AIR POLLUTION EMISSIONS FROM TURBINE POWERED AIRCRAFT

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ABSTRACT

The major pollutants that are emitted by jet aircraft include: particulate matter (soot), carbon monoxide, aldehydes, hydrocarbons, and nitrogen oxides. The first of the pollutants, particulate matter (smoke), constitutes not only a visual nuisance but is also a potential health problem. The rest, which are not visible, are irritants and in high enough concentrations can be toxic.

Since pollutants emitted by jet aircraft are of the same type as those given off by a car, a direct comparison is possible. In one landing take off cycle (LTO), a four engine jet aircraft emits the same amount of particulate matter as does approximately 2500 cars in one day. The result is a dense trail of exhaust smoke that is left behind during each jet aircraft landing and take off.

Jet aircraft which use the three major New York metropolitan airports emit almost 10,000 tons/year of particulate matter and carbon monoxide. They also emit over 5000 tons/year of nitrogen oxides and almost 2000 tons/year of unburned hydrocarbon. Finally, these jet aircraft produce nearly 1000 tons of aldehydes per year. Two of these contaminants contribute significantly to the total amount of air pollution in the New York Metropolitan area. These are particulate matter (3.7% of the total

emissions) and aldehydes (3.0% of the total emissions). With regard to carbon monoxide, hydrocarbons, and nitrogen oxides, jet aircraft contribute from 0.1 to 0.7% of the total from all sources.

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INTRODUCTION

Air pollution is one of the major problems confronting most of the large cities throughout the United States. At the present time, these smog bound cities are viewing the smoke emitted by jet aircraft with increasing concern. For example, a bill has been introduced into the California legislature that would force the airlines (engine manufacturers) to modify their engines to reduce smoke. New Jersey has even gone a step further. Officials of this state have sought a court order to bar jetliners that use Newark Airport from polluting their air.

The jet aircraft has always produced smoke, but the problem was confined mainly to the military until 1959. It was during this year that the first commercial U.S. jet aircraft became operational. These jets, which used water injection for additional power during take off, emitted highly visible exhaust plumes (unburned carbon). The use of water injection was originally blamed for this excessive smoke. However, the discontinuation of this practice has not eliminated the soot produced by this type of aircraft. In fact, the higher pressure ratio jet engine of today smokes more than the older lower pressure engines due most likely to a reduced penetration of the fuel spray in the denser air. It is anticipated that the total emissions from jet aircraft will increase in the future due to the use of more powerful engines and the increasing number of flights.

The major gaseous pollutants that are given off by jet aircraft are carbon monoxide, aldehydes, hydrocarbons, and nitrogen oxides. In addition, another pollutant, particulate matter (soot), is also emitted. This last pollutant is formed in the fuel-rich boundaries of the combustion zone. The smoke that is emitted by jet aircraft is composed of these carbon particles which usually have diameters of less than 0.6 microns. Since this contaminant is highly visible, it is prime target for any future control.

With the exception of a bill passed by the California legislature in July 1969 (only restricts visible air contaminants), there are no state or federal regulations that limit aircraft emissions at this time. In addition, there are no laws that require research into this area by either the airlines or engine manufacturers. (New Jersey is putting pressure on both of these groups.) However, the Air Quality Act of 1967 specifically stated that aircraft emissions are a potential hazard. In addition, a report issued by the National Air Pollution Control Administration in December 1968 indicates that if standards are required to control aircraft emission in the future, they should be developed in a manner similar to those instituted for the automobile, that is, on a Federal basis.

DISCUSSION

Causes of Exhaust Contaminants from Turbine Powered Aircraft

A gas that is heated and then allowed to expand at a high velocity in one direction creates thrust in the opposite direction. This is the principle upon which the jet engine is based.

A jet engine essentially consists of a compressor, burners and a turbine. The compressor is employed to force high quantities of air into the engine. Fuel is burned to greatly increase the temperature of this air and thus its volume. This expanded air flows rearward through a turbine. Some of the energy of the heated air is expended in spinning the turbine blades which drive the compressor. The remainder is expelled through the exhaust nozzles creating forward thrust. Since every action has an equal and opposite reaction, the thrust that is imparted to the air (increase in velocity) exerts a force on the jet aircraft which drives it forward. The formula that is used to calculate the amount of thrust is as follows:

$$F = M (V_2 - V_1)$$

where

F = the amount of thrust

M = the mass of air heated

V_1 = the inlet velocity of the air

V_2 = the outlet velocity of the air

At take off the thrust is the greatest since the inlet air is as a very low velocity (the jet aircraft speed is very low).

The primary function of jet fuel is to burn completely and release energy in order to increase the temperature of the air entering the turbine. Therefore, it seems reasonable that any fuel capable of releasing heat would be suitable for employment in a jet engine. However, the fuel that is used must vaporize completely. In addition, it must be fluid over a wide temperature range and not leave a residue when combusted. At the present time, JET A is the designation for the fuel that is used by commercial airlines. In addition, JP-4 and JP-5 are current designations for the distillate fuel used by the Air Force and Navy, respectively. The specification for JET A states that this product (7) must release a minimum of 18,400 BTU/lb. and meet the distillation, freeze point, gravity and flash point specifications as shown in Table 1 on the following page.

The fuel used in a jet engine is injected in the form of a spray into the combustion chamber. This fuel spray is then mixed with the air and evaporated. Actual mixing of

TABLE 1

Specifications for Commercial Airline's Jet A Fuel

ASTM Distillation	Specification Minimum	 Maximum
10% Evaporation, °F	350	400
50% Evaporation, °F	-	450
90% Evaporation, °F	-	500
95% Evaporation, °F	465	-
FBP %, °F	-	550
Freeze Point, °F	-	-46
Gravity - °API @60°F	39	51
Flash Point, °F	113	150

fuel and air in the primary zone of the combustor is an extremely complex process. The rapid mixing, which is required, is accomplished by means of very high velocity air jets. These jets inject the fuel at various angles and in different size droplets which penetrate various distances into the air stream. Hawthorne and Olso (11) report that the resultant levels of turbulances are significantly higher than those found in fully developed turbulant pipe flow. The air/fuel mixture then begins to combust in the primary zone at temperatures of approximately 2000°F (19). This combustion process takes place with a quantity of air that is nearly theoretical. An excessive amount of air is not used in the primary zone to eliminate the possibility of flame blowout. However, the unburned fuel (which continues to burn as it moves through the combustion chamber) is diluted with an excessive amount of air in the secondary combustion area. This dilution while serving to burn most of the remaining fuel also reduces the temperature of the gases to approximately 800°F. This reduction in temperature is necessary before the air reaches the turbine blades.

Even though a nearly theoretical quantity of air is employed in the primary zone and an excessive quantity in the secondary zone complete combustion does not occur.

The actual burning process takes place (19) in approximately 0.001 sec. (1×10^{-3} sec.). This is an insufficient amount of time for complete fuel combustion.

In the primary combustion zone, cracking of the n-paraffins present in the fuel readily occur. These fragments are quickly oxidized. However, ring (naphthenes) and branched (iso-paraffins) hydrocarbons can lose one or more hydrogens. This results in unsaturated products which readily condense. These condensed hydrocarbons are the first step in the formation of particulate matter (soot). Aromatics, which are already unsaturated, can also form soot precursors. Actual soot particles, which eventually contain very little hydrogen, begin to grow through polymerization of these unsaturated hydrocarbons. If allowed, these carbon molecules will burn to extinction. However, the excess air that is used to cool the engine walls and turbine blades can quench these molecules. In large concentrations, these unquenched carbon molecules become visible as a dense exhaust plume (smoke). During the combustion process, carbon monoxide, nitrogen oxides, hydrocarbons, and aldehydes are also formed. These contaminants, in particular carbon monoxide, are due to an insufficient quantity of air (oxygen).

In general, the following reaction occurs in a jet engine:

JET FUEL + AIR (O_2 + N_2) = CO_2 + H_2O (Vapor) + N_2
+ SOOT + CO + NO + NO_2 + Hydrocarbons
+ Aldehydes

The first three reaction products shown above (CO_2, H_2O, N_2) are the desired combustion products. The other gases are the undesirable by-products of the combustion process.

In summary, pollutants emitted from a jet engine, particularly soot particles and carbon monoxide, are formed when there is "insufficient" mixing of air or fuel or when the fuel to air ratio is too rich. If each hydrocarbon molecule had access to an unlimited supply of air (oxygen) during the combustion process, soot formation would not occur nor would carbon monoxide be formed.

Effect of Contaminants Emitted by Turbine Powered Aircraft on the Quality of the Air

As previously indicated, the undesirable by-products of combustion from a jet aircraft engine (turbine) are:

- carbon monoxide
- particulate matter (soot)
- nitrogen oxides
- aldehydes
- hydrocarbons

At this time, neither the peak concentration of carbon monoxide nor the average for varying climatological conditions have been determined for a major air terminal. Consequently, the toxicological effect on airport employees and passengers both in the terminal and boarding (deplaning) the aircraft are unknown. When (if) the concentrations of carbon monoxide are determined in this area, the potential adverse effects will be fairly obvious since numerous toxicological studies have been conducted. In one of these studies (14) it has been reported that 2 percent carbon monoxide in the blood (carboxyhemoglobin) may impair both judgement and some psychomotor abilities. This 2 percent level can be reached with exposure to approximately 10 PPM of carbon monoxide for about 4 to 8 hours. As the concentration in PPM of carbon monoxide increases, the exposure time decreases. It has been shown (20) that carbon monoxide has a definite effect on work output. The distance that mice ran was measured during the last 3 hours of exposure to carbon monoxide. The concentration of this pollutant was varied from test period (17 hours) to test period. The higher the carbon monoxide concentration, the shorter the distance the mice covered. In fact, when exposed to 80 PPM of this gas (carbon monoxide) the mice covered only about half the distance as compared to when they were not exposed to any carbon monoxide.

Except for particulate matter, the other contaminants emitted by jet aircraft do not have a direct effect on the human body. Rather, they tend to influence the overall quality of the air. For example, nitrogen oxides (NO and NO_2) are one of the primary ingredients in the formation of smog. The action of sunlight on nitrogen oxides in conjunction with oxygen, hydrocarbons, and various other contaminants results in a series of reactions leading to the formation of photochemical air pollution (smog). In this photochemical process, significant quantities of ozone (integral part of photochemical smog) are also formed. In addition, aldehydes are responsible, though not to the extent of nitrogen oxides, for forming ozone. It has been reported (12) that 0.02 PPM of ozone is the odor threshold. In addition, the threshold for nasal and throat irritation was found (26) to be about 0.3 PPM.

Occasionally this value has been exceeded in photochemical smog episodes. Ozone is also responsible for the oxidation of sulfur dioxide to sulfur trioxide which leads to the formation of sulfuric acid (aerosol)

Hydrocarbons enter into a variety of reactions. As one would expect, paraffins are the least reactive since they are saturated molecules. Aromatics and napthtenes are next on the order of reactivity. Finally olefins are by far the most reactive. The classes of chemical reactions that may occur with hydrocarbons are as follows(25):

- reactions between the various gases
- absorption on the surface of soot particles
- reactions that require catalyst
- photochemical reactions (smog formation)
- liquid (aerosol) phase reactions
- reactions with chemical species that are found on particulate surfaces

At this time, particulate matter (soot) has proven to be more of a nuisance than potentially harmful. However, it is this contaminant that smog bound cities are viewing with increasing concern. During each landing and take off turbine powered aircraft emit a highly visible exhaust plume (particulate matter). This soot eventually settles and contributes to the general filth of the city. Particulate matter even effects the airport industry. For example, the tail areas on the Boeing 727 aircraft have to be washed daily and repainted every week to overcome their dirty appearance which results from the emissions (soot) deposited during landing (reverse thrust) (23).

Contribution of Turbine Powered Aircraft to the Total Air Pollution Problem

The two major factors which affect the quantity of soot and the various other pollutants emitted by a jet aircraft are:

a) the time required for a landing take off (LTO) cycle.

b) the amount of fuel consumed.
  - the type (design) engine
  - the size of the engine
  - the number of engines per aircraft
  - the load carried by the aircraft
  - the temperature of the air

It has been estimated that the time for a landing take off (LTO) cycle for a four engine commercial jet aircraft is approximately 19 minutes (4). This (LTO Cycle) takes into account all the usual operations performed by an aircraft below a particular altitude (3500 feet). These operating modes include taxiing from the terminal, take off and climb out. They also take into account approach, once below 3500 feet, landing and taxiing to the terminal. For analysis purposes it will be assumed that emissions above 3500 feet do not reach the ground. In addition, it will be assumed that all emissions below 3500 feet contribute equally to the total amount of ground contamination. These simplifying assumptions are almost always employed (24) when evaluating the amounts of the various pollutants emitted by jet aircraft.

Provided in Table 2 is a breakdown of the elapsed time (4) for the various segments of an LTO cycle. In additon, estimates of the amount of fuel consumed (4) by a jet for each part of the cycle are provided. The quantity of the various pollutants emitted by jet aircraft will be determined in a latter part of this paper based on the information provided in Table 2. As shown, the total estimated time for an LTO cycle for a jet aircraft such as a Boeing 707 using four Pratt and Whitney JT3C-6 engines is 18.8 minutes. Note that only 3.5 minutes is allocated to taxiing from the terminal to the end of the runway. At many airports such as Kennedy (New York), the actual taxi time due to air traffic congestion can be 10 to 20 times greater. Therefore, the estimated quantity of fuel (approximately 777 gallons) that is consumed during each landing take off cycle can be significantly higher. In addition, the amount of pollutants emitted for each LTO cycle will be substantially greater.

In the United States the total demand for kerosene type jet fuel used by commercial airlines keeps increas-

TABLE 2

Estimated Time for a Jet Aircraft

Landing Take Off (LTO) Cycle

Aircraft Operation	Elapsed Time (Minutes)	Fuel Consumed (Gals/Jet)[1]
A) Departure to 3500 feet		
Taxi from terminal to end of runway	3.5	21
Take off and climb out	3.2	340
B) Arrival from 3500 feet		
Taxi from end of runway to terminal	4.5	27
Approach and landing	7.6	389
TOTAL (LTO Cycle)	18.8	777

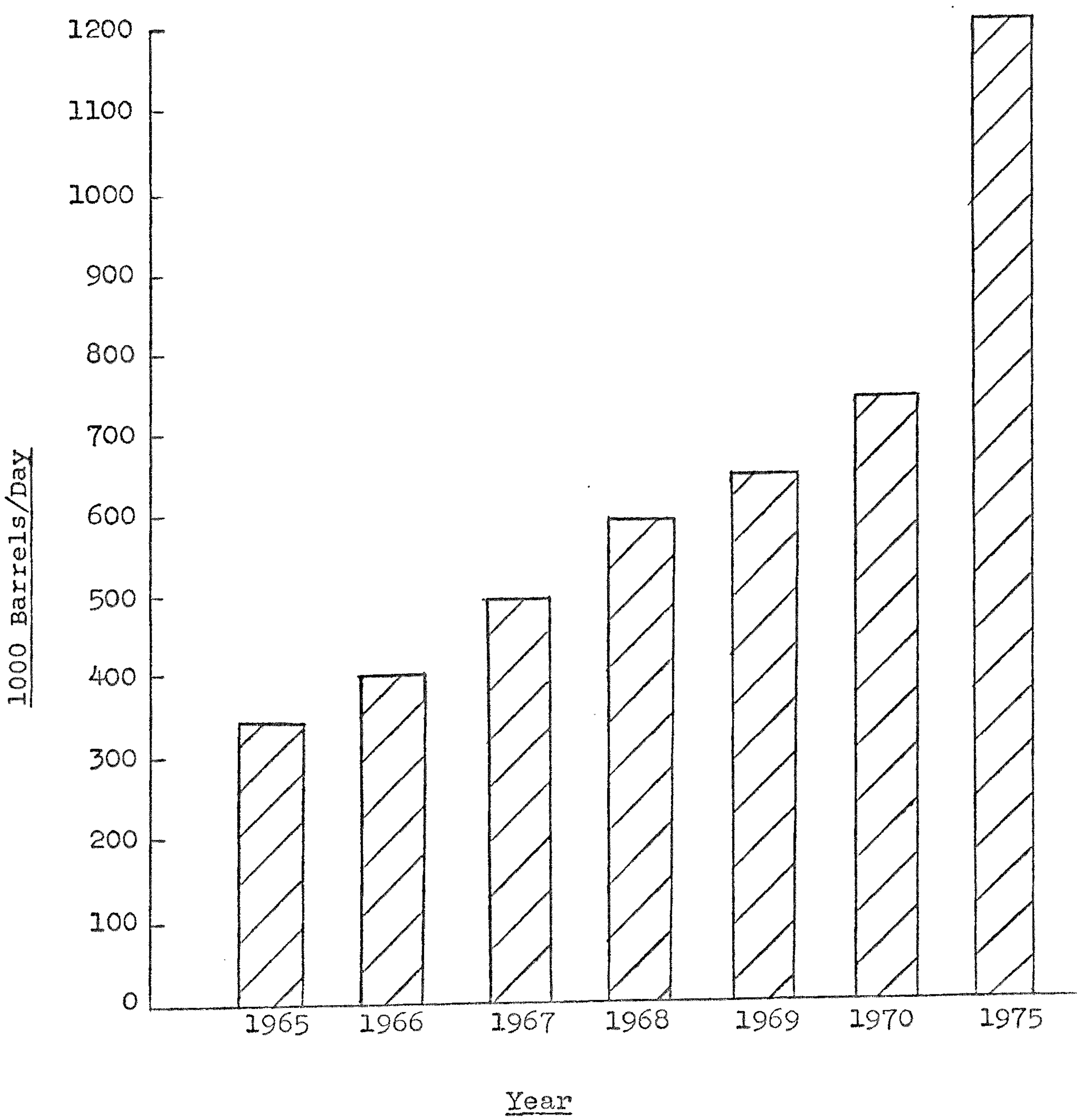
(1) Based on an aircraft using four Pratt and Whitney JT3C-6 engines such as a Boeing 707.

ing. Plotted in Figure 1 (17) are past, present and projected commercial demands for jet fuel. Note that the various airlines in 1968 used approximately 600,000 barrels per day (25,000,000 gallons per day). Also note that this consumption of middle distillate fuel is anticipated to reach 1,200,000 barrels per day in 1975 which is double the 1968 demand. In addition, the first Boeing 747 Jumbo jet will be delivered to Pan American by the end of 1969. These jets, which are twice as powerful as today's Boeing 707, (41,000 lbs. of thrust per engine as compared to 18,500) will consume more than twice as much fuel as today's biggest transports. If the introduction of these jets results in a great increase in the number of people flying due to a projected fare reduction, the 1975 fuel demand will have to be revised upward.

At this point it is interesting to note that a report by the Aerospace Industries Association (1) states that a complete study of the smoke produced with various fuels suitable for jet aircraft use showed that no real reduction in smoke could be attained by judiciously selecting a fuel. A number of fuel additives were also evaluated. It was found that some were effective but that they caused harmful side effects such as deposits on the turbine blades. Therefore, the antismoke additives that are commercially avail-

FIGURE 1

Commercial Airline Demand for Jet Fuel



able today are completely unsatisfactory for use in jet engines.

Since the pollutants emitted by jet aircraft are of the same type as those given off by a car (carbon monoxide, particulate matter, aldehydes, hydrocarbons, and nitrogen oxides), a direct comparison is possible. A car consumes approximately 800 gallons of fuel in a year. (This is nearly the same quantity used by a jet for one LTO cycle.) This yearly usage of fuel is based on the assumption that a car averages 15 miles per gallon and is driven 12,000 miles in a year. Another way to express the same relationship is; in one LTO cycle a jet consumes the same quantity of fuel as does 365 cars in one day. Shown in Table 3 is a comparison of the amounts of the various pollutants (lbs./1000 gals. of fuel) emitted by both jet aircraft and automobiles (16 and 21).

As shown in Table 3, a four engine jet aircraft contributes approximately seven times the amount of particulate matter in lbs./1000 gals. of fuel as does the automobile. (During one landing take off cycle a jet aircraft produces the same amount of soot as is emitted by approximately 2500 cars in operation for one day.) The result is a thick trail of exhaust smoke that is left behind during each landing and take off. In addition,

TABLE 3

Comparison of Emissions for Aircraft (Below 3500 Feet) and Automobiles

	lbs/1000 gals. of Fuel	
Contaminant	Aircraft[1]	Automobile[2]
Particulate matter	80	11
Carbon Monoxide	81.5	1700
Aldehydes	7.5	4
Hydrocarbons	17.3	300
Nitrogen Oxides	50	90

(1) Based on a four engine aircraft containing Pratt and Whitney JT3C-6 engines using water injection on take off.

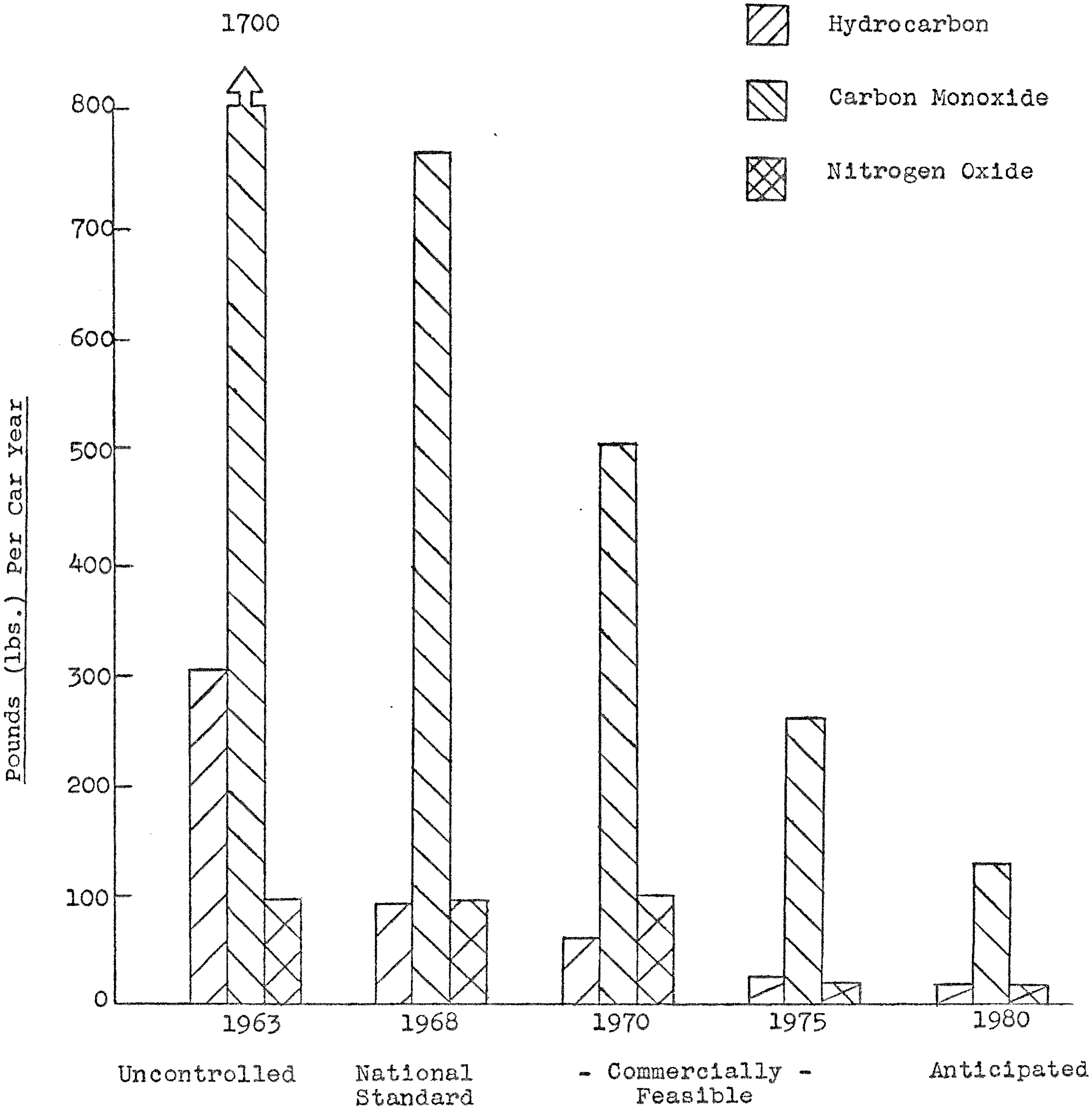
(2) Without emission control devices.

jet aircraft contribute approximately twice the amount of aldehydes in lbs. per 1000 gallons of fuel. Another way to express the same relationship is that during one LTO cycle a jet aircraft emits the same amount of aldehydes as is exhaust by nearly 650 cars in one day of normal driving. With regard to the amount of hydrocarbons, nitrogen oxides, and carbon monoxide emitted per 1000 gallons of fuels consumed, the automobile exceeds the jet aircraft. However, a four engine jet far surpasses the automobile in the amount of these pollutants emitted during each LTO cycle. For example, approximately 150 times as much nitrogen oxide is emitted during one LTO cycle as is given off by a single car in one day. In addition, over 20 times as much carbon monoxide and nearly 25 times as much hydrocarbons are emitted by a jet as compared to an automobile.

The data provided in Table 3 are for cars without emission control devices. When this equipment is installed on these vehicles, jet aircraft will contribute a significantly greater percent of the various pollutants (based on emission per 1000 gallons of fuel). Shown in Figure 2 are data comparing the past, present and estimated future hydrocarbons, carbon monoxide, and nitrogen oxide emission levels for automobiles. Note that in 1963 each car

FIGURE 2

Present and Anticipated Automobile Exhaust Emission Levels



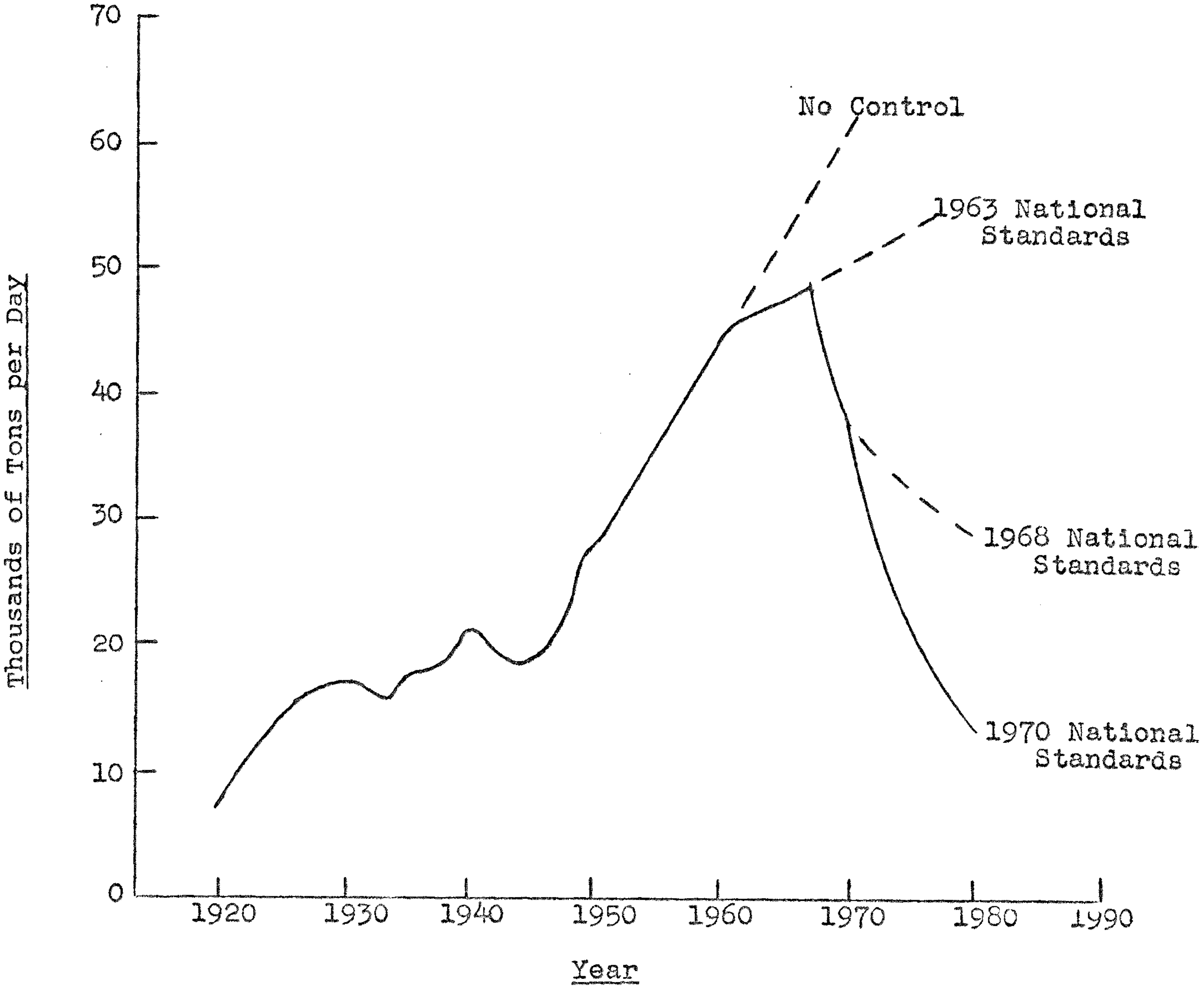
emitted approximately 300 lbs. of hydrocarbons per year. In addition, these vehicles emitted 1700 and 90 lbs. per year of carbon monoxide and nitrogen oxides, respectively. In 1962 the first regulations aimed at reducing tail pipe emissions took effect. These standards were established by California and were only for new cars produced in that year and for sale in that state. The emission control equipment installed on these vehicles consisted of an orifice type PCV valve (PCV = Positive crankcase ventilation), which was designed to trap the blowby gases that formerly escaped through the road draft tube. The following year the Federal government required that PCV valves be installed on all new cars. In 1966 both the Federal government and the state of California introduced even more stringent standards. (The air pollution limits established by the Federal government took effect in 1968.) The 1966 air pollution standards required installation of equipment (redesign of certain engine parts) to reduce the volume of carbon monoxide and hydrocarbons in the exhaust gases discharged from the tail pipe. As shown in Figure 2, the national standards that took effect in 1968 have cut the amount of hydrocarbons and carbon monoxide emitted by new cars to 70 and 750 lbs. per year, respectively. This is a reduction of more than 50 percent over the uncontrolled 1963 level. As of 1970 these standards will be revised (9). The allowable amount of tail pipe emissions will be reduced, and regulations effecting evaporative emissions will take effect. A system has been designed which will trap and hold for future combustion in the engine that gasoline that now evaporates from the gas tank and the carburetor. As shown in Figure 2, the amount of carbon monoxide and hydrocarbons emitted as of 1970 will be 500 and 70 lbs. per car year, respectively. To date all of the standards that are in effect have been aimed at reducing the amount of carbon monoxide exhausted, and the quantity of hydrocarbons exhausted and evaporated. Standards for controlling the amount of nitrogen oxide emitted are not in effect today since automotive technology has not developed to the stage where this pollutant can be effectively controlled (18). However, it is hoped that by 1975 it will be commercially feasible to control even this pollutant. The automobile industry is tentatively planning to recycle some exhaust gases back to the carburetor (or intake manifold) in order to lower peak combustion temperatures. This will lower the volume percent of nitrogen oxides in the exhaust gases. By 1975 the contaminants that are emitted by cars will be approximately 20 lbs. per year of hydrocarbons and nitrogen oxides and about 250 lbs. per year of carbon monoxide. By 1980 these levels will be again reduced in half.

It has been estimated (18) that there will be almost 300 million cars by the year 2000. This is nearly three times the amount of vehicles in operation today. With the emission controls in effect today and those that have been proposed, the total hydrocarbon level (18) in the year 1980 will be approximately the same as in 1925. A summary of the controls discussed above (national standards) and their effect on hydrocarbon emission are provided in Figure 3. Note that each succeeding emission control has significantly reduced the amount of hydrocarbons. As previously indicated, the reduction in carbon monoxide and nitrogen oxide emissions even though that will not be as great as those for hydrocarbons, will nevertheless be substantial.

It is interesting to note that the control of automobile emissions is a very complex problem. The auto industry has been forced by the establishment of Federal and State Standards over the past seven years to take steps to reduce these emissions. It is evident that this program is far from complete even after all these years. With regard to control of jet aircraft emissions, not even the most preliminary legislation has been enacted. If development of standards follow those for the automo-

FIGURE 3

Total Automobile Hydrocarbon Emissions in the U. S.



bile, it would probably be five to ten years before the trend of increasing pollution from jet aircraft is reversed.

With an automobile the amount of emissions varies depending on the driving condition. Similarly during a jet aircraft landing take off cycle, the amount of pollutants emitted vary to a great extent. Shown in Table 4 is an estimation of the average level of emissions in pounds per jet for each phase of this cycle:

- taxiing to and from the terminal
- take off and climb out
- approach and landing

The data (4) provided in Table 4 are based on a four engine jet aircraft containing Pratt and Whitney JT3C-6 turbojet engines employing water injection take off. They are also based only on emissions below 3500 feet. Note from these data that the greatest quantity of nitrogen oxides and hydrocarbons are emitted during approach and landing. It is during take off and climb out that the greatest amount of particulate matter is given off. More than four times the amount of this pollutant is emitted during take off and climb out as compared to taxiing to and from the terminal. It is this last pollutant, soot, which is evident as a dense smoke plume that is causing the greatest public

TABLE 4

Average Jet Aircraft Emissions
For Each Phase of the LTO Cycle

	Pounds Per Jet Aircraft			
Contaminant	Taxi To and from Terminal	Take Off and Climb Out	Approach and Landing	Total LTO Cycle
Particulate matter	7.4	31.4	23.5	62.3
Carbon Monoxide	40	11.2	12.2	63.4
Aldehydes	2.3	0.8	2.7	5.8
Hydrocarbons	2.5	4.3	7.7	14.5
Nitrogen	1.6	8.6	29	39.2

NOTE: Based on a four engine aircraft containing Pratt and Whitney JT3C-6 turbojet engines with water injection during take off. Also based only on emission below 3500 feet.

concern. However, the other pollutants such as carbon monoxide and nitrogen oxides are potentially more harmful (25). With regard to carbon monoxide, it is during idle (taxiing to and from the terminal) the greatest average quantity is produced. In fact, nearly four times as much is emitted as is given off during either the take off and climb out or approach and landing cycles. As aircraft spend increasingly greater amounts of time idling (waiting for take off), significantly greater amounts of carbon monoxide are emitted. As previously indicated, at many airports such as Kennedy jets often spend as long as 30 minutes idling due to air traffic congestion. Therefore, the amount of carbon monoxide emitted during idle for each LTO cycle can be as high as 400 lbs. In addition, peak emission density for carbon monoxide according to a report by the Secretary of Health, Education and Welfare (24) may be as much as 20 times the average. Exposure to very high concentrations of all the various pollutants emitted can occur under conditions of heavy airport traffic. According to some very preliminary calculations (6), the total concentration of all the various exhaust contaminants can reach 75-300 PPM level in the aircraft cabin during idle and taxi.

The jet aircraft emissions provided in Tables 2 and

4 represent one set of pollution data available at this time. It should be recognized that data on aircraft emissions have been generated by a number of different investigators (4, 13, 24). These data vary to a certain extent since they are based on different jet engines. For example, the Air Pollution Control District of the County of Los Angeles originally evaluated Pratt and Whitney JT3C-6 turbojet engines. On the other hand, Hochheiser and Lozano at a later date studied Pratt and Whitney JT8D and TF33 engines. These are newer types of propulsion engines which were not in commercial use when the Los Angeles Air Pollution Control District originally evaluated air contamination from jet aircraft. There is also another factor which contributes to the variation in emission data. That is, the values have been gathered using slightly different testing techniques. As a result, the data will differ even if the same engines were evaluated.

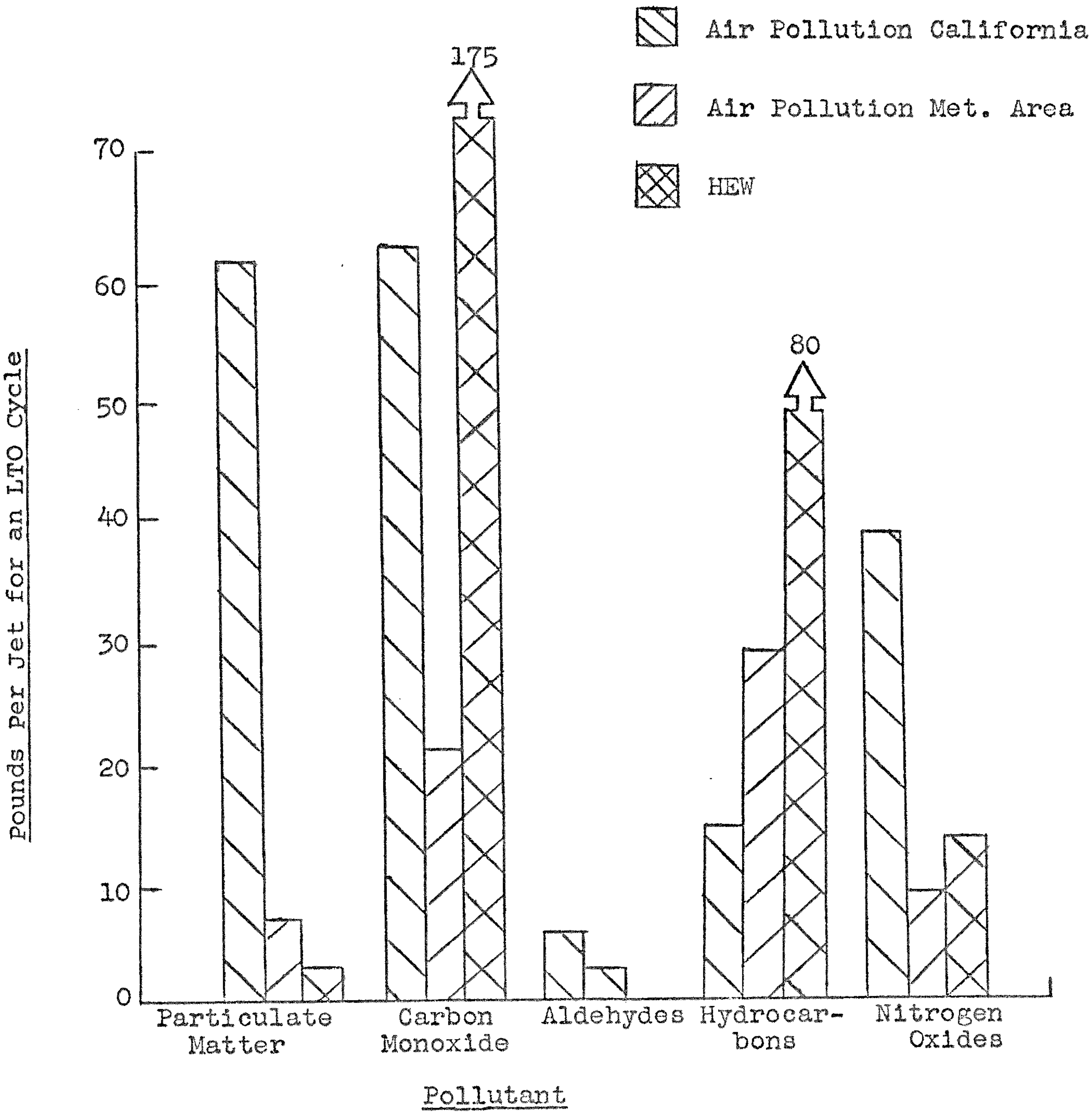
One of the testing techniques (15) employed consisted of the installation of sample probes in the exhaust pipes of a test stand jet engine. Due to the exceptionally high temperatures, stainless steel tubing was used for the sampling lines. Samples were continually taken from a manifold, which was approximately 40 feet from the engine in a control room, until reproduceable data were obtained. The exhaust gases were analyzed using various test methods. For example, an infrared spectrometer was used to determine the amount of carbon monoxide and a flame ionization detector to ascertain the quantity of hydrocarbons present.

At the present time there are a number of methods (22) used to measure smoke. These include optical systems (B. P. Hartridge Smoke Meter), quantitative gravimetric system (Bosch Spot System) and the so called soiled tape methods used by General Electric. However, it has proven very difficult to accurately determine the magnitude of the soot (smoke) emitted since it is a very complex variable. In addition, once the smoke is "measured" a correlation is necessary between this determination and the visibility of the exhaust plume.

In general, the measurement technology that applies to jet aircraft emission, particularly in the area of the characterization of smoke is in the early stages of development (24). Since these testing techniques (not only for the determination of smoke but also for the other contaminants) may not be completely precise and reproduceable, and since different engines were studied, data on jet emissions for an LTO cycle taken from three sources (4, 13, 24) are provided in Figure 4. These emission values are all

FIGURE 4

Comparison of Emission Data from Various Sources
(Based on a four engine jet aircraft)



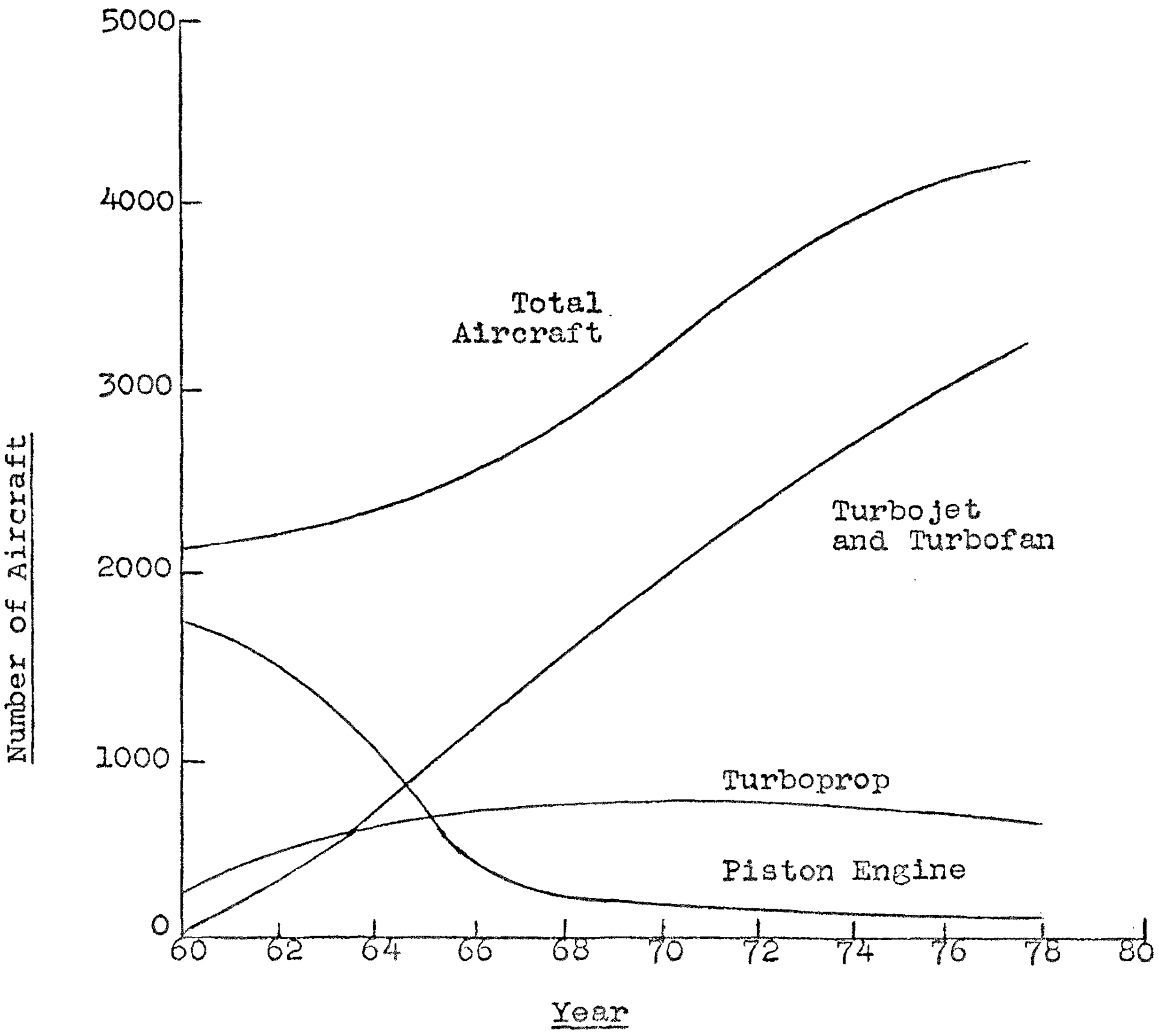
NOTE: information on aldehyde emission is not available in HEW report.

based on a four engine jet aircraft. Note that the report by the California Air Pollution Department gives the highest values for the amount of particulate matter, aldehydes, and nitrogen oxides emitted. On the other hand, the report by the Secretary of Health, Education and Welfare provides the greatest values for carbon monoxide and hydrocarbon emission. In no case does the SAE paper (Air Pollution Emissions from Jet Aircraft Operating in New York Metropolitan Area) written by Hochheiser and Lozano give the highest level of emissions for any of the pollutants. It does, however, provide the second highest values for the amount of hydrocarbons and nitrogen oxides emitted. As previously indicated, the Los Angeles Air Pollution Control District used Pratt and Whitney JT3C-6 engine. Hochheiser and Lozano (Air Pollution Emissions from Jet Aircraft Operating in New York Metropolitan Area) employed Pratt and Whitney JT8D and TF33. The third source of data, the HEW report, does not specify the type of engines used in determining the emission values.

Since commercial airlines account for over 90% of all the activity (consume approximately 98% of the fuel not used by the Air Force) at most major terminals, the size and composition of these fleets are important. In Figure 5, the composition of these fleets are provided (2).

FIGURE 5

Composition of the United States Air Carrier Fleet



In addition, it shows how these fleets have changed in numbers and composition since 1960. It also provides a prediction of the type and amount of aircraft that will be in service in 1978. Shown in the Figure are the three types of jet engines; turbojet, turbofan, and turboprop. Features common to each are a compressor, a segmented combustion section, a multistage turbine, and exhaust nozzle. The turbofan comprises the economy of the turboprop (contains a propeller) and speed of a turbojet (air enters directly into the compressor). On the other hand, the turbofan engine contains a fan (propeller) that is the size of the compressor and operates at approximately ten times the propeller speed.

Note from Figure 5 that the number of aircraft are projected to increase 50% between the base year of 1968 and 1978. In addition, these aircraft will be almost all turbine powered. The piston aircraft which comprised the commercial fleets during the 1950's and which were still in evidence during the early 1960's, will almost be nonexistent. The number of turboprops which were the first commercial turbine powered aircraft, will remain approximately the same.

The type of turbine powered aircraft very greatly. Therefore, the quantity of the various pollutants emitted per jet will also vary, based on the engine:

- type (particular model)
- size (thrust capabilities)
- number on each aircraft

Shown in Table 5 is a summary (13) of the type of jet aircraft operated by the various scheduled airlines at Newark, Kennedy and LaGuardia. Also included is a lising of the representative engines used in these aircraft. Note that there are both long range (Boeing 707, Douglas DC-8) and medium range (Boeing 727, Douglas DC-9) jet transports servicing the New York Metropolitan area. In addition, there are still a small number of turboprop transports such as the Lockheed Electra in use.

In this study the amount of contaminants emitted will be based on long range jet transport powered by <u>four</u> Pratt and Whitney JT3C-6 turbojet engines. Emission data (13) for the various jet transports, classified according to their size, are provided in Figure 6. As shown particulate matter and hydrocarbon emissions are greatest for the long range jet transport (4 engines). However, carbon monoxide and nitrogen oxide emissions are greatest for the three engine medium range type jet transport. The JT8D engine used in the Boeing 727 (3 engine) and Douglas DC9 (2 engine) emit more of these two pollutants <u>per engine</u>

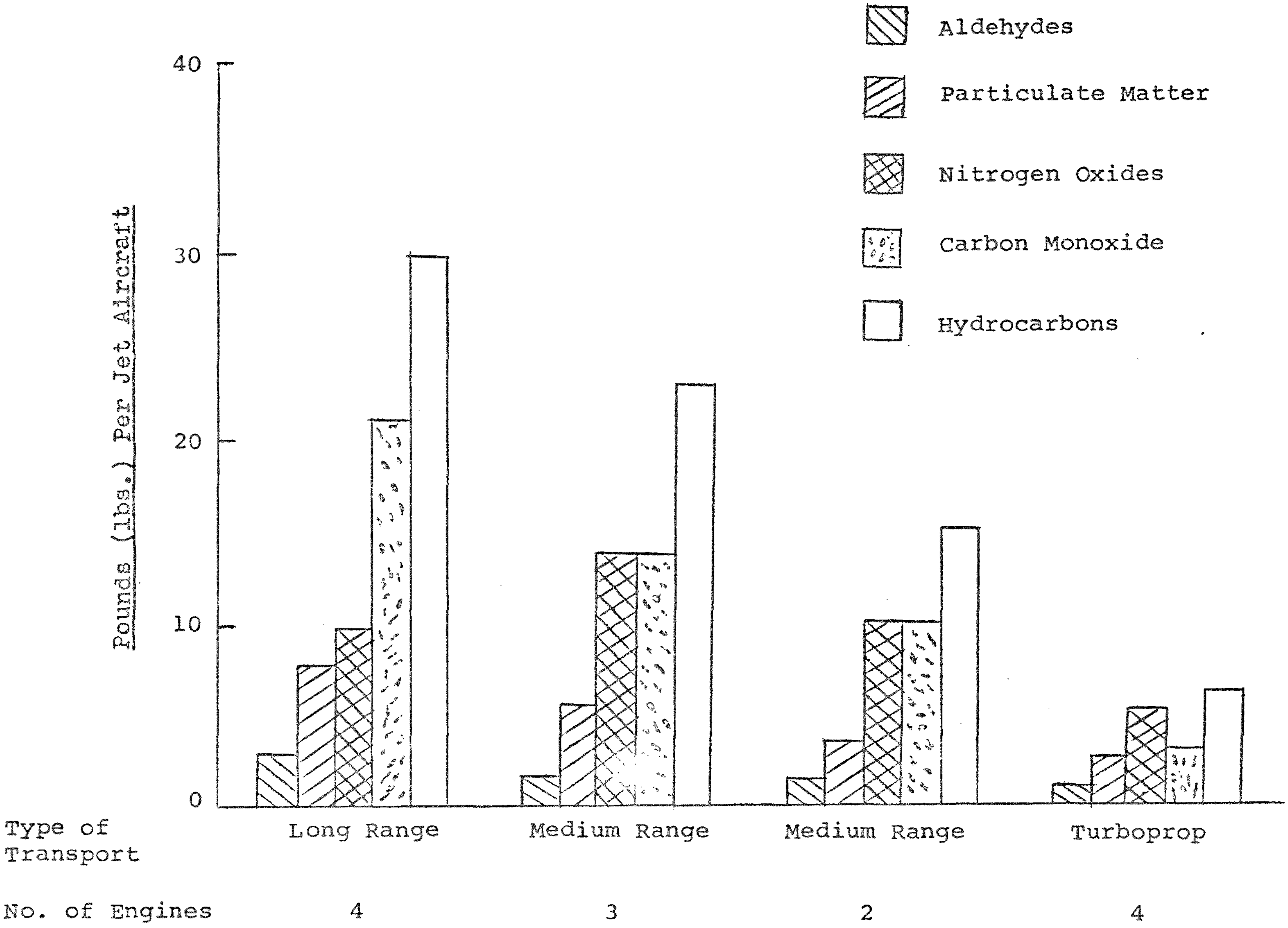
TABLE 5

Examples of Jet Aircraft Operated By Commercial Airlines in the New York Area

Aircraft Type	Examples	Representative Engine		Number of Engines
		Manufacture and Models	Type	
Long range transport	Boeing 707	Pratt & Whitney JT3D	fan	4
	Douglas DC-8			4
	Boeing 720			4
	Convair 880			4
Medium range transport	Boeing 727	Pratt & Whitney JT8D	fan	3
	Douglas DC-9	Pratt & Whitney JT8D	fan	2
	SUD Caravelle			2
Turboprop transport	Lockheed Electra	Allison 501-D13	prop	4
	Lockheed L-100			4
	Vickers Vanguard			4
	Vickers Viscount			4

NOTE: The engines shown above are representative of their particular group. Many other model engines produced by different manufacturers are also employed.

Comparison of Pollutants Emitted by Various Types of Jet Aircraft



than the JT3D used by the Boeing 707 (4 engine) and the Douglas DC8 (4 engine). Note in Figure 6 that a 4 engine turboprop transport produces the least amount of all various air pollutants (hydrocarbons, carbon monoxide, particulate matter, aldehydes and nitrogen oxides). A new factor in the type and quantity of emissions will be the introduction in 1970 of the Boeing 747 (17). This aircraft will be powered by four Pratt and Whitney JT9 engines (41,000 lbs. of thrust) and consume more than twice the quantity of fuel per mile as does the Boeing 707.

Aircraft operations at the three New York metropolitan airports (13), Newark, Kennedy, and LaGuardia, are shown in Table 6. Provided are the average number of LTO cycles that took place at each of these airports per day in 1967. As indicated, Kennedy Airport handles more commercial traffic than both Newark and LaGuardia combined, 464 landing and take-offs per day. The latter two airports handle approximately the same number of commercial flights. This gives a total number of LTO cycles of approximately 800 per day in 1967 from the three major New York metropolitan airports. For comparison purposes, the total number of LTO cycles for turbined powered aircraft per day for the nation (913 FAA controlled terminals) is approximately 11,000 (24). In addition there are almost 3000 LTO cycles per day from piston engine aircraft in the country.

TABLE 6

Average Number of LTO Cycles Per Day in 1967
At the Three New York Airports

Area	Turbojet and Turbofan (No. of Engines) 4	3	2	Turboprop No. of Engines 4
Kennedy	310	83	18	53
LaGuardia	0	78	77	18
Newark	37	59	32	35
- Total	347	220	127	106
- GRAND TOTAL		800		

The amount of the various pollutants emitted in tons per year at the three major New York metropolitan airports are provided in Table 7. These data are based on Tables 4 and 6. (Table 4 provides data on the level of emissions in pounds per jet for each phase of the LTO cycle; Table 6 provides information on the average number of LTO cycles.) As previously indicated, the amount of pollutants emitted are based on a four engine jet transport. It should be noted that the actual quantity of the various pollutants emitted for all jet aircraft (an average emission value) will be slightly less. It has been determined (10) that the average number of jet engines on an aircraft using the Los Angeles International Airport is 3.44. It is reasonable to assume that this value is also applicable for turbine powered aircraft using the New York Metropolitan airports (Kennedy, Newark and LaGuardia).

As shown in Table 7, Kennedy Airport accounts for over half the pollutants emitted by jet aircraft in the New York area. This is expected since more than 50% of the aircraft operating out of three metropolitan airports use Kennedy. As shown, the total amount of particulate matter and carbon monoxide emitted in a year is approximately 9000 tons (18,000,000 pounds per year). This is nearly 50,000 pounds per day. With regard to nitrogen oxide, and hydrocarbons, jet aircraft emit approximately

TABLE 7

Contaminants Emitted in Tons/Year by Jet Aircraft Using the Three New York Airports

	Pollutant Emitted (Tons/Year)				
New York Airport	Particulate Matter	Carbon Monoxide	Aldehydes	Hydro-carbons	Nitrogen Oxide
Kennedy	5200	5350	490	1140	3320
LaGuardia	1950	1980	180	420	1230
Newark	1840	1870	170	400	1160
- Total	8990	9200	840	1960	5710

3300 tons per year (18,000 pounds per day), and 1100 tons per year (6,000 pounds per day), respectively. Finally 2800 pounds per day of aldehydes (490 tons per year) is given off by jet aircraft operation in the New York metropolitan area. The amount of pollutants emitted by piston powered aircraft would increase the values provided in Table 7 by less than 10% (24).

The emission values provided in Table 7 are based on data generated by the Air Pollution Control District of the county of Los Angeles in 1960. As previously pointed out, data on aircraft emissions (Figure 4) have been generated by a number of different investigators. These values, which are based on different jet engines and have been gathered using slightly different testing techniques, vary to a certain extent. Therefore, minimum, maximum and average emission values for a four engine jet aircraft are provided in Table 8. For comparison purposes, the emission data found in Table 4 are also provided. Note that the amount of particulate matter and nitrogen oxides emitted are greater than the average for Table 4 (Los Angeles investigators). On the other hand, the amount of carbon monoxide and hydrocarbons are substantially less. The average amount of aldehydes and the quantity given in Table 4 are approximately equivalent. If these average

TABLE 8

Minimum, Maximum and Average Emissions For a Four Engine Jet Aircraft

Air Pollutant	Pounds Per Jet Aircraft For an LTO Cycle			From Table 4
	Minimum	Maximum	Average	
Particulate Matter	2.8	62.3	24.1	(62.3)
Carbon Monoxide	20.6	175	86	(63.4)
Aldehydes	2.2	5.8	4.0	(5.8)
Hydrocarbons	13.5	89.7	44.6	(14.5)
Nitrogen Oxides	9.2	39.2	20.9	(39.2)

aircraft emission data are employed, the values found in Table 7 will vary. The amount of various contaminants emitted in Tons/Year using these average values are as follows:

particulate matter - 3470
carbon monoxide -12400
aldehydes - 580
hydrocarbons - 6100
nitrogen oxides - 3100

Provided in Table 9 is a summary of the type, source, and quantity of the major air pollutants emitted in the United States as listed by the U.S. Public Health Service. These data are based on 1966 emission levels. As shown, the automobile is the largest single source of most of the contaminants (carbon monoxide, hydrocarbons, and nitrogen oxides). This vehicle produces approximately 90 percent of all the carbon monoxide and over 60 percent of all the hydrocarbons. It is also responsible for almost 50 percent of the nitrogen oxides emitted. Power generation and other industry sources produce the greatest quantity of sulfur oxides and particulate matter. It is interestingto note that in 1966 the jet aircraft was not considered to be a major contributor to any of the various contaminants listed in Table 9. Based on this study (Thesis), however, the jet aircraft should also be listed as a major source of air pollution.

TABLE 9

Major Air Pollutants Emitted in the U.S. in 1966

Source of Contaminant	Pollutant Emitted (Millions of Tons/Year)				
	Particulate Matter	Carbon Monoxide	Hydrocarbons	Nitrogen Oxide	Sulfur Oxide
Motor Vehicle	1	66	12	6	1
Industry & Power	9	3	5	5	21
Refuse Disposal	1	1	1	1	1
Space Heating	1	2	1	1	3
- Total	12	72	19	13	26

Provided in Table 10 is an estimation of the amount of the various pollutants emitted in 1966 in the New York metropolitan area. This information is from the New York/ New Jersey Air Pollution Abatement Activity, Abatement Program, National Center for Air Pollution, Cincinnati, Ohio.

The data shown in Table 10 indicate that carbon monoxide is by far the leading pollutant. Over five million tons of carbon monoxide is emitted in the New York metropolitan area each year by jet aircraft, cars, power plants, incinerators, space heaters, industrial plants, etc. The other pollutants are found in the following decreasing order: Hydrocarbons, nitrogen oxides, particulate matter, and aldehydes. Based on the New York area consisting of approximately 3000 square miles, the density of various pollutants in tons per square mile for each day are as follows:

- particulate matter - 0.22 tons/mi^2
- carbon monoxide - 4.80 tons/mi^2
- aldehydes - 0.025 tons/mi^2
- hydrocarbons - 1.28 tons/mi^2
- nitrogen oxides - 0.70 tons/mi^2

It is interesting to note that in New York City the density of the various pollutants is four to eight times greater

TABLE 10

Total Amount of Air Pollutants Emitted in 1966 in the New York Area

Area	Pollutants (thousands of tons per year)				
	Particulate Matter	Carbon Monoxide	Aldehydes	Hydro-carbons	Nitrogen Oxides
New Jersey[1]	104	2,510	12	620	333
New York City[2]	101	1,628	11	473	334
New York State[3]	36	1,160	5	319	102
- Total	241	5,298	28	1,412	769

1. New Jersey includes; Bergen, Essex, Hudson, Middlesex, Morris, Passaic, Somerset and Union Counties.

2. New York City includes; Bronx, Brooklyn, Manhattan, Queens and Staten Island.

3. New York State includes; Nassau, Rockland and Westchester Counties

than found in either New Jersey or other parts of New York State. For instance, the density of carbon monoxide in tons per square mile for each day is 3.5 in New Jersey and 3.98 in New York State as compared to 16.3 in New York City.

In the United States there has been an increasing trend toward urbanization. Provided on Table 11 are the anticipated urban population distribution (21). Note that in 1960 there were 78 major metropolitan areas with over 50,000 people. By 1980 this number will increase 40 percent to 117. In addition, there will be 145 cities (over 50,000 people) in the year 2000. At that time, nearly two thirds of the people will be living in these urban areas. Coupled with the urbanization has been the growth of airports. These airports were originally located outside of the cities. However, urban areas have grown up and now surround many of these airports. This is particularly true in the New York metropolitan area where all three airports (Kennedy, LaGuardia and Newark) are located in densely populated areas. Being situated in an urban area, it is only natural that these airports have become a nuisance. In addition to noise and traffic congestion, they tend to aggrevate New York's air pollution problem.

TABLE 11

Anticipated Urban Population Distribution

Area	Metropolitan Area (Over 50,000 Population Number of Cities	 % of Population
1960	78	48.3
1980	117	59.4
2000	145	65.9

Shown in Table 12 are the relative contribution of jet aircraft to the total amount of air pollution in the New York metropolitan area. It is clearly seen from these data that jet aircraft contribute significantly to the total amount of particulate matter (3.7% of the total) and aldehydes (3.0% of the total) emitted in the New York area. With regard to carbon monoxide, hydrocarbons, and nitrogen oxides, jet aircraft contribute from 0.1 to 0.7% of the total from all sources. These percentages are based on aircraft emission data generated by the Air Pollution Control District of the County of Los Angeles (Table 4) and applied to the New York metropolitan area.

Provided in Figure 7 are the minimum, maximum, and average percentage. These values are based on Table 8 (minimum, maximum and average aircraft emission values) and Table 6 (average number of LTO cycles per day in 1967). Note from Figure 7 that the average percent of particulate matter, aldehydes and nitrogen oxides are less than those provided in Table 12. On the other hand, the contribution of jet aircraft to the total from all sources is greater for carbon monoxide and hydrocarbons in Table 12. Even if the lowest emission values found in either the table or the figure are used, it is clearly seen that turbine powered aircraft contribute significantly to the air pollution problem in the New York area.

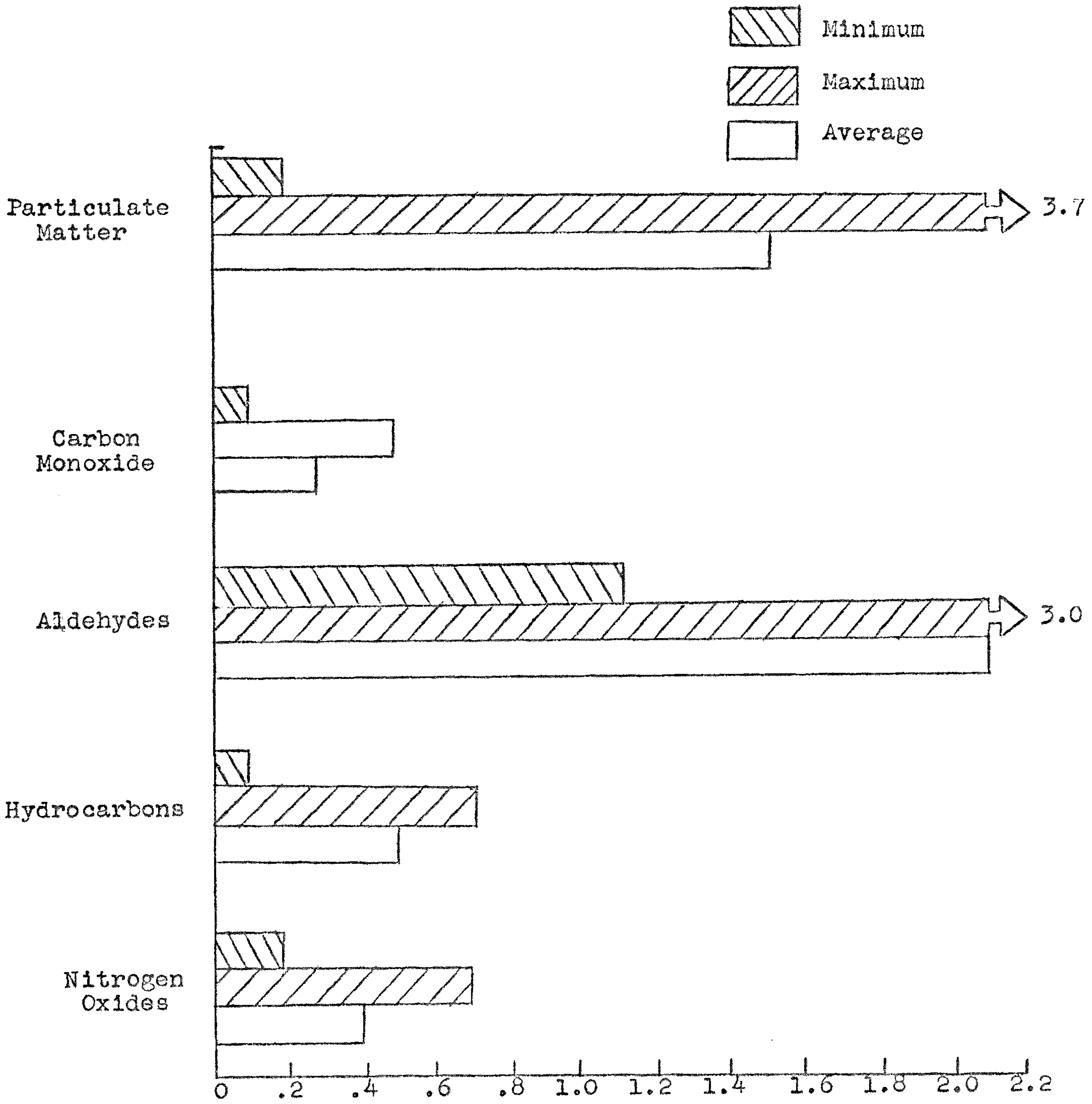
TABLE 12

Contribution of Jet Aircraft to the Total Pollution in the New York Area

Pollutant	Jet Aircraft Tons/year	All Sources Tons/year	Jet Aircraft Percent(%) of Total
Particulate matter	8,990	241,000	3.7
Carbon monoxide	9,200	5,298,000	0.2
Aldehydes	840	28,000	3.0
Hydrocarbons	1,960	1,412,000	0.1
Nitrogen oxide	5,710	769,000	0.7

FIGURE 7

Contribution of Jet Aircraft to the Total Amount of Air Pollution in the New York Area



Percentage of Pollution from all Sources

The Los Angeles County Air Pollution board has recently completed additional studies. At this time, their findings have not been released in a formal report. However a paper summarizing their results was published in the "Journal of the Air Pollution Control Association." Provided in Table 13 is a (10) comparison from that paper of the pollutants discharged daily from motor vehicles, jet aircraft and power plants in Los Angeles County during the first ten months of 1969. These sources are the three major fuel burners in the Los Angeles area. Also shown is the percent (%) contribution of jet aircraft. Note that turbine powered aircraft produced:

- 18% of the particulate matter
- 0.26% of the carbon monoxide
- 3.5% of the hydrocarbons
- 0.77% of the nitrogen oxides

These percentages (for the County of Los Angeles) can now be compared with those calculated for the New York metropolitan area (Table 12). The percent of carbon monoxide and nitrogen oxides emitted are nearly identical. On the other hand, the amount (percent) of particulate matter emitted by turbine powered aircraft is reported to be approximately 5 times greater for Los Angeles County than that determined for the New York metropolitan area. In addition, the percent of hydrocarbons discharged by jets

TABLE 13

Comparison of Emissions from Jets, Cars, and Power Plants

Average Daily Emissions (Tons/Day)	Contaminant			
	Particulate Matter	Carbon Monoxide	Hydrocarbons	Nitrogen Oxides
Cars	43	9282	1677	624
Power Plants	7	Neg.	10	280
Jets	11	24	61	7
- Total	61	9306	1748	911
% of Total for Jets	18	0.26	3.5	0.77

is 35 times greater in Los Angeles than calculated in this study (thesis) for the New York area.

It is interesting to note the difference in the percent contribution of motor vehicles with regard to the amount of particulate matter emitted between Tables 9 and 13. In Table 9, the amount of this contaminant (particulate matter) given off by power and industry is nine times greater than that discharged by motor vehicles. On the other hand, in Table 13 the amount of particulate matter emitted by only power generation is approximately 15% of that discharged by cars. It should be pointed out that the data in Table 9 are listed by the U.S. Public Health Service and are for both power generation and <u>all</u> industry while Table 13 is based (Los Angeles County Air Pollution Control District) only on power generation.

It has been projected (10)that the amount of the various contaminants will increase approximately 50% by the year 1975. In addition, it has also been estimated (4) that the amount of particulate matter emitted by jet aircraft will more than double in the next ten years. In still another source (24), it has been projected that by 1979 the various contaminants (carbon monoxide, hydrocarbons, nitrogen oxides, and particulate matter) will increase from approximately 60 to 300% depending on the pollutant. These approximations are based on the increasing jet aircraft activity and the use of much larger engines, such as those that will power the Boeing 747. Shown below are the approximate quantity (tons/year) of the various contaminants that will be emitted by jet aircraft in the New York area in 1975. These values are based on a 50% increase.

- particulate matter - 13500 tons/year
- carbon monoxide - 13800 tons/year
- aldehydes - 1250 tons/year
- hydrocarbons - 2900 tons/year
- nitrogen oxides - 8500 tons/year

Control of Exhaust Contaminants from Turbine Powered Aircraft

There has been a trend in the aircraft industry (engine manufacturers and carriers) toward modification of engines (combustors) to reduce visible smoke. However, modifying the burner can is a complex problem since any change that reduces smoke formation cannot adversely affect the performance of the combustor. In designing a "smokeless" burner the following factors have to be carefully considered (8):

- Life of the burner (durability)
- Carbon deposits
- Ignition at varying altitudes
- Combustion stability
- Efficiency of combustion
- Temperature profiles

Nevertheless, Pratt and Whitney have apparently developed a new burner can (a modified combustor). The new combustor features redesigned fuel-spray nozzles, more turbulence (air fuel mixing) in the primary combustion zone, and a higher quantity of combustion air. The purpose of all these modifications have been to provide a leaner air fuel mixture in the primary zone. This will tend to reduce fuel pockets, which are the main cause for visible smoke.

The evaluation of these new burner cans, which were designed to reduce visible smoke (particulate matter), are currently being undertaken by a number of airlines. At the present time, the effectiveness of these burner cans have not been completely studied. Nor have the possible detrimental effects on engine performance been 100 percent resolved.

The Los Angeles County Air Pollution Control District has conducted preliminary studies with test stand engines employing the new combustor cans. They substituted the new "smokeless" burner cans for the conventional ones used in the JT8D jet engine. In their studies, they found (10) that the amounts of particulate matter and carbon monoxide were reduced approximately 23%. In addition, the emission of hydrocarbons and organic gases were nearly eliminated. However, they found that the nitrogen oxides increased by approximately 40%. This increase in the amount of nitrogen oxides may affect any gains realized in the reduction of the other contaminants. As previously indicated (Effects of Contaminants Emitted by Turbine Powered Aircraft on the Quality of the Air) nitrogen oxides are one of the primary ingredients in the formation of photochemical air pollution (smog). In this photochemical process, significant quantities of ozone (integral part of smog) are also formed.

The County of Los Angeles, which has one of the most stringent air pollution control programs, has made little progress (3) in the last ten years in its battle to reduce smog. The growth in industry, automobile and jet aircraft traffic, has offset any gains made by instituting curbs for industry (banned the burning of high sulfur fuels) and imposing restrictions on motor vehicle emission. Therefore, the County of Los Angeles is considering additional restrictions. These would include an attempt to curb nitrogen oxides from industrial sources and the establishment of controls for used cars and <u>turbine power aircraft</u>. These restrictions for jet aircraft would not be the first. On July 15, 1969, the California State legislature (10) signed into law a bill that limits the emission of visible (particulate matter) air pollutants by aircraft. This law, which is the first of its kind, goes into effect on January 1, 1971.

Other agencies have also indicated their desire to reduce, and if possible, eliminate, jet aircraft emission. In his report to the United States Congress in 1968, the Secretary of Health, Education and Welfare stated, "that it is the intention of this department to encourage such action (improving turbine engine combustors to reduce emissions) by engine manufacturers and airline operators and to keep close watch on their progress. If at any time it appears the progress is inadequate...the department will recommend regulatory action to the Congress that statutory authority for such action be provided." In addition to this statement, a Superior Court judge of the state of New Jersey recently ruled (5) on an action brought by that state's Health Department. In his ruling, the judge indicated that steps must be taken immediately to curtail aircraft emissions, otherwise the airlines would be taken to court. (New Jersey is seeking an injunction to force the airlines to install devices, such as the new combustor can, in order to reduce the contaminants emitted by jets that use Newark Airport.)

It is evident that aircraft emissions contribute significantly to the air pollution problem in the New York Metropolitan area. It is also clear that this problem is not only confined to this urban area but also applies to any large city with a major airport. It is encouraging that aircraft emissions have been recognized as a potential hazard and that two states, California and New Jersey, are taking steps to curb these emissions.

CONCLUSIONS

1. Emissions from turbine powered aircraft are the same as those given off by motor vehicles and certain other energy sources. Consequently, aircraft emissions contribute to the overall pollution problem.

2. Jet aircraft emissions contribute significantly to the air pollution problem in the New York Metropolitan area at the present time. In particular, they are responsible for 3.7% of the total particulate matter and 3.0% of the total aldehydes discharged in the New York Area. In addition, jet aircraft account for 0.1 to 0.7% of the carbon monoxide, hydrocarbons and nitrogen oxides emitted.

3. At this time, neither the peak concentration of carbon monoxide nor the average for varying climatological conditions have been determined for a major air terminal. Consequently, the toxicological effects on airport employees and passengers both in the terminal and boarding (deplaning) the aircraft are unknown.

4. Without the installation of emission control devices, the contaminants emitted by turbine powered aircraft will increase at least 50% in the next 5-7 years. This is based on the anticipated growth in air traffic and the use of larger engines.

5. Emissions from turbine powered aircraft are not a problem confined only to the New York and Los Angeles areas. It also applies to and should concern any large city with a major airport.

6. No significant reduction in smoke emission can be obtained by selecting any of the readily available fuels that are suitable for use in today's turbine powered aircraft. In addition, the antismoke additives that are commercially available today are completely unsatisfactory for use in a jet engine.

7. Control of visible emission (particulate matter) will probably be feasible in the near future by use of the new "smokeless" burner can. This redesigned combustor will also reduce the amount of carbon monoxide and hydrocarbons discharge. However, a substantial increase in the amount of nitrogen oxides will occur. This increase may offset any gains realized in the reduction of the other contaminants.

8. With the exception of a bill passed by the California legislature in July 1969 (restricting visible air contaminants), there are no State or Federal regulations that limit aircraft emissions at this time. There are also no laws that require research in this area by either the airlines or engine manufacturers.

However, aircraft emissions have been recognized as a potential hazard. In fact, California has threatened to pass additional legislation designed to curb all aircraft emission. On the other hand, New Jersey has taken a different approach. This state is attempting to obtain a court injunction against the airlines that use Newark Airport from polluting the air.

RECOMMENDATIONS

1. Since reduction of jet aircraft emissions is desirable, additional legislation should be passed to force the airlines (engine manufacturers) to establish a timetable for this reduction.

2. Any legislation that is passed should not establish standards that exceed the technological capabilities of the aircraft industry. Initially, these standards should be aimed at the reduction of hydrocarbons and particulate matter (soot). These pollutants are the simplest to control from a design standpoint (elimination of fuel rich areas in the combustion zone).

3. When standards are established, they should be done on a Federal basis rather than on the State level.

4. As soon as possible, a technique for measuring smoking tendencies of jet aircraft should be perfected. This measuring technique is necessary to evaluate any equipment modifications such as the new combustor cans. In addition, only one method (instrument and employed) should be used by all enforcement agencies. This will eliminate confusion and delay in controlling the emission of particulate matter. Simple methods for determining the concentrations of the various other pollut-

should also be perfected. It is evident that control of jet aircraft emissions can only be effective when there are adequate measuring techniques.

5. At many airports, such as Kennedy, the actual taxi time due to air traffic congestion is often as long as 30 minutes. These movements should be minimized since the emissions that contribute to the air pollution problem are directly effected by the duration of these operations.

6. The peak concentration of carbon monoxide and the average for varying climatological conditions should be studied to determine if they exceed safe limits (Threshold Limit Value) in the airport environment. The levels of the other contaminants should also be determined and their effect on health assessed.

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