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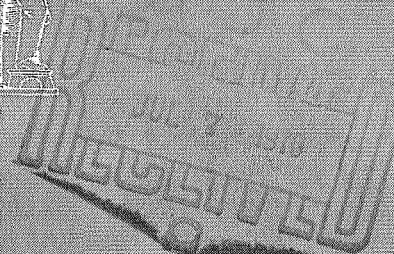
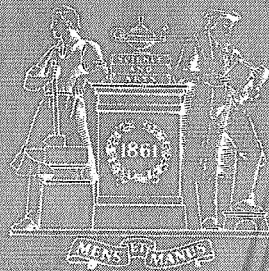
AIR POLLUTION FROM FUTURE GIANT JETPORTS

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May 1970

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FLUID MECHANICS LABORATORY



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Abstract

The planned expansion of major airports could lead to a new type of air pollution problem. These giant jetports will be capable of handling annually a hundred million passengers and more than a million aircraft operations. The pollutants emitted by aircraft during landing, taxiing, and take-off will cause higher ambient levels than is now encountered at existing airports. Because aircraft arrive and depart in a generally upwind direction, the pollutants are deposited in a narrow corridor extending downwind of the airport. Vertical mixing in the turbulent atmosphere will not dilute such a trail, since the pollutants are distributed vertically during the landing and take-off operations. As a consequence, airport pollution may persist twenty to forty miles downwind without much attenuation. Based on this simple meteorological model, calculations of the ambient levels of nitric oxide and particulates to be expected downwind of a giant jetport show them to be about equal to those in present urban environments. These calculations are based on measured emission rates from jet engines and estimates of aircraft performance and traffic for future jetports.

Introduction

Emissions of air pollutants from jet aircraft are presently only a small proportion of the total emissions in a metropolitan area¹⁻³. However, if these pollutants are considered to be emitted mostly in the immediate vicinity of an airport, then the rate of emissions per unit area is comparable to that found in urban industrial environments². A five-year old survey¹ at JFK airport showed that ambient air particulate concentrations were not significantly in excess of those in surrounding urban areas. Nevertheless, concern has been expressed³ that the increase in air traffic and reduction in ground based emissions will make the aircraft-generated pollutants a more significant factor in the overall air pollution problem of metropolitan areas.

Several major airports have plans for expansion of aircraft handling capacity at present sites. O'Hare airport is reported⁴ to expect a tripling of its passenger movements by 1980, reaching a level of about 90 million passengers per year, to be accommodated within the present site area. Based on present operational practice, this would imply about 900,000 landing and take-off cycles (LTO) per year. Proposed or possible expansions of other existing major airports would bring them to levels between 500,000 and 1,000,000 LTO's per year. In most cases, this expansion incorporates use of parallel runways so spaced as to require little increase in the total land area of the airport.

If one accepts the conventional measure of the intensity of aircraft pollution, namely, the rate of emission of pollutants per unit of airport area, the installation of multiple runways in a limited area clearly portends higher ambient concentrations of pollutants originating from aircraft. The most recent survey¹ (1965) of ambient particulate concentrations in the vicinity of JFK airport occurred at a usage level of about 10,000 LTO's, or a factor of five to ten less than what might ultimately be expected for giant jetports ten to twenty years hence. One cannot expect this out-of-date study to provide adequate information for assessing the possible effects of the contemplated expansions.

Although the flight of aircraft after take-off or approaching a landing exposes to view their smokey exhausts, it is intuitively felt that, at sufficient altitude, the pollutants emitted cannot significantly contribute to ground level ambient concentrations. For this reason, an arbitrary ceiling is selected, (usually taken to be 3,000 or 3,500 feet) above which emissions are considered to be a negligible contributor to pollutant concentrations at ground level, and may therefore be disregarded. Although not explicitly stated, the selection of a 3,000 foot ceiling appears to have originated with a Los Angeles study⁵ in which this height was chosen to be equal to average inversion levels in Los Angeles. Most urban area meteorological models use mixing layer depths much less than 3,000 feet, so that it would not be expected, according to these models, that pollutants emitted at this level would be mixed down to ground level. It would therefore appear that the conventional estimates

of total emissions during landing and take off are arbitrary to the extent that they are proportional to this estimated ceiling.

In the following section we describe a meteorological model for use in estimating ambient levels of aircraft pollutants which is based upon the motion of the aircraft as a moving source and for which no arbitrary emission ceiling need be chosen. In this model, the only important dilution process is lateral mixing, which is generally slow because of the wide corridor through which aircraft move during the LTO operation. Using data on emissions from existing aircraft, we subsequently estimate the ambient concentrations of some pollutants as a function of wind speed and frequency of LTO cycles.

A Meteorological Model for Aircraft Pollution

The customary urban area meteorological models make use of distributed ground sources (or multiple point sources) located on a lateral scale which is very much greater than the vertical height of the atmospheric mixing layer into which the emitted pollutants are mixed. For this reason, vertical mixing of polluted air with clean air above it is the principal process by which the pollutant concentration tends to be reduced in the downwind direction. Lateral mixing tends mostly to smooth out the distribution of concentration from point sources, and has only a minor effect in reducing concentrations by mixing in clean air at the fringes of the city.

There are two special features of aircraft sources which require a new meteorological model for their treatment. First of all, during

ascent or descent the pollutants are distributed vertically in the atmosphere. Secondly, the aircraft flight direction is predominantly in the upwind direction. Thus the pollutants can be considered to have originated in a vertical plane parallel to the wind direction, in contrast to their origin in a horizontal (ground) plane for the case of ground sources in an urban area. As a consequence, horizontal rather than vertical mixing is the important diluting mechanism for aircraft pollution.

In order to depict graphically the distribution of pollutants from aircraft approaching or leaving an airport in the upwind direction, the aircraft flight paths through the atmosphere for a particular case are plotted in Figure 1. The paths of aircraft landing and taking off at the rate of one LTO cycle every six minutes, for a two hour period, are located with respect to the atmosphere, which is assumed to be moving downwind at 10 mph in a shearless flow. Thus these paths show the location of the deposition of pollutants during landing or take off. Deposition rates are approximately comparable along a path of ascent or descent. (Flight paths are those specified in Reference 3. Note the exaggeration of the vertical scale in Figure 1.) Downwind of the airport, the doubly hatched region is one in which the deposition of pollutants is on the average uniform in both vertical and downwind directions. Any vertical or downwind mixing will not affect the concentration of pollutants in this region.

For the purposes of estimating downwind concentrations, we shall specify a priori the horizontal lateral extent w (normal to the wind

direction) of the downwind polluted region. This width will be partly determined by the angle between the wind direction and runway or flight path, the distance between parallel runways when several are in use, and the lateral mixing due to atmospheric turbulence. We would expect w to be between one and two miles under average circumstances.

It is now possible to calculate, using the principle of mass conservation, the average concentration c of a pollutant emitted at a mass rate m per unit of vertical ascent and descent during an LTO cycle, if the frequency f of such cycles and wind speed y is given:

$$c = \frac{mf}{vw} \quad (1)$$

Although there is some uncertainty in the choice of the width w of the downwind trail, the remaining quantities are well defined. As w increases with distance from the airport due to lateral mixing, the concentration c will diminish according to Equation (1). However, if w were initially one or two miles, it would not be expected to double in size until about ten miles downwind. Thus the concentration would decay only slowly with downwind distance.

Estimate of Pollutant Concentrations

Table I, calculated from data given in Tables IX and X of Reference 3, summarizes mass deposition rates m for various pollutants. Unfortunately, this data incorporates emissions from ground operations of taxiing and idle, which are not distributed vertically in the atmosphere as are those emitted during take-off and approach. Use of the rates of Table I will therefore result in an overestimate of these concentrations,

principally of carbon monoxide and hydrocarbons. However, the data of Reference 3 are the most recently reported and include measurements of engines equipped with "smokeless" combustors which will be installed on all new and existing aircraft.

Using the data of Table I, mean annual concentrations of pollutants were calculated from Equation (1) for the case of 10^6 LTO's per year, a mean wind speed of 16 km/hr, and assuming a value of 2 km for $\underline{w}$. These values of concentrations are shown in Table II for the aircraft types given in Table I. The values chosen for $\underline{f}$, $\underline{v}$ and $\underline{w}$ are believed to be typical of what might be expected for major jetports of the future.

Table I. Mass Deposition Rates (gm/m)

	<u>4-engine Turbofan JT8D-1</u>	<u>4-engine "smokeless" Turbofan JT8D-7</u>
Particulates	16.6	12.8
Carbon monoxide	22.6	17.6
Oxides of nitrogen	10.7	15
Hydrocarbons	150	1
Sulfur dioxide	3.5	3.5

Table II. Mean Annual Pollutant Concentrations ($\mu\text{gm}/\text{m}^3$)

($f = 10^6$ LTO/yr., $v = 16$ km/hr., $w = 2$ km)

	<u>4-engine Turbofan JT8D-1</u>	<u>4-engine "smokeless" turbofan JT8D-7</u>
Particulates	60	46
Carbon monoxide	81	63
Oxides of nitrogen	39	54
Hydrocarbons	540	3.6
Sulfur dioxide	13	13

Discussion

Accepting for the moment the proposed values for the parameters $\underline{f}$, $\underline{v}$ and $\underline{w}$ on which Table II is based, the resulting mean annual concentrations of particulates (principally soot) and oxides of nitrogen are nearly the same as those in urban atmospheres of most large American cities, while other pollutants exist in less than usual concentrations⁶. Given the slow rate of lateral mixing, because of the large transverse scale $\underline{w}$ of the polluted region, there will be only slow reduction of these concentrations in the downwind direction. The influence of the aircraft pollution might then still be felt at distances of twenty to forty miles downwind, before pollutant concentrations were greatly reduced by dilution.

For periods of the day where LTO frequencies are higher than average, and during periods of low wind speed, hourly average pollutant concentrations will greatly exceed the values listed in Table II. From statistical information on flight frequency and wind speeds, the probability distribution of pollutant concentrations can readily be calculated with the aid of Equation (1).

There are several factors which tend to make the estimates of Table II too high. It has already been mentioned that the effects of ground level operations have been included in the data of Table I, and hence also Table II. We have assumed that the average vehicle of the future is the equivalent of a present-day four engine turbofan powered transport. Perhaps the lateral width $\underline{w}$ has been underestimated. On

the other hand, there are factors which would increase these estimates. The trend of engine development is to increase overall pressure ratios, and hence temperatures, which tend to increase nitrogen oxide formation. Aircraft tend to increase in size, permitting more fuel to be burned per vehicle and, at limiting traffic frequencies, more pollutant production per unit time.

Taking into account all these factors, it is difficult to escape the conclusion that the expansion of airports to capacities near 10^8 passengers/yr will result in a noticeable air pollution problem for large distances downwind from the airport. Unless emissions of particulates and oxides of nitrogen during landing and take-off are significantly reduced below present levels, air pollution in large areas surrounding such proposed giant jetports cannot be avoided.

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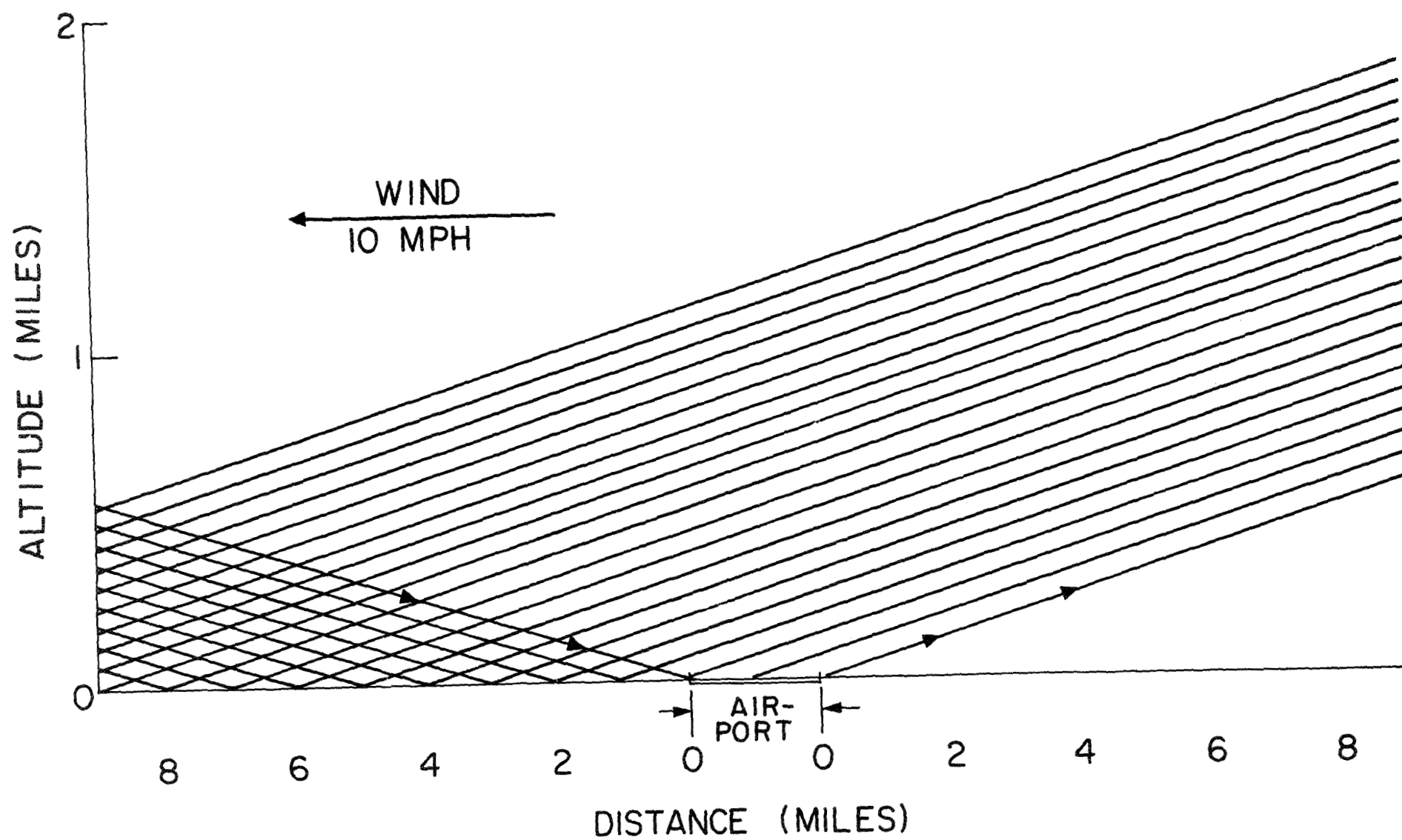


Figure 1. Paths of deposition of air pollutants for aircraft landing at six minute intervals.