The highest CO_2 concentrations detected with the Stretch DC-8 and the 737-2 correlate with the increased CO and NO_X concentrations. This sampling does however support the action of testing individual aircraft exhaust plumes at the exhaust outlet.

In summary, CO concentrations collected 400 feet parallel to the threshold lights and midrunway were well below NAAQO levels. CO, CO_2, and NO_X concentrations were increased when air samples were collected at the threshold lights and behind aircraft during engine startup. Carbonyl concentrations were significantly increased in the colder temperatures experienced during the Phase II sampling period.

7.1.3 Apron

Samples were collected on the apron during heavy and light traffic periods. *Table 22* indicates the maximum concentrations of pollutants on the apron, during normal daily activities.

TABLE 22. Maximum Apron Air Quality During Normal Airport Operational Activities

	Phase I		Phase II		Phase III
Average Temperature (°Celcius)	-6		-20		22
Traffic Condition	**Heavy**	**Light**	**Heavy**	**Light**	
CO(ppm)	5	2	4	2	2
CO_2(ppm)	374	340	541	551	269
NO_X (ppm)	*	*	*	*	*
Particulate Mass (µg/m^3)	**	**	113	249	61
1,3-butadiene(µg/m^3)	12	4	3	11	2
2-methylbutane(µg/m^3)	107	121	16	44	48
benzene(µg/m^3)	20	34	22	46	3
toluene(µg/m^3)	62	69	49	64	18
m&p-xylene(µg/m^3)	93	28	54	37	8
o-xylene(µg/m^3)	37	10	30	13	4
1,2,4-trimethylbenzene(µg/m^3)	42	19	44	12	9
formaldehyde(µg/m^3)	8	6	20	30	10
acetaldehyde(µg/m^3)	4	4	7	6	3
acetone(µg/m^3)	3	*	8	*	3

* *not reportable*
** *not collected*

The concentrations listed for Phase II are an average of the concentrations collected during the continuous monitoring.

Carbon Monoxide

The concentration levels of CO in this area did not exceed the NAAQO maximum acceptable level for a 1-hr period. However, the presentations of real-time continuous measurements depicted in *Figure 12*, collected during Phase I showed several peaks of CO which exceeded the NAAQO. *Figure 13* illustrates the CO concentrations on the apron during Phase II and III.

FIGURE 12. Continuous Monitoring of CO (ppm) at the Apron During Heavy and Light Traffic Conditions in the Fall Season -Phase II

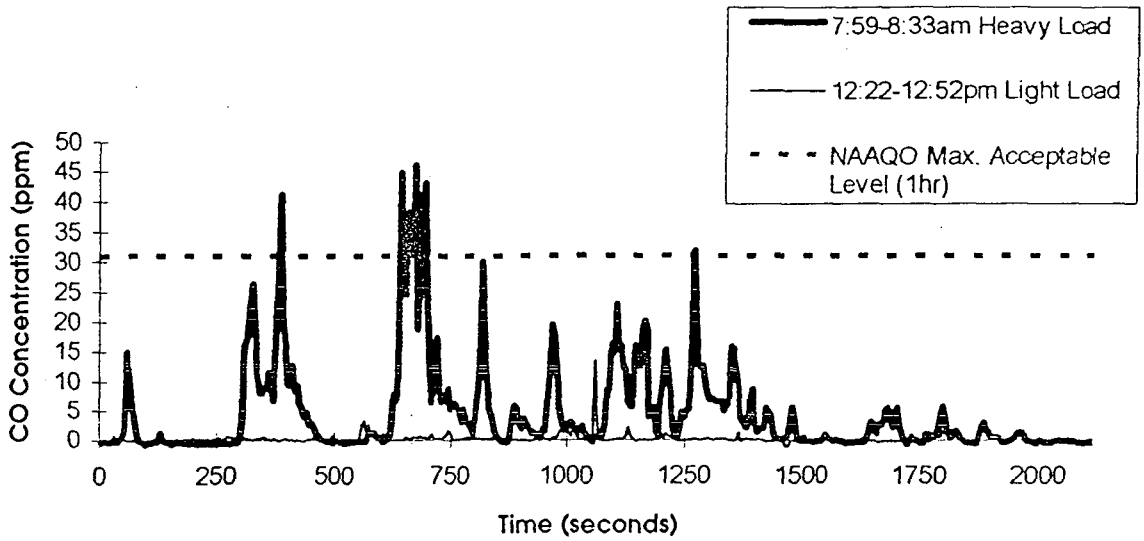
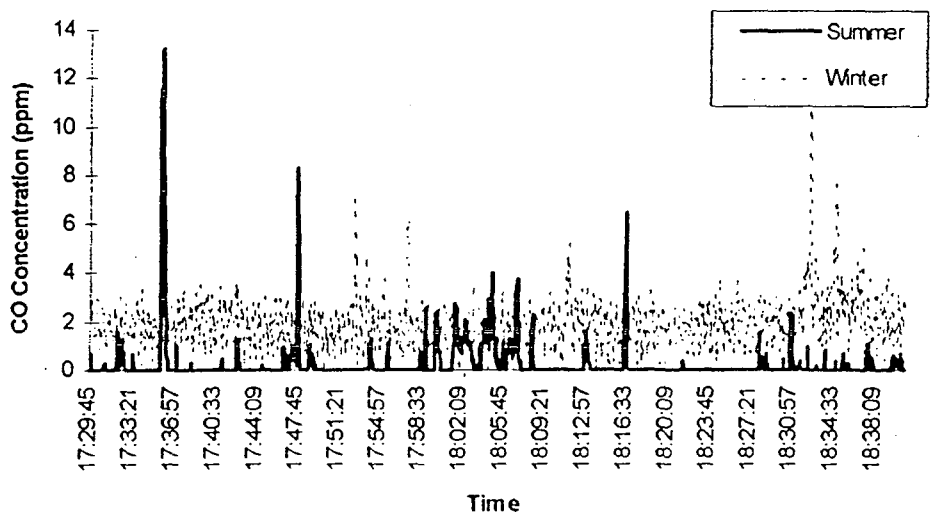


FIGURE 13. Continuous Monitoring of CO (ppm) at the Apron During the Winter and Summer Season



Oxides of Nitrogen

NO_x concentrations were at the detection limits of the analytical instruments.

Total Suspended Particulate Matter

The particulate concentrations were higher in the colder winter temperatures compared to the concentrations detected in the Phase III summer conditions.

Hydrocarbons

Figure 14 illustrates the VOC concentrations detected, during all test Phases, at the apron. The majority of the VOC concentrations were the lowest in the summer test phase.

With regards to the VOC concentrations and traffic conditions; 1,3-butadiene, 2-methylbutane, benzene, and toluene displayed higher concentrations in the light traffic condition of the -20°C test condition compared to the -20°C heavy traffic condition. However, with the exception of 1,3-butadiene, these compounds displayed a lower concentration in the light traffic period of the -6°C test condition compared to the heavy -6°C test condition.

FIGURE 14. VOC Speciation at the Apron during all test Phases at Heavy and Light Traffic Conditions (µg/m³)

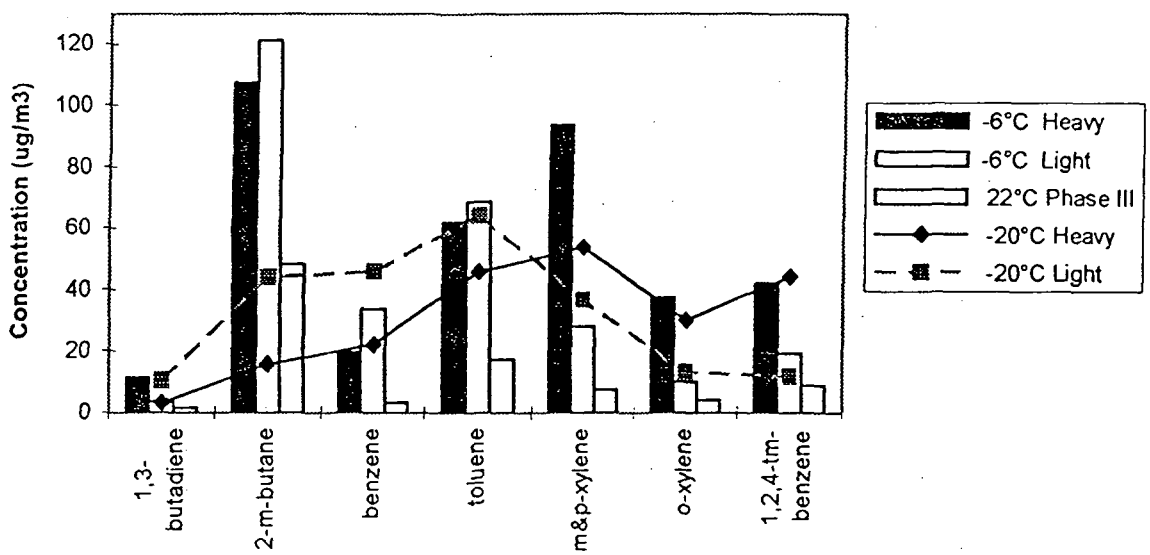
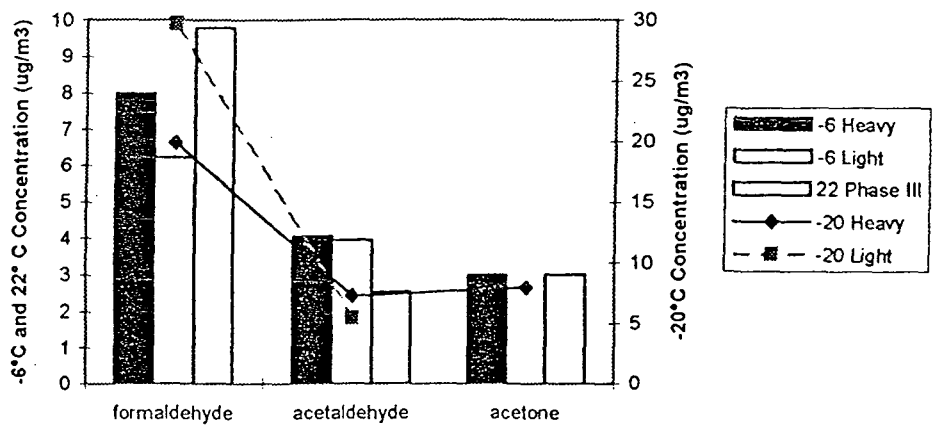


Figure 15 illustrates the carbonyl concentrations detected at the apron.

As with the VOC concentrations the highest carbonyl concentrations were detected in the winter test phase. However, the winter phase carbonyl results were only, on average, 3 times higher than the fall and summer results. Not all compounds had the lowest concentration in the summer test phase. There was no relationship between carbonyl concentration and traffic condition.

FIGURE 15. Target Carbonyl Concentrations Detected at the Apron (µg/m³)

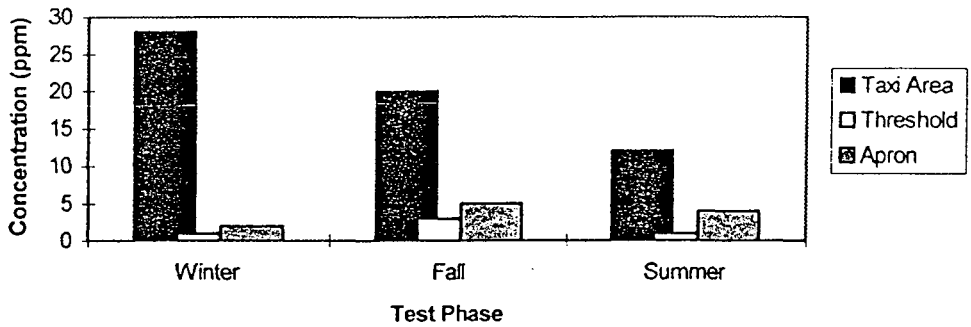


Overall, the air quality testing at the apron showed peaks of CO which exceeded the NAAQO, during continuous monitoring only, and all of the target carbonyl compounds were increased in the coldest test phase.

The following paragraphs provide a brief summary of the air quality results detected from all three of the ambient air test sites: the passenger taxi loading area, the thresholds of the runway, and the apron. CO, particulate matter, and VOC concentrations are examined with respect to the air sampling test locations.

Figure 16 illustrates the the maximum CO concentrations detected for each phase, regardless of the traffic condition, at each of the ambient air test sites. All of the CO concentrations were the highest at the taxi stand, during each test Phase, and the CO concentrations on the apron were higher than those detected on the thresholds.

FIGURE 16. CO Concentrations (ppm) Detected at all Ambient Air Test Sites



The CO concentrations detected at the thresholds of the runway and the apron were quite similar to the 1-hr maximum concentration (4.2 ppm), detected at the Ottawa airport, sited in a Transport Canada study reviewing airport air monitoring.[18]

Figure 17 illustrates the total suspended particulate matter concentrations detected at each ambient air test site. The highest concentrations were noted at the thresholds during the winter season. All of the concentrations detected in the winter season were higher for each location compared to the summer season. Fall particulate matter results were not available for the threshold and the apron.

FIGURE 17. Total Suspended Particulate Matter Concentrations ($\mu g/m^3$) Detected at all Ambient Air Test Sites

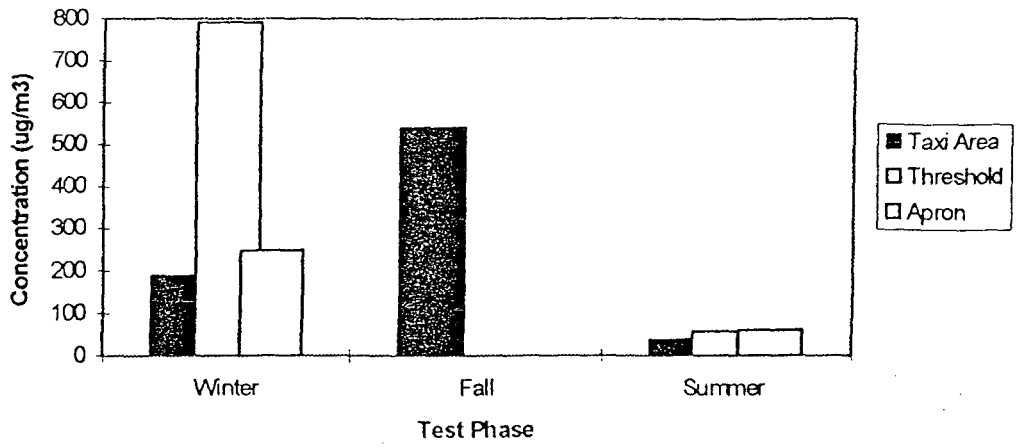
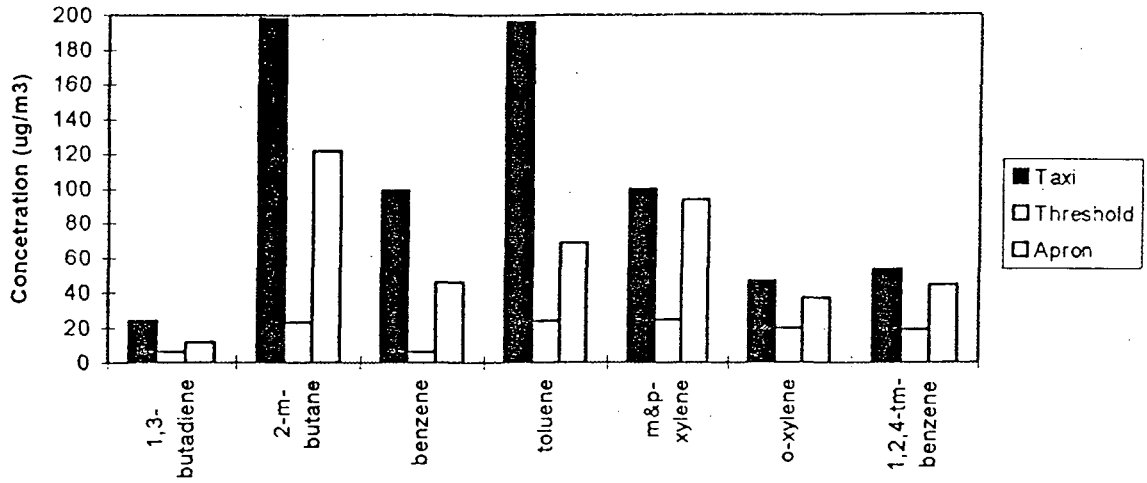


Figure 18 graphically displays the maximum concentrations detected at each ambient air site, regardless of traffic condition or temperature. For the majority of the target VOC compounds the highest concentrations were detected at the taxi stand and the apron. These results substantiate the testing of the specific mobile sources, service vehicles and aircraft, and the refueling process in order to identify the greatest contributors to these increased concentrations of VOCs on the apron.

FIGURE 18. Maximum Target VOC Concentrations (µg/m³) at the Ambient Air Test Sites



Although specific hydrocarbon compounds are not regulated by the NAAQO, other guidelines exist. The National Institute for Occupational Safety and Health (NIOSH) has such guideline levels for some carbonyl and VOC compounds. For information purposes, all the hydrocarbon species monitored, for which NIOSH guidelines exist, were within the 8-hr TWA NIOSH limits.[19] However, the maximum VOC concentrations were significantly higher than typical Canadian outdoor ambient air levels (i.e. benzene 4.4 µg/m³ and toluene 12.1 µg/m³).[20]

7.2 Aircraft Refueling

In conjunction with the evaluation of the air quality on the apron during normal daily airport operations, air samples were collected in proximity to an aircraft while being refueled. The probe was located under the refueling nozzle in Phase I and was located at the vent of the plane in Phase II. The results from this activity are found in *Table 23* .

TABLE 23. Emissions During Aircraft Refueling ($\mu g/m^3$)

Compound	Phase I	Phase II
1,3-butadiene	13	12
2-methylbutane	41	*
benzene	34	65
toluene	67	181
m&p-xylene	49	155
o-xylene	19	69
1,2,4-trimethylbenzene	25	54

** not quantitated*

The concentration level for 2-methylbutane (Phase II) is not listed in the above table. Due to compound interferences, the concentration of 2-methylbutane was not quantitated.

With the exception of 1,3-butadiene, the VOC concentrations were higher in Phase II . Since the samples were collected during different weather conditions and different probe locations, no conclusions may be drawn.

Figures 19 and *20* illustrate the different concentration levels of target VOCs detected during the refueling process and the air quality sampling on the apron for Phase I and Phase II respectively.

FIGURE 19. Target VOC Speciation (µg/m³)
During the Refueling Process and Apron Activities for Phase I

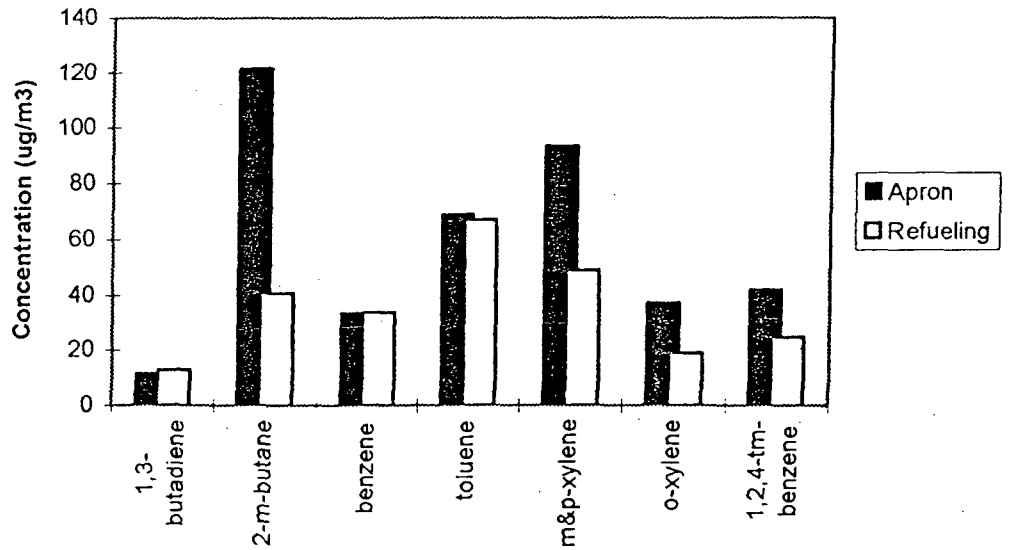
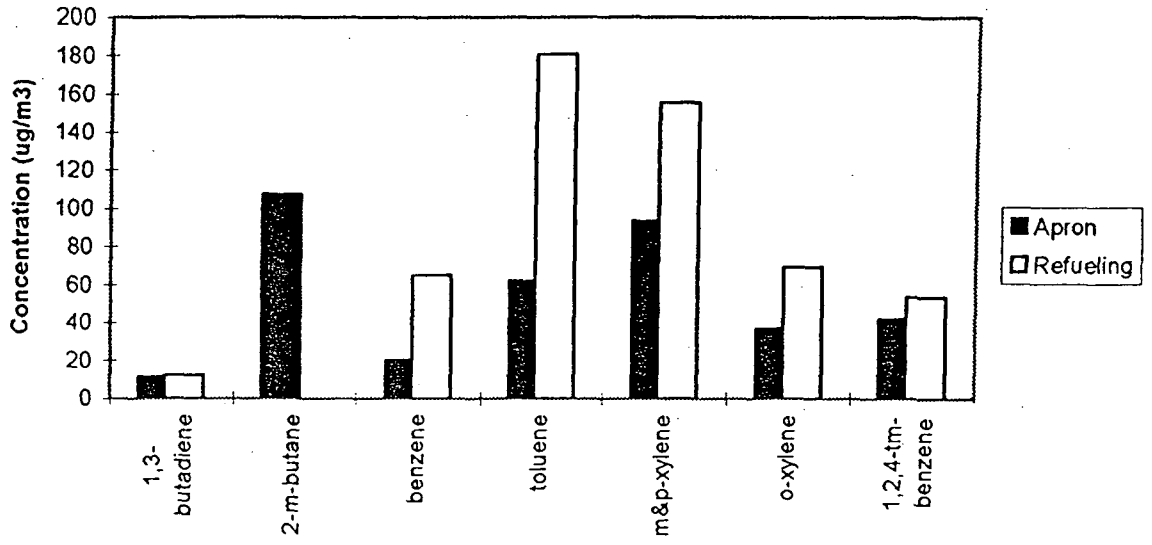


FIGURE 20. Target VOC Speciation (µg/m³)
During the Refueling Process and Apron Activities for Phase II



7.3 Airport Mobile Sources

7.3.1 Service Vehicles

The final section of the field testing consisted of evaluating each specific type of service vehicle being used on the apron. This group of mobile sources included the units that were observed during the apron air quality testing and vehicles that were used on a seasonal basis, such as aircraft heaters and the deicing trucks. All of these vehicles were tested by simulating the engine operation under 'no load' steady state operation. This procedure, although more applicable to the operation of the auxiliary power units, aircraft heaters and the deicing truck, did however provide a conservative indication of the emissions that would be expected to occur when these sources were in operation.

The simulation did not include the engine startup and warm-up as these operations do not always occur on the apron. Except for the ground power units and seasonal heaters, these operations are conducted at the storage lot for these vehicles. At this airport, this occurs at the lots of Hudson General and Air Canada. These emissions are not to be discounted as they add to the pollution burden on the airport site. Of particular importance is the particulate mass that occurs during engine startup until operating temperature is reached.

For each type of service equipment, the technician representing the fleet owner was requested to operate the engine in a mode which best simulated its normal apron operation. The engine was then run for 10 minute sampling periods, at each point in the operation considered to be normal by the technician. During these periods, a probe located in the exhaust outlet of the vehicle was used to collect exhaust stream emission samples.

Tables 24-A and *24-B* list the mass emission rates of the ground service equipment tested in grams per minute for CO, CO_2, NO_X, and particulate matter for Phase I and Phase IV respectively. The mass emission rate was calculated using the concentration of the pollutant at the exhaust outlet, the density of the pollutant and the volume displaced by the engine. This calculation was based on several calculations[21], the specifics of which are listed in Appendix B.

Regulated emission results from the Hudson General vehicles (heater and deicing truck) were not presented due to increased moisture and condensation in the Tedlar sample collection bag. The condensation would have had a negative effect on the analysis instruments used to quantify the exhaust emissions and result in an underestimate of the emission rates.

TABLE 24-A. Mass Emission Rates Determined from the Service Vehicles and Equipment-Phase 1

Vehicle/Equipment	APU	Paymover Tow Truck	Tractor	Clark Tow Truck #1	GPU #2
Fuel	Diesel		Diesel		
Compound	Mass (g/min)				
CO	0.23	0.23	0.86	1.1	1.5
CO_2	21	11	81	123	507
NO_X	0.2	0.15	0.58	0.59	9
HC	*	*	0.08	0.45	1.1
particulate matter	*	*	0.08	0.14	1.8

** not detected*

TABLE 24-B. Mass Emission Rates Determined from the Service Vehicles and Equipment-Phase IV

Vehicle/Equipment	Clark Tow Truck #1	Clark Tow Truck #2	Clark Tow Truck #3	Hobart GPU #3
Fuel	Diesel	Diesel	Diesel	Gasoline
Compound	Mass (g/min)			
CO	1.7	0.75	0.64	403
CO_2	68.5	103	89	545
NO_X	0.76	1.4	1.1	n/a

n/a = not available

Emissions from the Clark Tow Truck were comparable between Phase I and IV, although, these vehicles were tested with different systems and the testing took place within several months of each other, with no monitoring of the vehicle in between test Phases.

The exhaust samples from the service vehicles were also subjected to hydrocarbon speciation. Discrepancies in the analysis of the hydrocarbons from C_4-C_5 resulted in poor identification of these compounds. Therefore not all volatile organic compounds listed for the ambient air conditions are listed for the mobile sources. The VOC results detected from the service vehicles are summarized in *Table 25,* for Phase I.

TABLE 25. Target VOC Mass Emission Rates Determined from the Service Vehicles and Equipment-Phase I

Vehicle/Equipment	APU	Paymover Tow Truck	Heater	Deicing Truck	Tractor	Clark Tow Truck	GPU #2
Fuel	Diesel		Gasoline		Diesel		
Compound	Mass (mg/min)						
benzene	0.82	0.68	3	206	2.2	4	5
toluene	2	1.74	1.2	222	0.99	4	6
m&p-xylene	0.32	0.27	0.68	34	0.43	3	9
o-xylene	0.15	0.1	0.22	9	0.22	2	5
1,2,4-tm-benzene	1.5	0.14	0.59	4	1.1	8	18

Evaluation of individual carbonyl compounds was performed on the emissions generated from the service vehicles and equipment. During sampling in Phase I, the increased moisture in some samples allowed for sample breakthrough on the sample media cartridge and the results were underestimates of the actual emission value. In Phase IV, with the use of the dilution tunnel, this moisture problem was reduced, however, the sample was too diluted with ambient air and individual compounds were not able to be quantitated. *Table 26* lists the carbonyl compound mass emission rates determined from the service vehicles and equipment in Phase I. These emission rates were calculated using the sample flow rate, the length of the sample period, the mass of the compound found on the cartridge and the flow rate through the engine, as detailed in Appendix B.

TABLE 26. Carbonyl Compound Mass Emission Rates Determined from the Service Vehicles and Equipment-Phase 1

Vehicle/Equipment	APU	Paymover Tow Truck	Heater	Deicing Truck	Tractor	Clark Tow Truck	GPU #2
Fuel	Diesel		Gasoline		Diesel		
Compound	Mass (mg/min)						
formaldehyde	3.16	1.43	0.18	7.22	0.37	1.07	1.69
acetaldehyde	0.98	0.49	0.71	6.08	0.67	2.47	5.4
acetone	4.08	3.2	0.36	2.77	*	*	0.03
acrolein	0.25	0.07	0.02	3.13	0.16	1.73	0.44
propionaldehyde	0.26	0.11	0.16	1.34	0.07	0.56	0.98
crotonaldehyde	0.13	0.06	0.08	0.67	*	0.07	*
methyl ethyl ketone	0.44	0.09	0.28	1.48	0.06	0.43	0.22
benzaldehyde	0.14	0.1	0.76	5.12	0.03	0.05	*
methyl isobutyl ketone	0.09	0.1	0.8	5.01	*	0.03	*
hexanaldehyde	0.77	0.78	0.07	0.62	*	*	*

* *not detected*

The total PAH value and target PAH concentrations are listed in *Table 24-C.* The complete listing of PAH values detected from the service vehicles and equipment is located in Appendix C.

TABLE 27. Target PAH Mass Emission Rates Determined from the Service Vehicles and Equipment-Phase 1

Vehicle/Equipment	Heater	GPU #1
Fuel	Gasoline	Diesel
Compound	Mass (mg/min)	
Total PAH	2	16.5
acenaphthylene	0.15	2.71
acenaphthene	0.2	3.17
flourene	0.34	2.44
2-methyl flourene	0.32	2.52
phenanthrene	0.68	5.7
anthracene	0.03	0.36
flouranthene	0.03	0.04
pyrene	0.03	0.01

7.3.2 Aircraft Engines

To complete the field testing of the airport mobile sources, the exhaust emissions from three aircraft were tested. The mass emission rates collected from the Boeing 727, the DASH-8 and the Jet Ranger are presented in *Table 28* through *Table 30*. The calculated mass emission rates, in kilograms per hour and grams per hour, are listed for each of the aircraft tested.

The mass emission rates were calculated based upon a carbon balance equation. Fuel air ratios and the dry air rate were calculated using the fuel flow rate, the concentration, the density of each pollutant and the exhaust temperature. In some instances the fuel flow and exhaust temperature were not available, therefore the mass emission rates were calculated using the average parameters determined from previous testing on data obtained from the same aircraft but from a different test date. The specifics of the mass emission rate calculation are described in Appendix B. Where available the individual hydrocarbon mass emission rates are provided.

Boeing 727

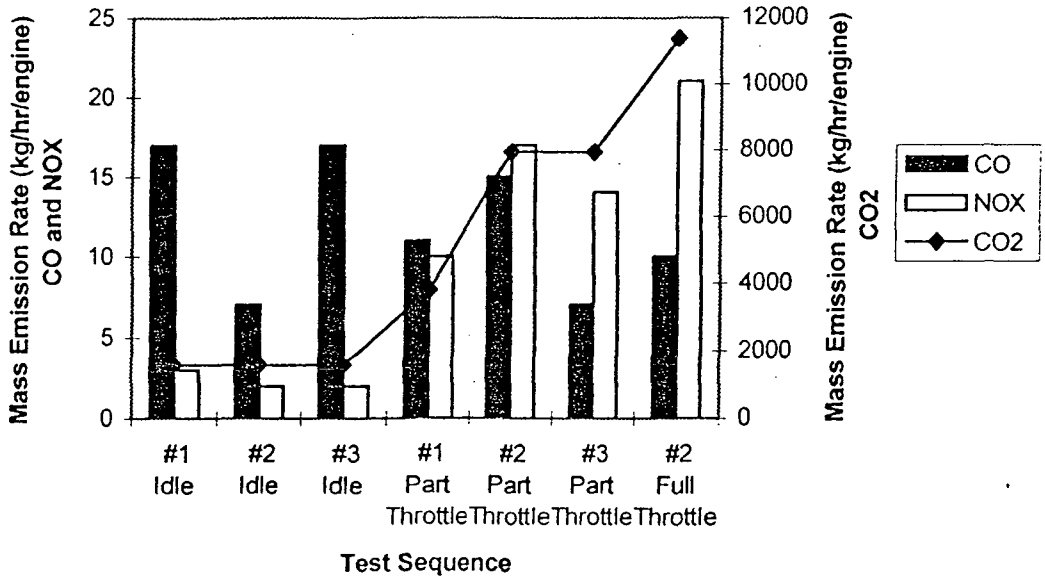
Though the test team had the opportunity to discuss the engine operating sequence with the aircraft technicians, the sampling was totally dependent on the operators discretion as to the definition of each operating point. In the cases where repeats were conducted on different days it was not always possible to use the same operational personnel. This occurrence added a variable to the testing which was unavoidable. As the sampling was totally dependent on the aircraft technicians, there was a limited sample number and not all hydrocarbon species were collected at each test sequence.

Table 28 lists the results from the exhaust emissions sampled from the Boeing 727 housing the JT8D engine. CO, CO_2 , and NO_X mass emission rates are listed in kilograms per hour per engine. *Figure 21* displays the mass emission rates versus engine mode for the three test sequences.

TABLE 28. CO, CO_2, and NO_X Mass Exhaust Emission Rates (kg/hr) Detected from the Boeing 727

Compound	Test Sequence #1		Test Sequence #2			Test Sequence #3	
	Idle	Part Throttle	Idle	Part Throttle	Full Throttle	Idle	Part Throttle
	Mass Emission Rate (kg/hr)/engine						
CO	17	11	7	15	10	17	7
CO_2	1,596	3,793	1,599	7,949	11,370	1,593	7,941
NO_X	3	10	2	17	21	2	14

FIGURE 21. CO, CO_2, and NO_X Mass Exhaust Emission Rates Detected from the Boeing 727 (kg/hr) versus Engine Mode



As noted in the above table and graph, CO_2 emissions increased with the increase in engine throttle. NO_X mass emission rates also followed this trend. Conversely, during test sequence #1 and #2, CO emissions where increased in the idle test phase and decreased in part throttle. In test sequence #2, CO emissions were higher in the part throttle mode but lower in the full throttle mode.

As stated above, there were several variables in the testing procedure. However, the emission rates for CO_2 and NO_X were very repeatable for the idle phase and for the test sequence #2 and #3 part throttle mode. The CO numbers were comparable between test sequence #2 and #3.

Tables 28-A to 28-C list the mass emission rates of the hydrocarbon compounds detected from the Boeing 727. The hydrocarbon emission rates were calculated using the sample volume, sample flow rate, and the dry gas density of air flowing through the engine. As with the hydrocarbon speciation of the service vehicles, discrepancies in the analysis of the hydrocarbons from C_4-C_5 resulted in poor identification of these compounds. Therefore not all VOCs listed for the ambient air conditions are listed for the mobile sources. Table 28-A lists the VOC speciation in grams per hour per engine.

TABLE 28-A. VOC Speciation Mass Emission Rates (g/hr) Detected from the Boeing 727

Compound	Test Sequence #1		Test Sequence #2
	Idle	Part Throttle	Part Throttle
	Mass Emission Rate (g/hr)/engine		
benzene	149.89	53.45	*
toluene	58.91	20.85	4.96
m & p-xylene	17.06	4.73	12.57
o-xylene	6.65	1.82	3.51
1,2,4-tm-benzene	0.08	0.01	*

* *not detected*

The target VOC compounds displayed the highest concentrations in the idle mode compared to part throttle.

The mass emission rates of all of the carbonyl compounds identified during analysis are listed in Table 28-B, in grams per hour per engine.

TABLE 28-B. Carbonyl Mass Emission Rates (g/hr) Detected from the Boeing 727

Carbonyl Compound	Test Sequence #3	
	Idle	Part Throttle
	Mass Emission Rate (g/hr)/engine	
formaldehyde	304	810
acetaldehyde	193	401
acetone	92	39
acrolein	74	163
propionaldehyde	41	74
crotonaldehyde	23	50.4
methyl ethyl ketone	52	52
benzaldehyde	15	47
methyl isobutyl ketone	11	36
hexanaldehyde	17	35

With the exception of acetone and methyl ethyl ketone, mass emission rates for the carbonyl compounds were increased with the increase in throttle.

Table 28-C lists the target PAH mass emission rates in units of milligrams per hour per engine. The complete listing of PAH emissions is found in Appendix C.

TABLE 28-C. Target PAH Mass Emission Rates (mg/hr) Detected from the Boeing 727

PAH Compound	Test Sequence #2	
	Part Throttle	Full Throttle
	Mass Emission Rate (mg/hr)/engine	
Total PAH	1,050	7,990
acenaphthylene	100	1,350
acenaphthene	170	930
flourene	170	1,430
2-methyl flourene	450	2,930
phenanthrene	160	1,350
anthracene	*	130
flouranthene	*	140
pyrene	*	100

** not detected*

The total PAH and the individual target PAH emission rates, as with CO_2 and NO_X, were significantly higher in the full throttle mode of the JT8D engine compared to the part throttle mode.

Transport Canada DASH-8

Table 29 lists the mass emission rates of exhaust components detected from Transport Canada's DASH-8. During this testing the propeller blades were set at flat pitch.

TABLE 29. Mass Exhaust Emission Rates Detected From the DASH-8

Compound	Start-Up and Idle	70% Power
	Mass Emission Rate (kg/hr)/engine	
CO	3	1
CO_2	440	938
NO_X	1	1

CO emissions were higher during startup and idle and less for the 70% power as opposed to CO_2 which showed the reverse relationship.

For the PAH sampling only one PUF was collected for the idle and 70% power, flat pitch, position, the results for which are listed in Table 29-A. The complete listing of PAHs is found in Appendix C.

TABLE 29-A. PAH Exhaust Emission Rates (mg/hr) Detected From the DASH-8

PAH Compound	Idle and 70% Power Mass Emission Rate (mg/hr)/engine
Total PAH	350
acenaphthylene	50
acenaphthene	50
flourene	50
2-methyl flourene	90
phenanthrene	110
anthracene	*
flouranthene	*
pyrene	*

** not detected*

Helicopter-Jet Ranger

Table 30 lists the mass emission rates of exhaust components as determined from the Jet Ranger helicopter.

TABLE 30. Mass Exhaust Emission Rates Detected From the Jet Ranger

Compound	Idle	17% Power
	Mass Emission Rate (kg/hr)/engine	
CO	5	4
CO_2	3,055	249
NO_X	0.67	0.7

Tables 30-A and *30-B* list the carbonyl and PAH emission rates respectively. Both types of hydrocarbon speciations were collected while the Jet ranger was idling, only. The complete listing of PAH mass emission rates for the Jet ranger are listed in Appendix C.

TABLE 30-A. Carbonyl Mass Emission Rates (g/hr) Detected From the Jet Ranger

Carbonyl Compound	Idle
	Mass Emission Rate (g/hr)/engine
formaldehyde	23
acetaldehyde	18
acetone	*
acrolein	28
propionaldehyde	4
crotonaldehyde	0.8
methyl ethyl ketone	3
benzaldehyde	1
methyl isobutyl ketone	0.76
hexanaldehyde	1

** not detected*

TABLE 30-B. PAH Mass Emission Rates (mg/hr) Detected From the Jet Ranger

PAH Compound	Idle
	Mass Emission Rate (mg/hr)/engine
Total PAH	4,110
acenaphthylene	3,190
acenaphthene	220
flourene	160
2-methyl flourene	260
phenanthrene	290
anthracene	*
flouranthene	10
pyrene	*

** not detected*

8.0 DISCUSSION

The determination of the impact of the emissions generated by mobile sources at an airport is a complex undertaking. The physical differences between the various mobile sources, such as their unique operating, propulsion and auxiliary systems, coupled with the varying Canadian climate, provides a high degree of variability within the study. As described in the previous sections, a significant amount of effort was required prior to actual field measurement work, to develop specific sampling systems and test methodologies that would result in accurate and representative data under these varying conditions.

During the field testing, it was not possible to eliminate the influence of all of the variables in order to have repeatable and source specific emissions data for each particular sampling condition. During the field evaluations a number of situations were encountered which complicated the data measurement and analysis, including:

- climatic conditions, particularly the dispersion effects of the wind
- restrictions on probe locations
- cooperation of mobile source operators/owners
- 'breakthrough' on specific sample media, the result of high concentration levels
- high moisture content in raw exhaust samples

However, efforts were directed wherever and whenever possible to ensure consistent test procedures and conditions.

This following section of the report provides a discussion of the specific testing and data that resulted from the field testing for each location and mobile source type.

Passenger Taxi Loading Area

In this location, the taxi fleet is a major contributor to the localized air quality. In addition, the emissions generated by private automobiles, public transit vehicles, and delivery trucks also play a significant role in the pollution burden experienced. However, this pollution burden may also be influenced by the dispersion effects of the weather conditions.

With respect to the taxis in this location, the actual vehicle engine operation and, therefore, the emissions generated, is a function of the volume of aircraft arrivals and departures. During the light periods of aircraft traffic either the vehicle is left idling with the operator inside or the engine is turned off while the operator leaves the vehicle. It was observed during the testing that a number of taxis were left idling for long periods of time in this area while waiting for a fare. It was difficult to ascertain whether the presence of the test team influenced the decision of the drivers, causing them to turn off their engines when ordinarily the drivers would have left their vehicles idling. Under heavy aircraft volume conditions, the taxi engine operation is substantially different, with the idling times being reduced but with an increased number of taxis entering and accelerating away from the loading zone.

The continuous monitoring that was conducted for CO showed that there were numerous short periods of time when the concentration levels exceeded the NAAQO. Although this procedure was not employed for the other compounds, which are known to be in the exhaust streams of passenger cars, it is expected that similar trends would be observed.

The CO concentrations determined, at all of the ambient air test sites, were the highest at the passenger taxi loading area. These high concentrations may be due to the increased volume of traffic and the long idle times of vehicles combined with the decreased air flow and ventilation in this area. This is of major importance as this outdoor area of the airport has the most passenger traffic. CO even in low concentrations may cause adverse health effects in humans such as blood and organ disorders. CO is able to bind to hemoglobin, the oxygen carrying molecule present in blood, and therefore decrease the oxygen carrying capacity of blood. Dizziness, headaches, and suffocation are possible effects of decreased oxygen in the human blood stream.

The VOCs in this area were increased in the winter test phase. It has been noted in other MSED studies that the VOC mass emission rates increase in the colder ambient air temperatures. In one study, for example benzene mass emission rates increased from 7 mg/mile @ 20°C to 30mg/mile @ -6°C and toluene increased from 10 mg/mile @ 20°C to 48mg/mile @ -6°C, when the vehicle was fueled with commercial unleaded gasoline.[22] Most target VOCs detected at the ambient air test sites at this airport increased in the colder temperatures of the winter season.

The location of the sample probe, as noted in *Figure 8*, is critical for the determination of the actual peak concentration levels that people are subjected to, at the passenger taxi loading area. Though the probe was positioned close to the curb (for the timed average sampling), it may not have detected the maximum concentrations as a vehicle exhaust pipe may not have been directly in line with the probe at any one time. It was assumed, however, that the location in proximity to the exhaust pipe of a vehicle would have the highest peak concentrations. Thus, the area at the curb where passengers enter the taxis would have the poorest short term air quality in this location.

Thresholds of Runway 07/25 and 14/32

The initial rationale for collecting samples at the thresholds of the runways was twofold. The primary reason was to determine the contribution of this airport/aircraft activity to the pollution levels of the surrounding airport air quality. Secondly, it was anticipated that the field measurements at this location would provide a level of quantitative and qualitative data regarding the exhaust emissions from various types of aircraft while in a landing mode and while the engines are at full thrust during takeoff. However, the location of the probe for the sampling system, essentially the distance from the aircraft engines, prevented the testing from identifying a 'finger print' for the emissions from each type of engine. The sampling did however, provide an indication of the contribution of this activity to the ambient concentration levels of a variety of compounds.

The highest concentrations of total suspended particulate matter were noted at the thresholds during the fall season. This particulate matter may have occurred from the fallout from aircraft while in the approach mode prior to landing.

Though the field testing at this location did not provide the emissions data specific to each aircraft engine, a slight change to the location of the probe and sampling train did provide an indication of the differences between aircraft engines. This change resulted in the probe being positioned in the path of the engine exhaust stream as the aircraft sat on the taxiway adjacent to the threshold. A combination of this data plus engine specific exhaust emissions sampling, from the aircraft, with dispersion modeling will provide an accurate and realistic model for predicting airport air quality pollution levels, based on aircraft traffic volume.

Apron Air Quality

The air quality on the apron was evaluated in the same manner as the other locations in the study, with sampling being conducted at different periods during the day based on the volume of mobile source traffic. The objective was to provide an indication of the air quality on the apron during normal operational activities and to provide some insight into the contribution of the various forms of mobile sources to this pollution burden. The mobile sources of concern in this location included aircraft, baggage carriers, auxiliary power units, aircraft towing trucks, conveyor belts and refueling trucks.

The continuous monitoring of CO, in this area, showed peaks which exceeded the NAAQO, although the timed average sampling did not. The target VOCs showed the highest concentrations at the apron and may be the result of the combination of emissions generated from the different fueled service vehicles and aircraft and the refueling processes. More detailed testing should be conducted to verify target hydrocarbon levels as specific compounds are known to be carcinogenic.

The VOC levels were increased in the colder test phases. This could possibly be due to the increased number of service vehicles on the apron during the winter i.e. snowploughs, deicing trucks, and glycol recovery trucks, and the longer start up and idling times, and barometric pressure changes and influences.

These field measurements indicate the overall impact on the air quality on the apron from the operation of mobile sources. However, in order to develop a correlation between apron air quality and mobile source activities it is necessary to have specific emission rates for each mobile source configuration. This information, in conjunction with the effects of the prevailing ambient conditions and the volume of vehicles, may result in a model for predicting air quality at this location.

In the above sections, mention was made of the effects of CO and VOCs on the health of passengers and airport personnel at the taxi stand and the apron. The effects of these compounds

on the environment, i.e. their contribution to ground level ozone as described in the Section 3.1, should not be neglected.

Aircraft Refueling

The air sampling during an aircraft refueling operation was conducted in an effort to quantify the impact of this activity on the airport air quality. The positioning of the sample probe and the ambient air temperatures had an effect on the refueling samples.

Airport Mobile Sources

As noted at the beginning of the Discussion, there were a number of difficulties that were experienced during the sampling that necessitated sampling system modifications for future phases. The measurements involving diesel engine raw exhaust sampling proved to be the most problematic. With the probes located in the exhaust stream at the exhaust outlet during high RPM no-load operation, the sample streams were on many occasions laden with moisture. The moisture was in most cases trapped by the double particulate filter system located upstream from the analysis instrument. Though this incidence prevented moisture from contaminating the analysis instrumentation, it also resulted in void samples for some of the particulate media, condensation in some of the Tedlar bags used for total hydrocarbon samples and breakthrough in some of the 2,4-DNPH cartridges. The end result of these problems was a limited number of samples for this portion of the study, with the additional possibility of an underestimation of the total contribution of this source to the air pollution burden at the airport.

Service Vehicles

As noted previously, the test team was informed by the Hudson General operator that the majority of the service vehicles used by the company were normally started and warmed up in their parking facility prior to being used on the apron. This action is beneficial for the air quality on the apron as the observed particulate matter generated by the various configurations of service vehicle is significant for the first minutes of operation.

For the service vehicles that have similar engines, as on-road vehicles, it would be expected that the mass emissions would be comparable under loaded operating conditions. As an example, the larger aircraft tow trucks, when tested at operational RPM setting (although under no-load condition), generated approximately eight grams of CO and five grams of NO_x. For urban bus engines under idle and steady state conditions, the emissions compared to the service vehicles are as follows:

TABLE 31. Comparison of Exhaust Emission Rates-Idle (g/min)

Emission	Bus*	ClarkTow Truck-Phase I	GPU-Phase I
CO	0.57	1.1	1.5
NO_x	1.1	0.6	9
CO_2	80	123	507
THC	0.4	0.5	1

** urban transit bus powered by a Detroit Diesel 6V71*

The recorded values for the bus in this table were the result of loaded chassis dynamometer testing conducted in the MSED laboratory. Though there is some variability between sources, the emission ranges are the same with the only exception being NO_x for the GPU. For this particular source as well as the 'heaters', it was observed that the engines were operated at maximum RPM which would be conducive to high NO_x emissions.

Aircraft

For the aircraft engine testing, the measurements are limited to three different aircraft due to the difficulty in coordinating the availability of aircraft within the operator's busy flight schedules. The pretest measurements that were undertaken on the 727 - JT8D to establish the test protocol resulted in an effective system for exhaust emission determination from all forms of aircraft engines while in the operational mode on the ground. This is evident from the field measurements that were obtained in this phase of the testing. Though the JT8D exhaust emission measurements included full thrust operation for a short time period, less than three minutes, this would not be common practice as most operators are not prepared to operate their engines at this position for testing purposes. For other configurations, specifically propeller, fixed wing and rotary wing aircraft, it is not possible to run the engines at the operational power setting to simulate a takeoff mode, as the aircraft would respond accordingly. Therefore during the testing of the DASH-8 and the Ranger helicopter the propellors/rotors were in a flat pitch position. The emissions data obtained through this methodology would be a conservative value compared to actual airport operational activities.

9.0 SUMMARY

The following outline summarizes the results found from the ambient air monitoring and the mobile source monitoring at the Macdonald-Cartier International Airport.

- continuous monitoring of CO in the passenger taxi area indicated on a number of instances that the peak concentrations levels exceeded the NAAQO
- taxiway and threshold air sampling identified differences in the concentration levels of known compounds when different aircraft configurations were in the location

- continuous CO emissions monitoring on the apron identified periods of time when the NAAQO were exceeded
- most target VOC concentrations were highest at the passenger taxi area and the apron
- the program indicated, that by undertaking a thorough analysis of the various airport mobile sources, an accurate model could be developed for predicting airport air quality
- the field testing resulted in the development of a sampling system for the measurement of continuous aircraft engine exhaust emissions during ground operation
- the field testing for the airport mobile source emissions study has resulted in a number of suggestions/recommendations that have the potential to reduce the pollution burden experienced in this location

10.0 RECOMMENDATIONS

As indicated by this study, the major sources contributing to this pollution burden are the aircraft traffic, service vehicles related to the airport operation and the taxis carrying people to and from this location. As each group is distinct in design, with the service vehicles and taxis being similar in relation to their propulsion system, the techniques that could be utilized for reducing the pollution from these sources is also distinct. The following is a discussion of the techniques as they relate to the various sources.

Airport Taxi Fleet

As this fleet is comprised of light duty passenger cars, many of which are converted to a gaseous fuel, natural gas or propane, many of the available methods for reducing the exhaust emissions are equivalent to those for the equivalent gasoline vehicles. The following is a list of possible options that if implemented would have the potential effect of reducing the pollution burden presently being experienced at the taxi pick-up point at the airport.

1. All airport taxis should be subjected to an exhaust emissions inspection at least once per year. This process would ensure that the engine operation is well maintained and all of the emission control equipment is functioning properly.

2. All of the vehicles used for taxis should be operating on a gaseous fuel, either natural gas or propane, as these fuels emit less toxic compounds than a gasoline equivalent.

3. Implement restrictions on idling of vehicle in the passenger loading and unloading area. If it is necessary for the taxis to wait for a fare, it should be made mandatory that their engines be turned off during this period of time.

4. A curb level exhaust system, designed to exhaust a high percentage of the exhaust stream from the taxi's tailpipe while picking up passengers. This concept is illustrated in *Figure 22.*

Airside Service Vehicles and Equipment

As detailed in the text of this report, this fleet consists almost exclusively of the vehicles that are required for the ground operation of the airplane traffic. The majority of the vehicles at this site are powered by diesel engines. The following are methods and technologies which have the potential for reducing the pollution being emitted from this form of vehicle.

1. For the diesel powered vehicles, low sulfur diesel fuel should be used. In addition, if no. 1 and no. 2 diesels are available in the low sulphur configuration, no.1 fuel should be used as it has the potential to reduce particulate emissions.

2. These vehicles should be required to undergo an engine 'tune' check at least once per year to ensure that they are operating as efficiently as possible and all components are functioning properly.

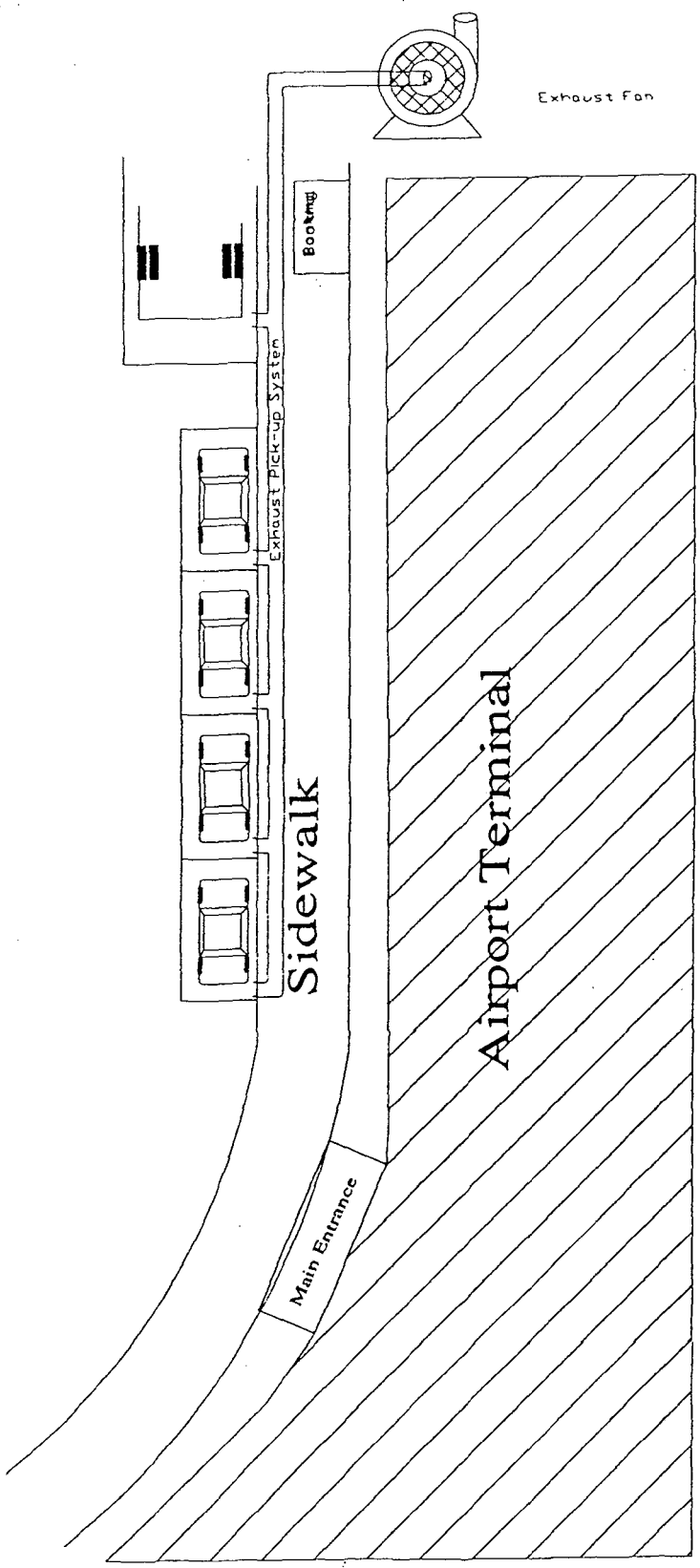
3. Consideration should be given to the use of alternative biodiesels, as 20% methyl soyate/80% commercial diesel, as a method of reducing particulate emissions. The MSED will be participating in a study in 95/96 which will evaluate the impact of this fuel on energy consumption and exhaust emissions. This information will be available for review by Transport Canada at completion of the project.

4. Depending upon the vehicle configuration and application, oxidation catalysts and particulate traps could be employed to reduce the hydrocarbon and particulate mass emissions. With the use of a particulate trap, it is possible to reduce the particulate mass emissions up to 95%. The MSED would be prepared to provide support to a pilot project to evaluate the exhaust emissions from a small fleet of airport service vehicles equipped with these technologies.

5. For vehicles powered with gasoline engines, consideration should be given to equipping the vehicles with catalyst technologies and to converting the vehicles to operate on natural gas or propane.

FIGURE 22.

Proposed Taxi Loading Area - Curb Level Exhaust Syste



Aircraft

With this form of mobile source, the options available for reducing the exhaust emissions from the propulsion engines is limited due to the application. The concepts are limited to operational procedures on the ground and to emissions reduction equipment independent of the airplane.

1. In an effort to improve the air quality on the apron, the aircraft engines should only be started and warmed up after the engines have been towed to a designated area, which is an acceptable distance from the apron.

2. As with the inspection and maintenance programs that have been implemented for on-road vehicles, a program of this nature could be developed for evaluating the exhaust emissions from the aircraft engines while being operated on the ground. For the study being described in this report, the MSED developed a sampling system to quantify the exhaust emissions from the type of engine presently being used in the aircraft industry. This system provides the capability to measure the exhaust emissions from the gas turbine exhaust stream at startup, idle and during power-up while the airplane is stationary. This information could then be evaluated against a reference standard for the engine being tested, to determine the state of operation.

3. A concept that could be explored for reducing the pollution being emitted from these engines during some of the operational functions on the ground, is the application of hydrocarbon traps and NO_x reduction catalysts. Systems of this nature would be located in designated areas for startup, warm-up and takeoff or they could be employed as portable systems on mules for relocation behind individual aircraft during these activities. At specific periods the hydrocarbon traps would be oxidized and purged.

4. As with the Auto/Oil program that was initiated for ground transportation, a similar study should be initiated to investigate the potential for reformulating the fuels used in the aviation industry. The primary objective of this government/industry/university effort would be to reduce the pollution burden from this source.

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APPENDICES

Appendix A

A 1. Characteristics of the Spectrometers

A 2. Specific Details of VOC Analysis

A 3. Method of PAH Sample Determination

A 4. Target List of PAH Compounds

Appendix B

B 1. Example Calculations for the Determination of Mass Emission Rates Detected from Service Vehicles

B 2. Example Calculations for the Determination of Mass Emission Rates Detected from Aircraft

Appendix C

C 1. Complete Listing of PAH Masses Detected from the Service Vehicles and Aircraft

A 1. Characteristics of the Nicolet FTIR

	Nicolet REGA 710	Nicolet REGA 740
Inferometer	Michelson	Michelson
Detector	Mercury Cadmium Telluride	Mercury Cadmium Telluride
Cell Path Length	20 meter	10 meter
Resolution	2 cm^{-1}	0.5 cm^{-1}

A 2. Specific Details of VOC Analysis

HP 5890 Run Conditions

Column	HP-1 60m 0.32mm 1.05um film
Oven Temperature	-50°C hold 3 minutes, 10°C/min to 50°C, 5°C/min to 200°C hold 2 minutes
Carrier Gas	Helium 17 psig @ 30°C (2.0 ml/min)
Detector Temperature	300°C

ENTECH M2000 Concentration Conditions

Nafion Dryer	25°C
High Volume Cryotrap	-171°C for concentration 180°C for desorption
Focus Trap	-191°C for concentration 150°C for injection
Sample Flow Rate	50 ml\min
Manifold transfer line	110°C
GC transfer line	110°C
Eight port valve	110°C

A 3. Method of PAH Sample Determination[23]

Polyurethane Foam Plug (PUF) Sample Preparation:

PUFs are placed into a 500 ml pre-extracted soxhlet body using clean forceps. After spiking *surrogate mixture (100ng of 7 isotopically-labelled PAH compounds) on the surface of the top* foam, PUFs are extracted overnight in 700 ml cyclohexane at a rate of 3 to 5 cycles/hour. The raw extract is then filtered through Na_2SO_4 and concentrated to < 1ml by rotary evaporation exchanging the solvent to hexane.

Analysis:

The final purified extract is analyzed under the following conditions:

Instrument:	HP 5890 GC interfaced directly to HP5970 MSD.
Injection:	1 uL, on -column.
Column:	30 m DB-5 fused silica, 0.25 mm ID and 0.25 um film thickness.
Oven Temp:	90^0C for 1 min, to 200^0C at 20 C^0/min, to 210^0C at 3 C^0/min, then to 280^0C at 5 C^0/min and hold for 15 min.
Detection Mode:	Selected Ion Monitoring
Quantitation:	The internal standard quantitation method was used for all target compounds. MS relative response factors determined for standard mixture components on the same day were used to quantitate sample levels of target analytes.

A 4. Target List of PAH Compounds

Acenaphthylene
Acenaphthene
Fluorene
2-Me-fluorene
Phenanthrene
Anthracene
Fluoranthene
Pyrene
Benzo(a)fluorene
Benzo(b)fluorene
1-Me-pyrene
Benzo(ghi)fluoranthene
Benz(a)anthracene
Chrysene/Triphenylene
7-Me-Benz(a)anthracene
Benzo(b+k)fluoranthene
Benzo(e)pyrene
Benzo(a)pyrene
Perylene
3-Me-cholanthrene
Indeno(1,2,3-cd)pyrene
Dibenx(a,h)anthracene
Benzo(b)chrysene
Benzo(ghl)perylene
Anthanthrene

B 1. Example Calculations for the Determination of Mass Emission Rates Detected from Service Vehicles[21]

Example calculation for Service Vehicles and Equipment

Measured Values
Measured outlet air flow
Radius of exhaust outlet
Shape of outlet
Measured temperature of exhaust at outlet

Calculated Values
Area of outlet pipe
Volume of exhaust flow = exhaust flow rate * area of outlet pipe

To correct volume exhaust flow for standard temperature:

$$\frac{P1*V1}{T1} = \frac{P2*V2}{T2}$$

Where P = *Pressure = 1 atm*
T = *Temperature*
V = *Volume of exhaust flow*

Calculation of mass emission rate of pollutant:

where X = pollutant

Mass Emission Rate (X) = Concentration (X) * Density (X)* exhaust volume

For Calculation of carbonyls, particulate matter and PAH mass emission rates:

$$\text{Concentration} = \frac{\text{mass of pollutant (X) on media}}{\text{flow rate} * \text{sample time}}$$

Mass Emission Rate = Concentration (X) * exhaust volume

B 2. Example Calculations for the Determination of Mass emission Rates Detected from Aircraft[21]

The calculation of dry gas mass emission rate of pollutants emitted from aircraft was based on a carbon balance equation. The measured fuel rate and the $\%CO^2$ emitted were used to calculate the air fuel ratio and the air rate through the engine. Together with the air rate and the fuel rate were used to calculate the wet gas rate and then the dry gas rate, which was used to determine the mass emission rate.

air/fuel ratio =
(lbCarbon/lbFuel)*(MolecularWeightDrygas/MolecularWeightCarbon)*(100/$\%CO_2$)+(9*(lbH_2/lbFuel)-1)

$$\text{air rate} = \frac{\text{fuel rate}}{\text{fuel/air ratio}}$$

wet gas = air rate + fuel rate

moisture produced = fuel rate * 9 * (lbH_2/lbfuel)

dry gas rate = wet gas - moisture

$$\text{dry gas rate} = \frac{\text{dry gas rate}}{\text{density of dry gas}}$$

$$\text{dry gas (ppm)} = \text{wet concentration in ppm} * \frac{\text{wet gas flow - moisture}}{\text{wet gas (ppm)}}$$

mass dry gas emission rate =
$$\text{dry gas concentration} * \text{density of the gas} * \frac{\text{dry gas rate}}{\text{density of dry gas}}$$

For the calculation of carbonyls and PAHs:

Concentration = Mass of pollutant on the media * flow rate * sample time

$$\text{Mass emission rate} = \text{concentration} * \frac{\text{dry gas rate}}{\text{density}}$$

C1. Complete Listing of PAH Masses Detected from the Service Vehicles and Aircraft

	727 Idle g/hr	727 Part Throttle g/hr	DASH 8 g/hr	Jet Ranger g/hr	Hudson General US Air Heater mg/min	Hudson General GPU mg/min
Acenaphthylene	0.10	1.35	0.05	3.18	0.15	2.70
Acenaphthene	0.17	0.93	0.05	0.22	0.20	3.17
Fluorene	0.17	1.43	0.05	0.16	0.37	2.44
2-Me-fluorene	0.45	2.93	0.09	0.26	0.32	2.52
Phenanthrene	0.16	1.35	0.11	0.29	0.68	5.70
Anthracene	*	0.13	*	0.00	0.03	0.36
Fluoranthene	*	0.14	*	0.01	0.03	0.04
Pyrene	*	0.10	*	*	0.03	0.01
Benzo(a)fluorene	*	*	*	*	0.01	*
Benzo(b)fluorene	*	*	*	*	*	*
1-Me-pyrene	*	*	*	*	*	*
Benzo(ghi)fluoranthene	*	*	*	*	0.01	*
Benz(a)anthracene	*	*	*	*	*	*
Chrysene/Triphenylene	*	*	*	*	*	*
7-Me-Benz(a)anthracene	*	*	*	*	*	*
Benzo(b+k)fluoranthene	*	*	*	*	*	*
Benzo(e)pyrene	*	*	*	*	*	*
Benzo(a)pyrene	*	*	*	*	*	*
Perylene	*	*	*	*	*	*
3-Me-cholanthrene	*	*	*	*	*	*
Indeno(1,2,3-cd)pyrene	*	*	*	*	*	*
Dibenx(a,h)anthracene	*	*	*	*	*	*
Benzo(b)chrysene	*	*	*	*	*	*
Benzo(ghl)perylene	*	*	*	*	*	*
Anthanthrene	*	*	*	*	*	*
Total	1.05	**7.99**	**0.35**	**4.10**	**1.85**	**16.54**