NASA Technical Memorandum 78506

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(NASA-TM-78506) AIR POLLUTION FROM AIRCRAFT OPERATIONS AT SAN JOSE MUNICIPAL AIRPORT, CALIFORNIA (NASA) 23 p HC A03/MF A01 CSCL 13B

N79-12585

Unclas G3/45 37193

November 1978

National Aeronautics and Space Administration

NASA Technical Memorandum 78506

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AT SAN JOSE, CALIFORNIA, MUNICIPAL AIRPORT

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SUMMARY

This paper describes a computational method for estimating the contribution to air pollution of air traffic at San Jose Municipal Airport. Aircraft emission levels were estimated as a function of the time and location at which the pollutants were discharged. The relative contributions of certificated carrier and general aviation traffic to air pollution were estimated.

INTRODUCTION

This paper presents estimates of the amount of air pollution discharged by arriving and departing aircraft at the San Jose Municipal Airport. These estimates were made for each one hour interval of a summer weekday in 1977. The contributions of both general aviation (personal and business aircraft) and certificated air carriers (scheduled airliners) were considered. The locations at which the pollutants were discharged were estimated by approximating the flight paths of arriving and departing aircraft. Three types of pollutants were considered: carbon monoxide (CO), hydrocarbons (HC), and oxides of nitrogen (NO_x).

This study was undertaken in support of current efforts to model air pollution from all sources in the San Francisco Bay Area (ref. 1). This paper is a first step toward modeling airplane operations as one of the sources of air pollution. It does not account for the dispersion of the pollutants after they are released; transport of pollutants from all sources is being considered in the larger Bay Area pollution model.

AIR TRAFFIC AT SAN JOSE MUNICIPAL AIRPORT

Air traffic at the San Jose Municipal Airport in 1977 consisted of three types of aircraft operations: certificated air carriers, commuter airlines, and general aviation. Ten certificated carriers served San Jose; they flew seven different aircraft types, their average traffic amounting to 150 daily operations. An "operation" is either a takeoff or landing. General-aviation activity consisted of about 1000 daily operations by a wide assortment of airplane types and sizes (ref. 2). Commuter airline traffic totaled about 18 operations daily (ref. 2); for the purposes of this study, commuter airlines were included as general aviation traffic.

The pollution discharged by certificated carriers was estimated by computing the contribution of each aircraft and summing all operations. This approach was possible because of the relatively small number of operations (150) and aircraft types (7) and because certificated carrier flight paths were predictable.

In contrast, it was not practical to account for each general-aviation operation individually because of the large number of operations ($\sim$1000), the diversity of aircraft types and sizes, and the unpredictability of individual flight paths. Therefore, the contribution of general-aviation traffic to air pollution was estimated by defining an average general-aviation aircraft and an average pattern of operation.

Figure 1 illustrates the hourly frequency of certificated carrier and general-aviation operations at San Jose Municipal Airport for a summer weekday in 1977. Data for the certificated carriers were obtained from published schedules of arrivals and departures. The hourly frequency of general-aviation operations was based on a national survey in which was expressed the number of operations during each hour as a fraction of the total number of daily operations.

AIRPLANE FLIGHT PATHS

A computer program was developed that approximated each airplane flight path as a combination of straight and spiral line segments. Each segment was defined by three initial spatial coordinates, an initial true heading, a flight path angle relative to horizontal, a turn radius, and some end-of-segment indicator. The end point and final heading of a segment became the initial point and heading of the subsequent segment.

All airspace near the airport was considered to be divided into sub-volumes, each sub-volume with dimensions of 1' longitude by 1' latitude by 100-m altitude. Each aircraft was assumed to be a point source of pollution traveling along its flight path at some velocity and discharging pollution at a certain rate. The time spent by an aircraft in any volume of airspace was the length of the flight path in that volume divided by the airplane's velocity. The quantity of pollution discharged into any airspace volume was the product of the engine emission rate and the time the aircraft spent in that volume.

Flight path angle, airspeed, and engine emission rates were expressed as empirical functions of engine power setting for each type of aircraft. For departing aircraft the engine power setting was the independent variable from which climb angle, airspeed, and emission rates were determined. For arriving aircraft, the flight path angle was the independent variable used to compute airspeed and power setting. Commercial transports were distinguished by manufacturer and model — DC-8, Boeing 727, etc. However, one set of performance relationships was used to define the flight paths of all general-aviation operations.

Aircraft turns were assumed to be standard-rate instrument turns (3°/s). The lengths of line segments representing the takeoff and landing ground runs were determined as a function of aircraft type.

One set of five flight paths, each composed of a standard sequence of flight path segments, was assumed to account for all certificated air-carrier traffic at the San Jose Airport. These flight paths, illustrated in figure 2, were based on local instrument flight rules (IFR) procedures (ref. 4). Each certificated carrier operation was assigned one of these flight paths based on the airplane's direction of arrival or departure.

A different set of five flight paths was assumed to represent general-aviation traffic at the airport. General-aviation flight paths, illustrated in figure 3, were chosen to be representative of typical visual flight rules (VFR) procedures. Each flight path was assumed to account for a fixed fraction of general aviation operations within any period of time. The quantity of air pollution emitted by a nominal number of average general-aviation airplanes operating along these flight paths was scaled up or down according to the level of general-aviation air traffic during each hour of the day.

Each certificated air carrier and general-aviation operation was assumed to include a taxi segment defined by some average time spent on the ground at idle power. The time required for a general-aviation airplane to taxi to or from the runway at San Jose Airport is a little more than three minutes. Prior to takeoff this time is substantially longer since engine run-up and pre-takeoff checks must be performed. Realistically, however, many general-aviation operations are touch-and-go and involve no taxiing. Thus an average taxi time per operation should be somewhat shorter than the time required for one airplane to taxi to or from the runway. A nominal taxi time of three minutes was assumed for each general-aviation operation.

The time required for a commercial transport to taxi to or from the runway is about 3½ min, yet instrument departures in congested airspace often include delays on the ground waiting for clearances. Thus an average taxi time of 6½ min, somewhat longer than expected without delays, was assumed for each certificated carrier operation. Because the time spent taxiing was uncertain, taxi times both longer and shorter than the nominal times cited here were also considered.

ENGINE EMISSION RATES

Based on data from references 5 and 6, the emission rates of CO, HC, and NO_x were expressed as functions of engine power setting for each type of engine (figs. 4, 5, and 6). General-aviation engine emission rates were approximated by defining an average emission rate vs power setting curve for each pollutant. These average rates were based on emissions data from a wide range of horizontally opposed piston engines.

The average number of engines per general aviation airplane at San Jose Airport is 1.14 (ref. 2). Thus, the emission rate of the average general-aviation aircraft was assumed to be 1.14 times the single engine emission rates illustrated in figures 4, 5, and 6.

RESULTS

The quantities of aircraft pollution were estimated as functions of space and time. This resulted in a four-dimensional array describing each pollutant. These data were most easily presented when two or more of these dimensions were eliminated.

The horizontal distributions of pollutants discharged by aircraft below 2 km in one day are illustrated in figures 7, 8, and 9. These distributions reflect those flight paths air traffic was assumed to follow. More significantly, however, these figures show that pollution concentrations are highest in the immediate vicinity of the airport.

Relative to other flight paths, high concentrations of NO_x are found along departure flight paths of certificated carriers (fig. 7). This is because turbine engines discharge NO_x at much higher rates at high power settings than at low power. Concentrations of NO_x along general-aviation flight paths are low because, compared to turbine engines, piston engines emit very little NO_x. In contrast, general-aviation flight paths appear prominently in both the HC and CO distributions compared to certificated carriers (figs. 8 and 9). This is primarily because of the larger number of general-aviation operations since turbine engines produce CO and HC at rates comparable to piston engines. In addition, general-aviation aircraft fly at airspeeds significantly lower than commercial transports and thus each general-aviation aircraft spends more time in the airport area than does a commercial transport.

The vertical distributions of pollutants discharged by aircraft during one day are illustrated in figure 10. The pollution concentrations are highest in the first 100-m above the ground where airplanes, involved in taxi, takeoff, and landing, spend a disproportionate amount of time. In addition, aircraft on or near the ground operate at either idle or maximum power where emission rates of one or more pollutants are highest.

Together, figures 7, 8, 9, and 10 illustrate that pollution discharged by airplanes is concentrated at the airport and close to the ground. It was difficult to estimate absolute quantities of pollution emitted in this region because of the uncertainty in predicting average taxi times. However, it was possible to estimate the amounts of CO, HC, and NO_x relative to each other and to compare the contributions of general aviation and certificated carriers to each.

Figure 11 illustrates estimated amounts of CO, HC, and NO_x emitted by aircraft at the airport below 100-m during each hour of the day. The CO levels are substantially higher than levels of HC and NO_x. This is primarily because idling turbine and piston engines emit more CO than HC and NO_x. The CO and HC levels illustrated in figure 11 are sensitive to the assumed taxi times because (1) turbine engine emission rates of CO and HC are highest at idle power, and (2) at idle power, piston engine emission rates of CO and HC, though lower than at high power, are still significant. On the other hand, the NO_x levels illustrated in figure 11 are insensitive to the assumed taxi times per operation. Piston and turbine engines emit NO_x at much higher rates at takeoff power settings than at idle. Thus, although the time spent at idle power is relatively long, the NO_x discharged during the brief takeoff and first segment of climb far exceeds that emitted during taxi.

Compared with certificated carriers, general-aviation traffic produces very little NO_x at the airport (fig. 12). Even when general-aviation taxi times are assumed to be three times as long as for certificated carriers, the NO_x emitted by general-aviation traffic is insignificant.

General-aviation operations contribute substantial portions of the HC and CO discharged by airplanes at the airport. The precise portions depend on the relative taxi times per operation for general-aviation and certificated carriers. The shares illustrated in figures 13 and 14 are based on the nominal taxi times of 3 min for each general aviation operation and 6 1/2 min for each certificated carrier operation.

CONCLUSIONS

This paper describes a method for estimating the contribution to air pollution of air traffic at the San Jose Municipal Airport. By this method it was found that the largest quantities of aircraft pollutants were discharged in the immediate vicinity of the airport. A substantial portion of CO's and HC's emitted by airplanes was attributable to general-aviation traffic; the contribution of general aviation to NO_x emission levels was estimated to be negligible.

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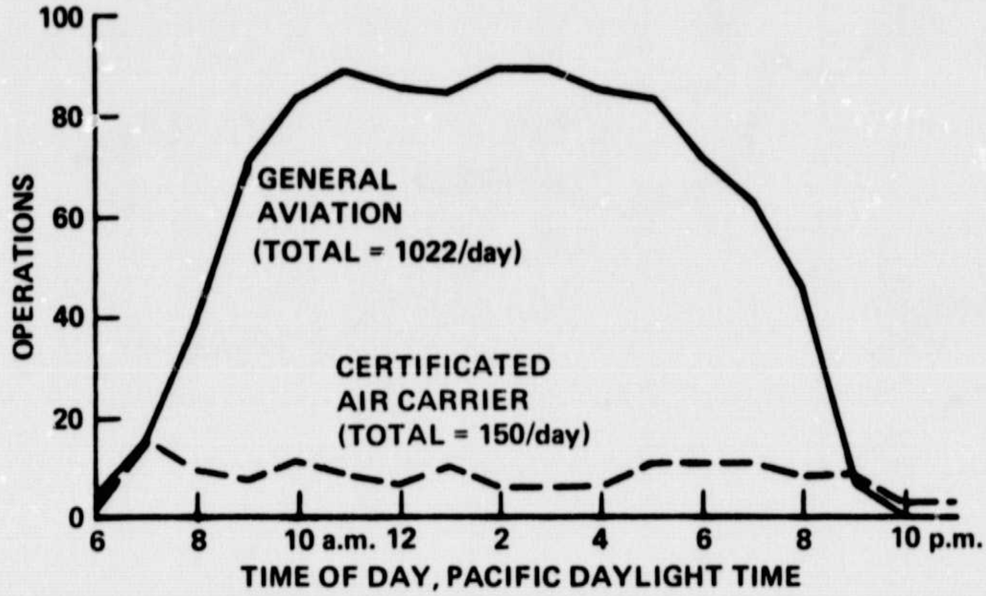

Figure 1. San Jose air traffic, average summer weekday, 1977.

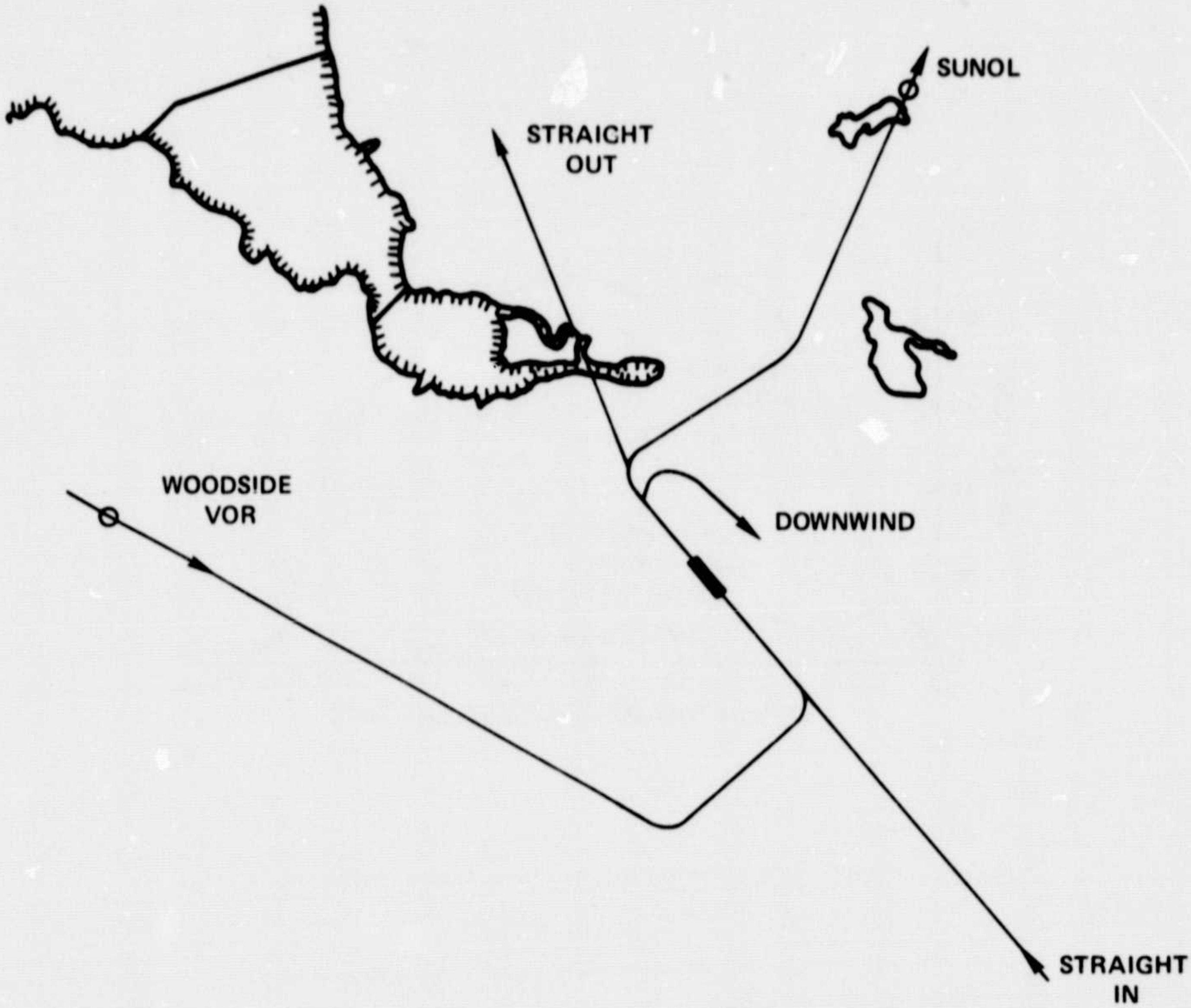

Figure 2. Certificated air carrier traffic patterns.

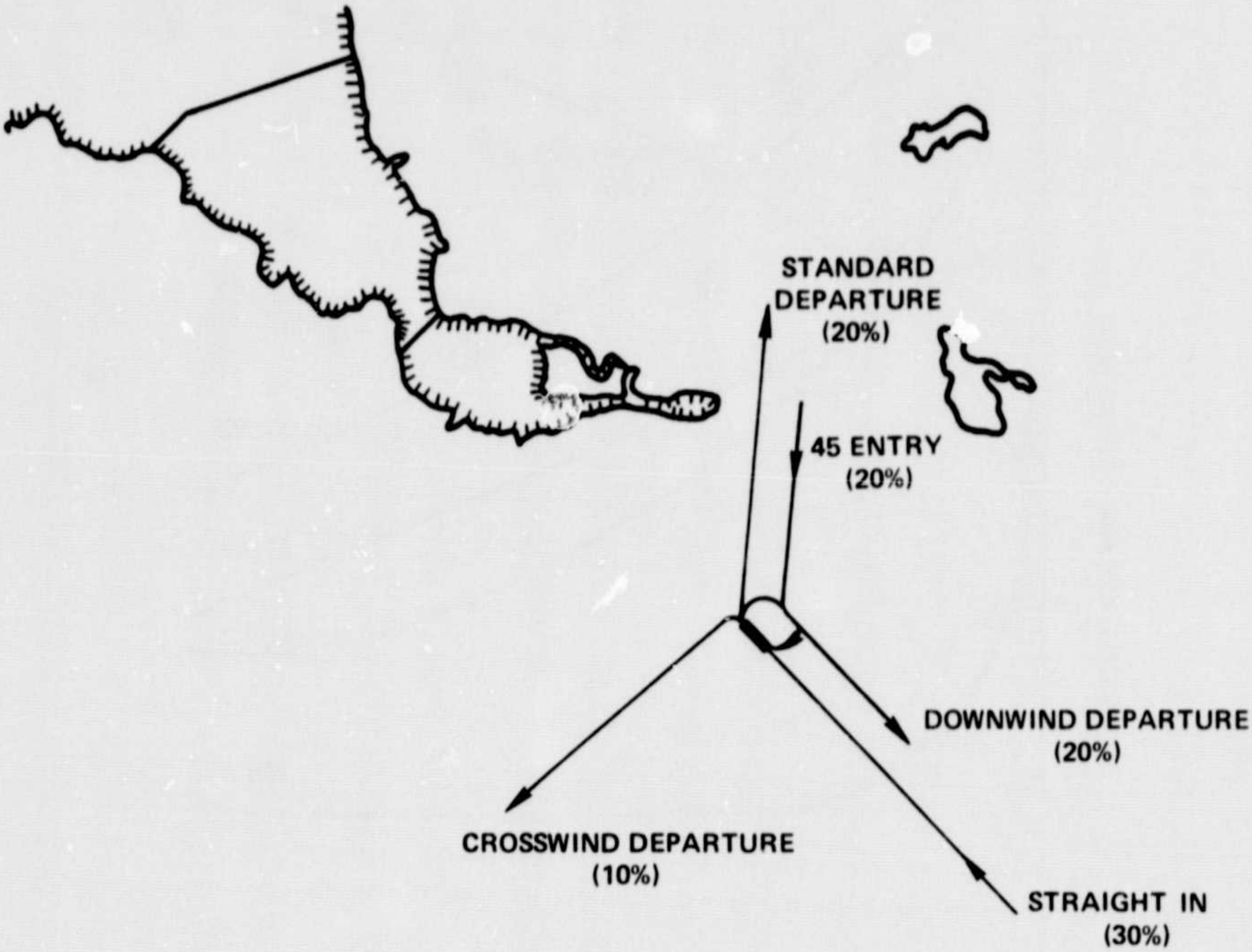

Figure 3. General-aviation traffic patterns.

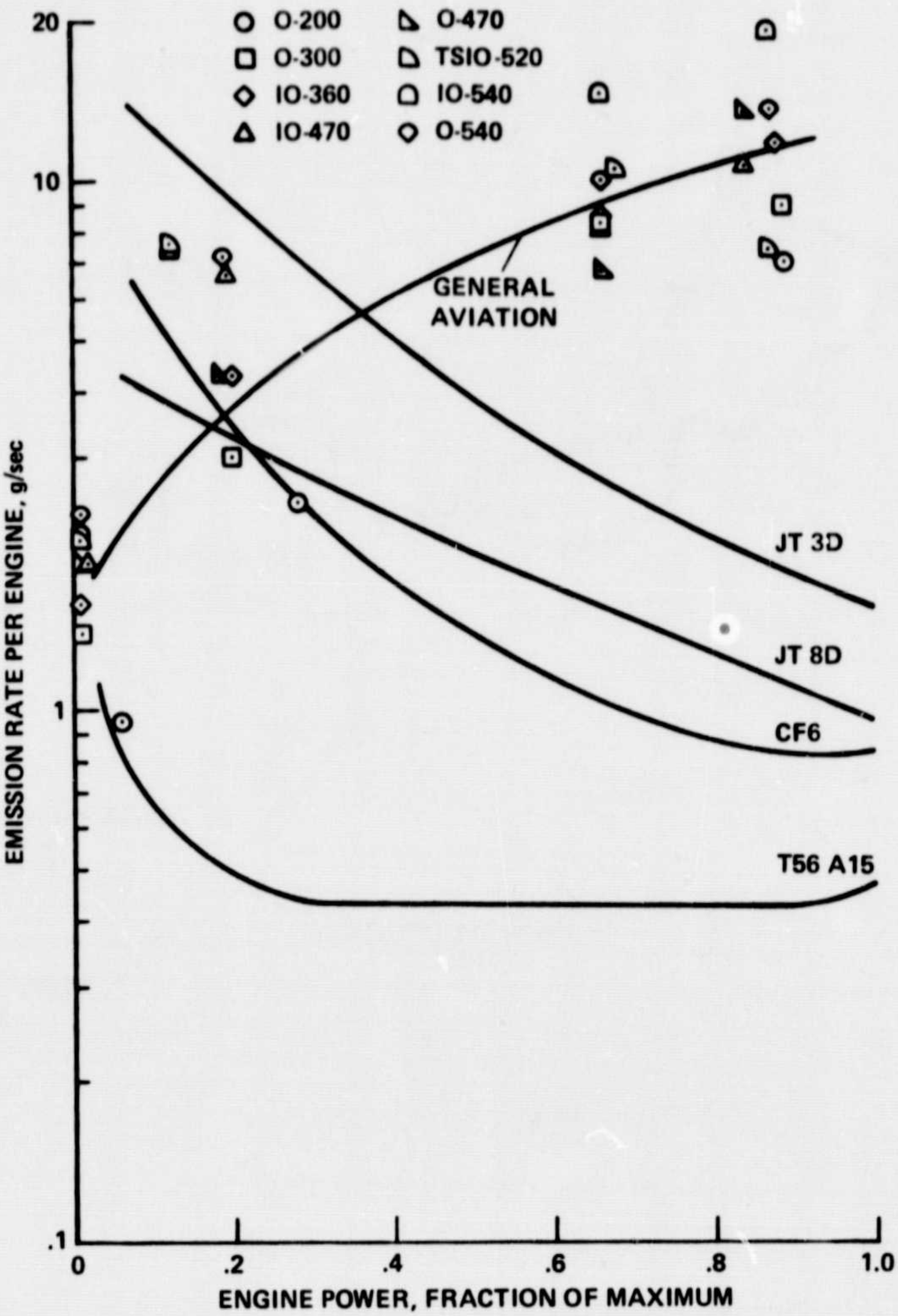

Figure 4. Carbon monoxide emission rates.

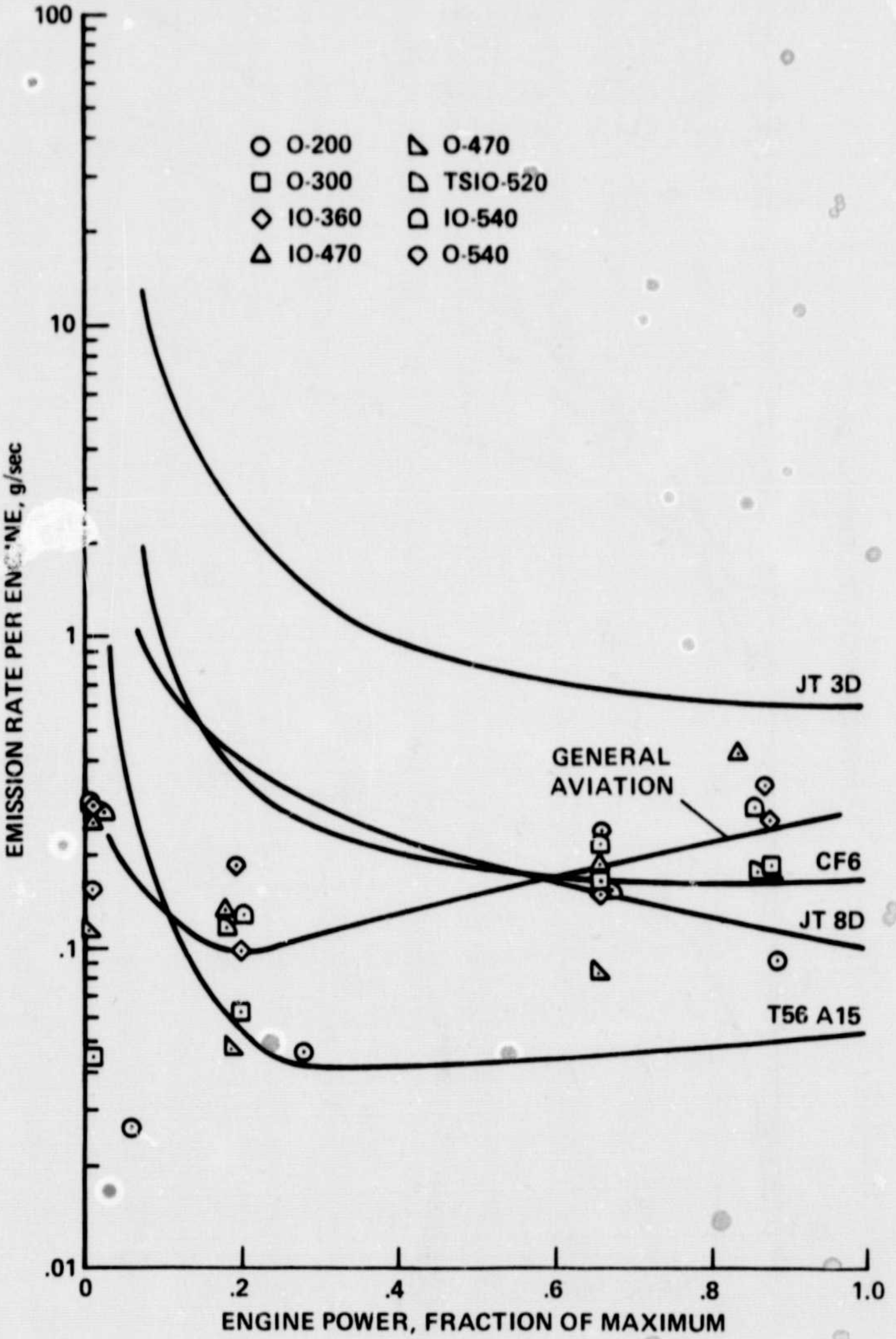

Figure 5. Hydrocarbons emission rates.

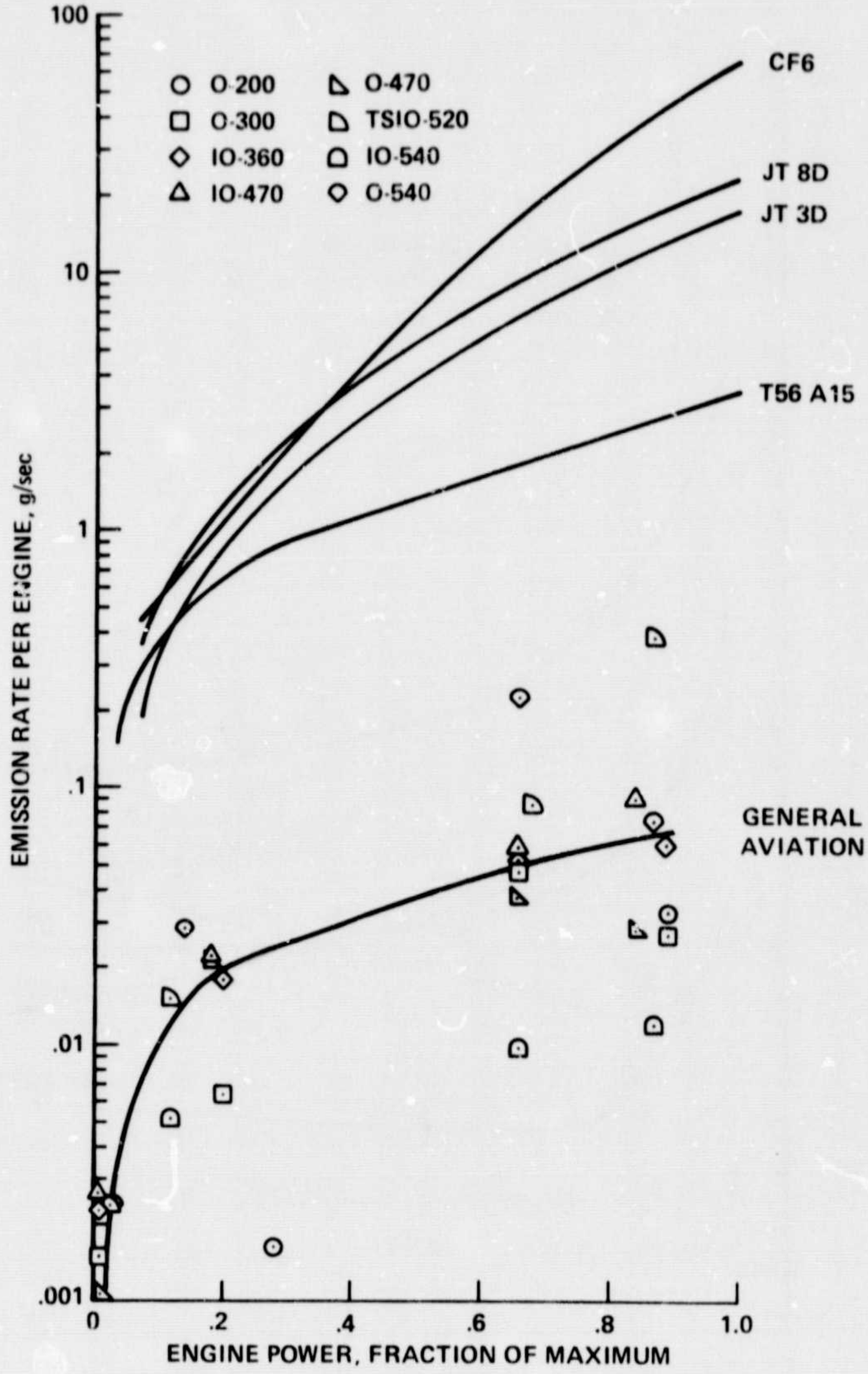

Figure 6. Oxides of nitrogen emission rates.

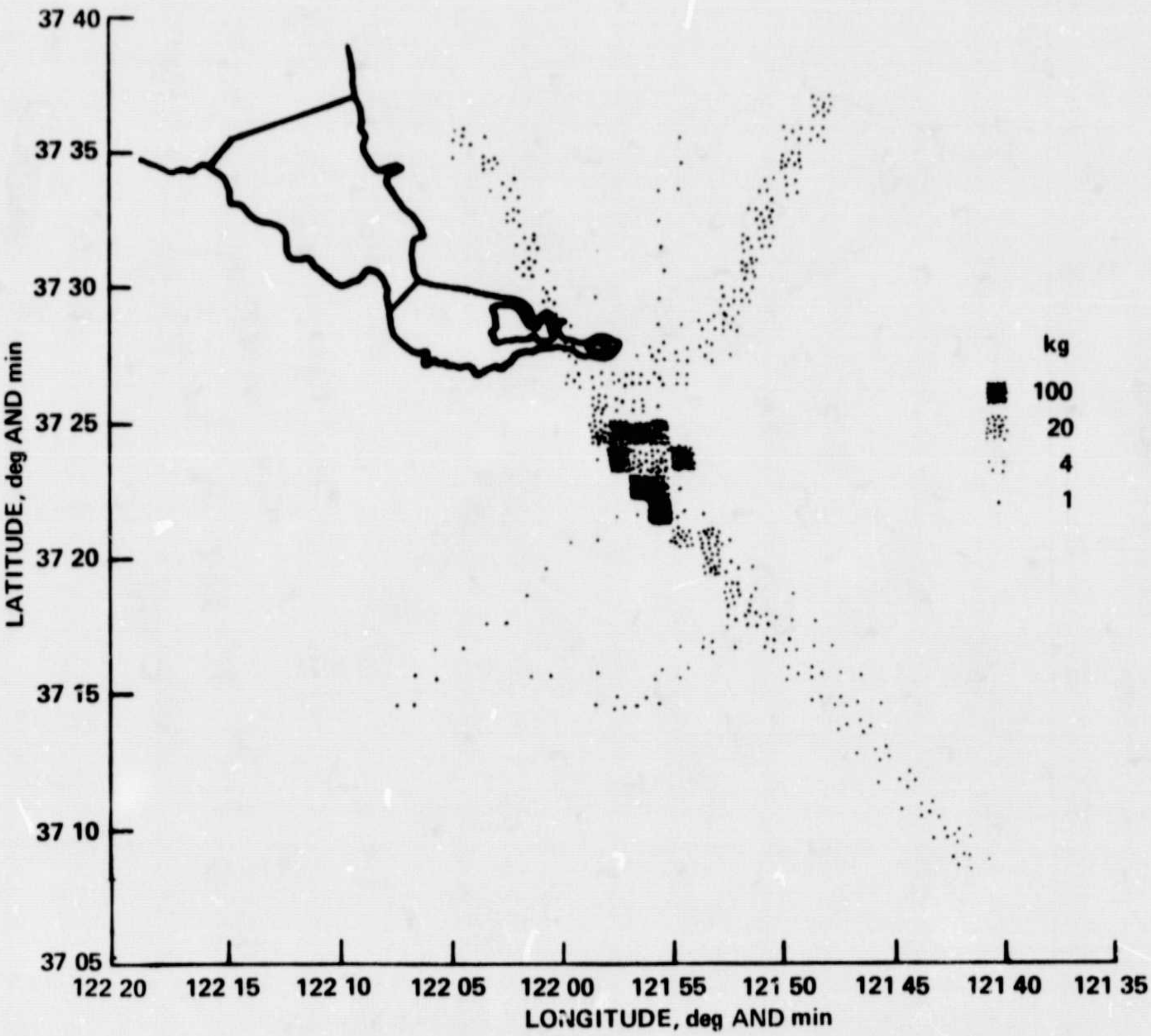

Figure 7. Oxides of nitrogen discharged below 2-km altitude.

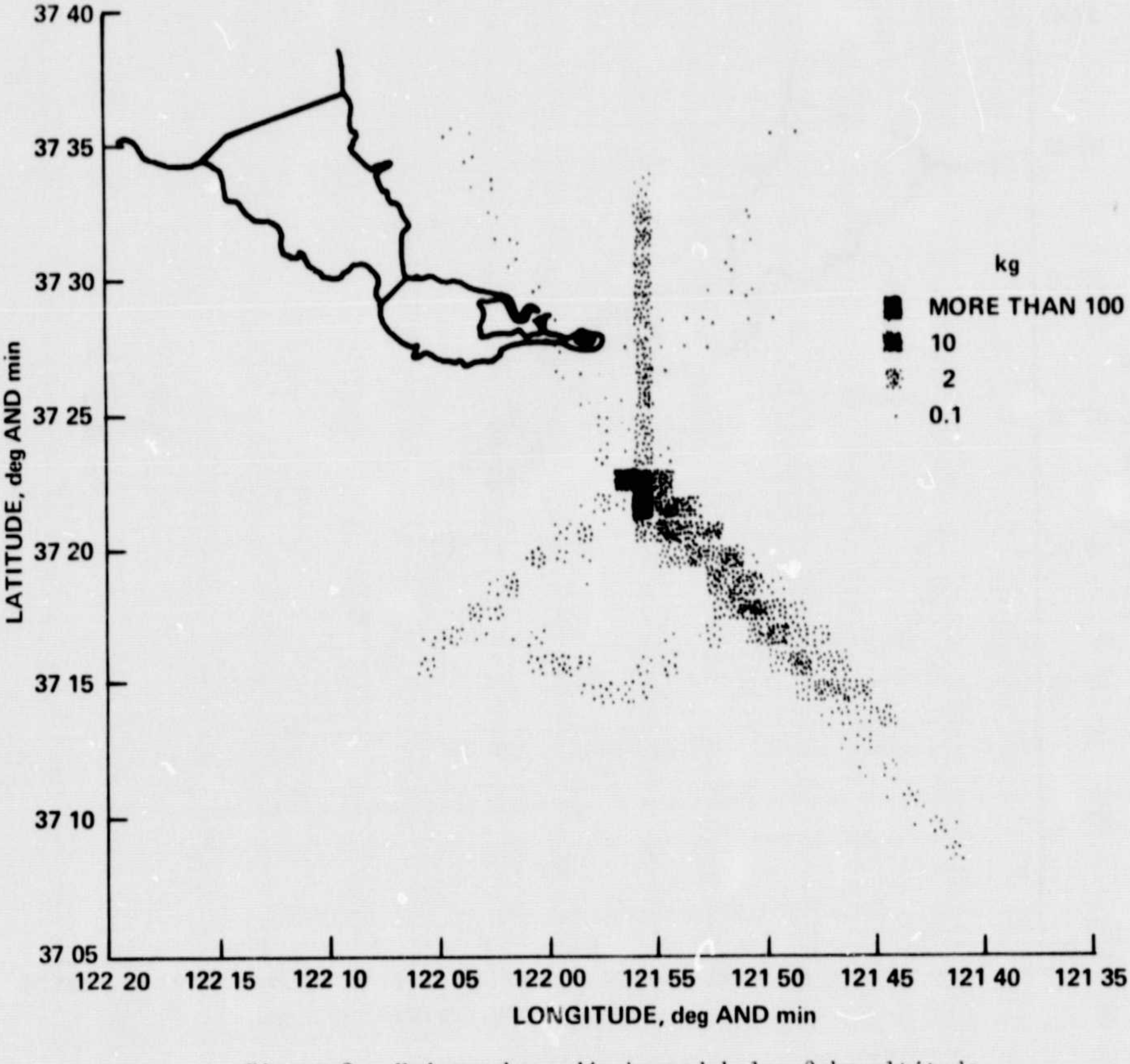

Figure 8. Hydrocarbons discharged below 2-km altitude.

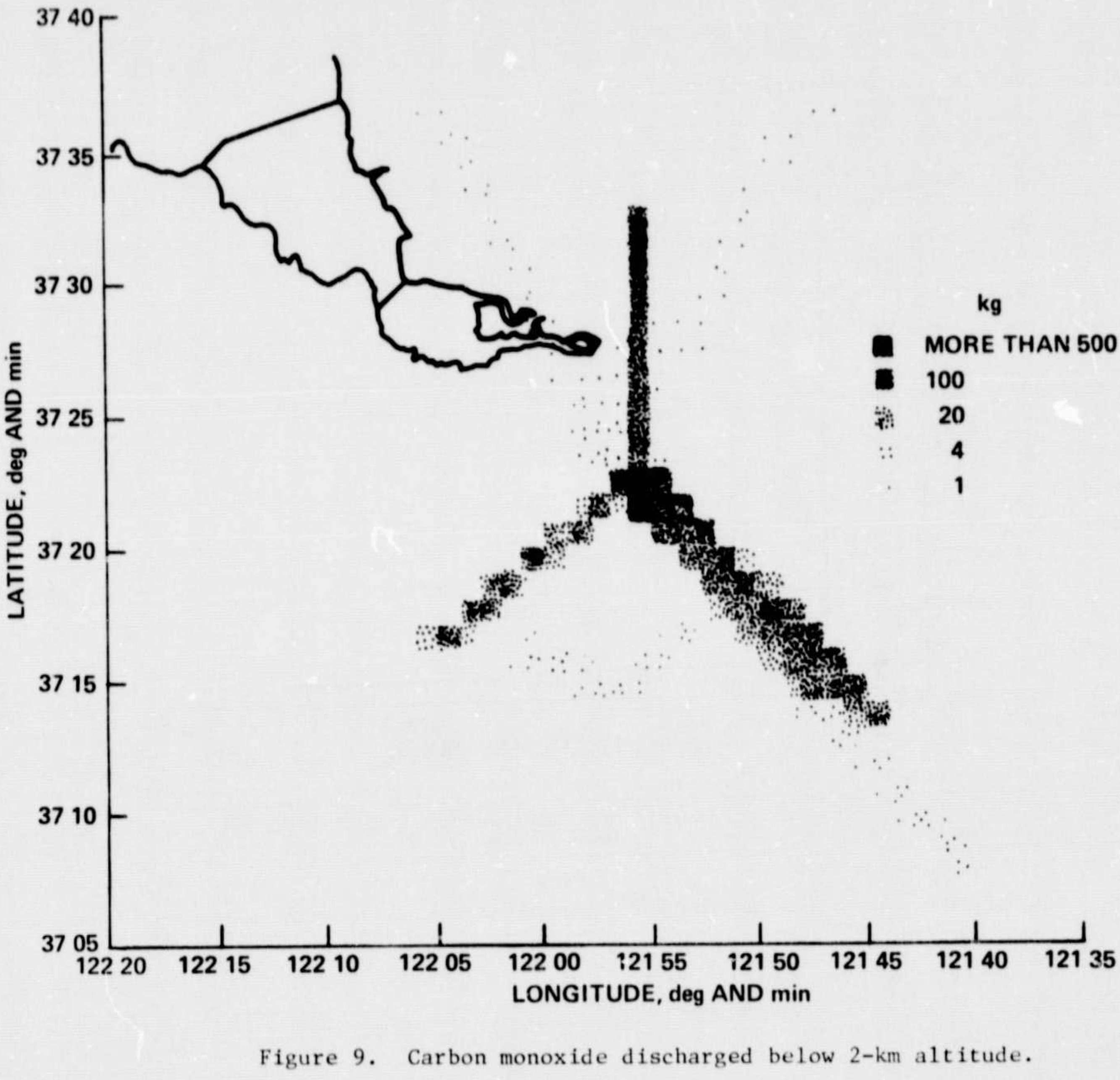

Figure 9. Carbon monoxide discharged below 2-km altitude.

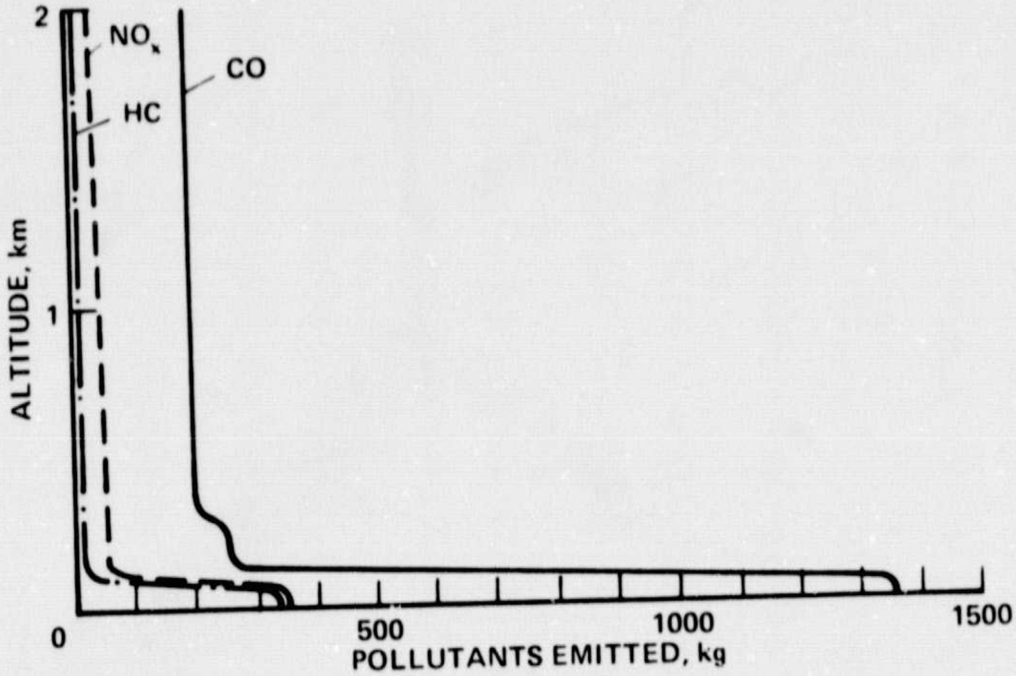

Figure 10. Vertical distribution of pollutants.

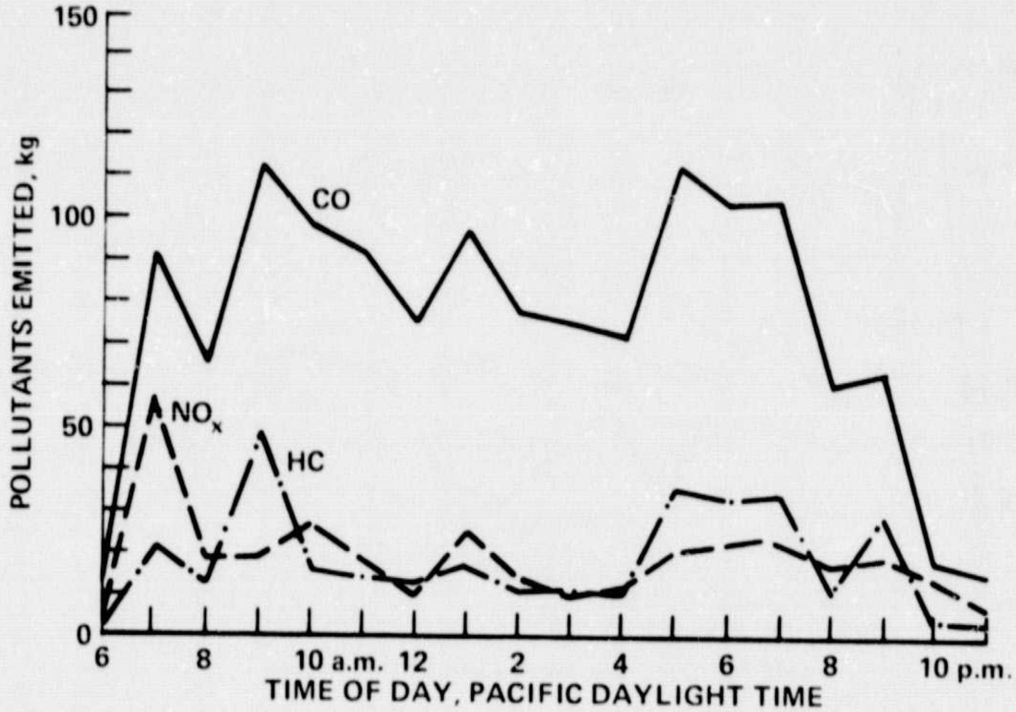

Figure 11. Pollutants discharged below 100-m altitude.

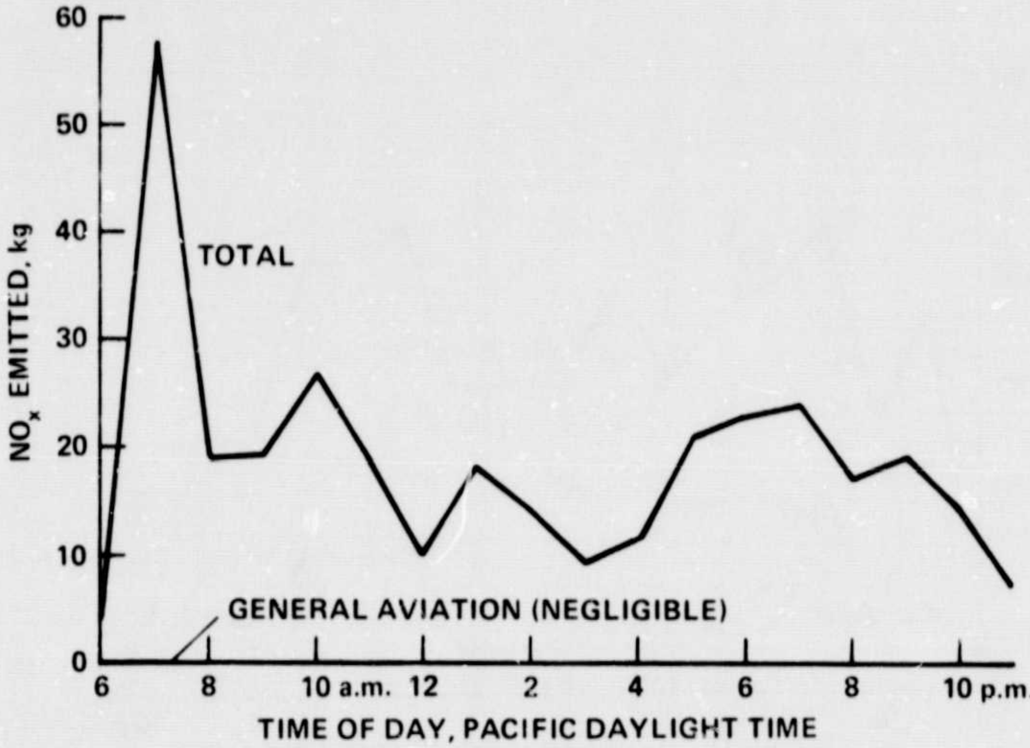

Figure 12. NO_x discharged below 100-m altitude.

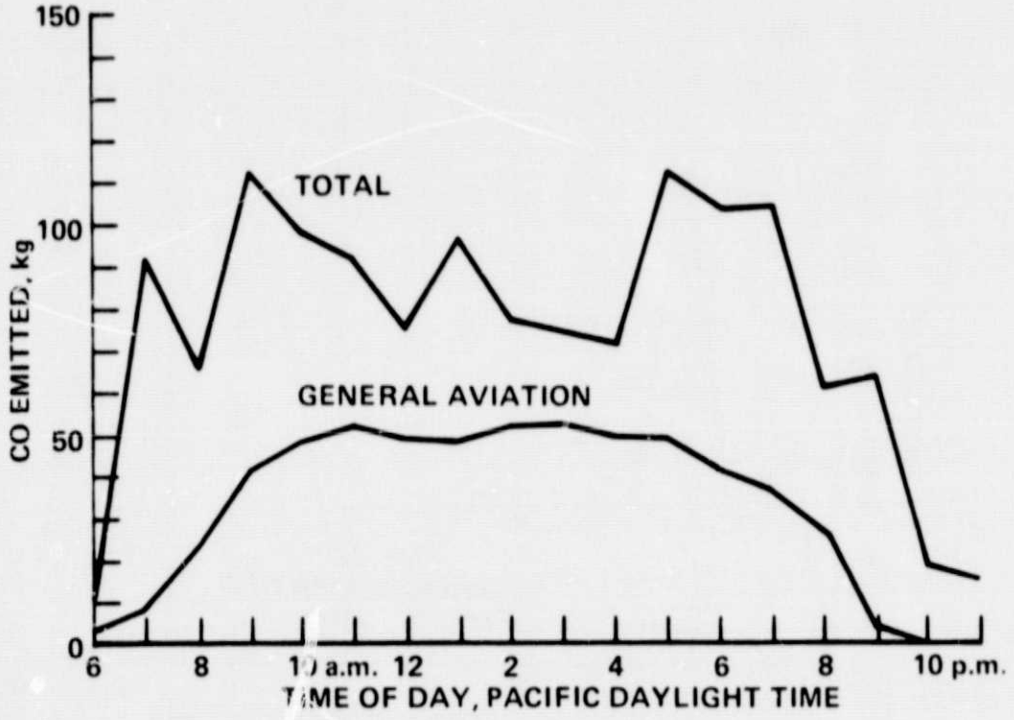

Figure 13. CO discharged below 100-m altitude.

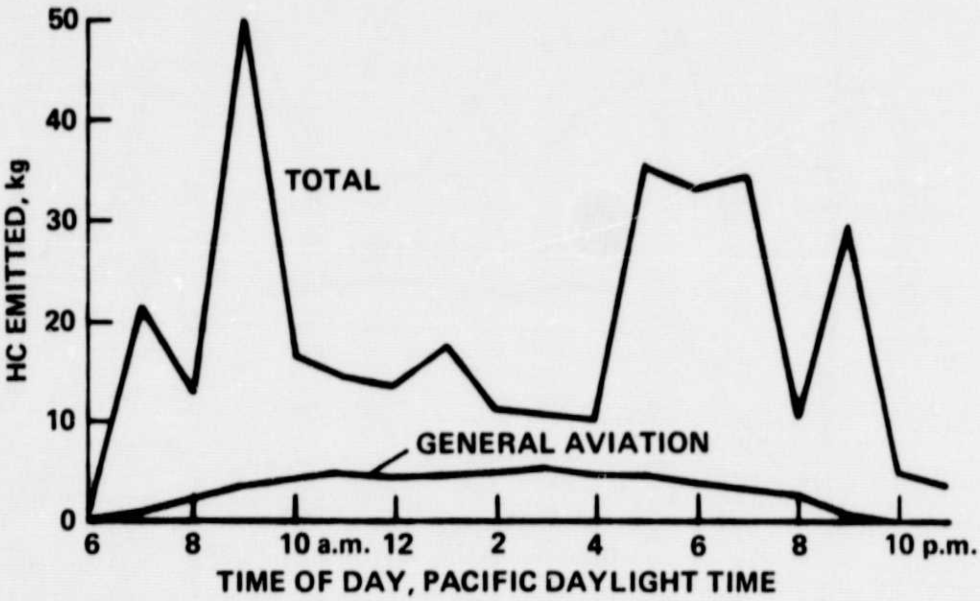

Figure 14. HC discharged below 100-m altitude.