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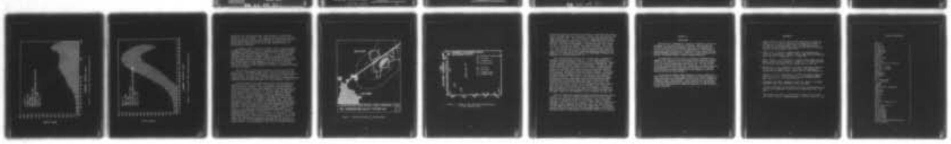

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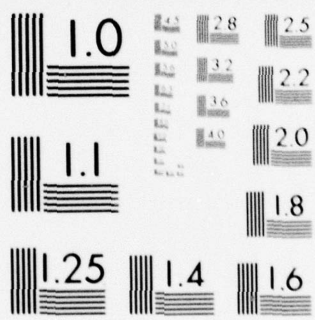

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MEASUREMENT AND ANALYSIS OF AIRPORT EMISSIONS

PETER S. DALEY
DIRECTORATE OF ENVIRONICS
ENVIRONMENTAL ASSESSMENT RESEARCH DIVISION

SEPTEMBER 1978

INTERIM REPORT FOR PERIOD 1 MARCH 1977–1 JULY 1978

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CIVIL AND ENVIRONMENTAL ENGINEERING DEVELOPMENT OFFICE
(AIR FORCE SYSTEMS COMMAND)
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FLORIDA 32403

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This paper is of interest to those involved in regulation and analysis of aircraft related air pollution problems. USAF efforts to measure and model airport pollution are summarized. Efforts include: (1) a joint EPA study at Williams AFB, AZ which involves both modeling and measurement, (2) photographic studies to track plume rise, (3) theoretical modeling studies to analyze airport pollution. The author concludes that the Williams study, soon to be completed, will greatly aid in determining the accuracy of airport air pollution dispersion models, that air quality modeling studies have shown that state-of-the-art

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Air Force engines cannot be cost effectively modified to reduce pollution except possibly in the hydrocarbon area and that, at present, unpredictable thermal plume rise of aircraft exhausts renders model ineffective at locations close (<1 km) to the source.

PREFACE

This interim report was prepared by Det 1 ADTC Civil and Environmental Engineering Development Office (CEEDO), Tyndall AFB Florida. This work was accomplished under JON 21035A28. Maj Peter S. Daley, Det 1 (CEEDO) ADTC was the project officer.

The report was originally prepared as a background paper for the International Civil Aviation Organization Committee on Aircraft Engine Emissions. It summarizes a number of aircraft related pollution research programs being carried out by the Air Force and some of the conclusions that may be drawn from them. Because the original paper was used strictly internally by ICAO, it has been updated and published as a technical report to give the subject matter wider dissemination.

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

The issue of airport pollution is of great concern to the international aviation community. Today we stand at a decision point critical to this issue. The direction we take could have a major effect on engine designs and costs. The decision is not an easy one. Data collected through extensive airport pollution measurement programs have not clearly demonstrated the influence of airports on the environment. Although air pollution dispersion modeling studies have not been fully accepted as predictors of airport air quality, many have indicated a small impact for most pollutants. Reviews of both measurement and modeling studies have been published. In March of this year, the United States Environmental Protection Agency published a comprehensive review of past work to assess the air quality impact of commercial aircraft (Reference 1). The 1975 Federal Aviation Administration review of modeling assessment techniques presents a comprehensive look at all but the most recent developments in airport air quality modeling (Reference 2). These studies have outlined strengths and shortcomings of both measurement and modeling. The following discussion will briefly address some of the issues identified in these reports and review several Air Force programs which are dedicated to resolving the outstanding problems.

A. Measurement Programs

Major airport air quality measurement programs have been conducted at several sites since passage of the 1970 Air Pollution Control Act. These measurement programs have generally been conducted in conjunction with computer modeling studies in an attempt to verify modeling techniques. The studies have all suffered from the inability to clearly separate the airport and background urban pollution components. For this reason the US Navy, Environmental Protection Agency and Air Force joined together to measure and model pollution at an active military air base located far enough from urban centers to assure that the urban plumes would not obscure aircraft emissions. The base chosen was Williams AFB, Arizona, 40 miles east of Phoenix. Table 1 compares Williams operational frequency and emissions with Chicago O'Hare and Pittsburgh airports. The high activity level at Williams AFB is due to its mission as a major pilot training base. The primary aircraft operated there are the T-37 and T-38 trainers powered by J-69 and J-85 engines, respectively. Both engines antedate any pollution control efforts and the latter is a particularly large carbon monoxide emitter. Aircraft at Williams AFB account for approximately 60 percent of the carbon monoxide atmospheric pollution in the vicinity of the base. Because of these high carbon monoxide emissions and its relative ease of measurement, carbon monoxide was chosen as the pollutant of choice for emission tracking, although NO_x, hydrocarbon and particulate matter were also measured.

TABLE 1. ANNUAL OPERATIONS AND EMISSIONS FOR AIRCRAFT OPERATIONS

	Chicago O'Hare *	Pittsburgh *	Williams AFB
Landing and Takeoff Cycles, (thousands)	345	145	155
Emissions (Metric Tons)			
Nitrogen Oxides	4138	883	120
Hydrocarbons	8674	863	1416
Carbon Monoxide	14009	262	4255

* 1976 FAA Data

The field phase of the Williams work lasted thirteen months and cost approximately $870,000. Table 2 delineates the instrumentation used in the study. Five complete air sampling and meteorological stations were assembled and sited as shown in Figure 1. Data were collected continuously by a minicomputer connected by telephone lines to each station. Final data reduction was accomplished by the Environmental Protection Agency at their Las Vegas facility. As is typical of all ambient measuring studies, instrumentation operation was not faultless. Valid data were recovered for over 70 percent of our operating time; this compares favorably with Environmental Protection Agency (EPA) experience operating similar stations. The EPA rejects data from stations with data recovery rates of less than 70 percent. Figure 2 is a typical graphical display of the preliminary results for one month of carbon monoxide sampling at one station. One hour average concentrations and other results were computed from one minute samples. Results indicate that concentrations are generally low with some significant short-term excursions for CO and hydrocarbons.

One of the questions that has continually plagued measurement programs is whether or not the exhaust plume was passing over the monitoring station undetected due to plume rise. The Air Force and Federal Aviation Administration have addressed this question in two separate studies, an in-house AF effort in which smoke traced plumes were tracked photographically (Reference 3) and a joint Air Force Federal Aviation Administration study in which carbon monoxide concentrations were measured at various heights as plumes passed 25 meter towers. The final report from the latter study is now being prepared. Figures 3 and 4 show graphical traces of typical plumes photographically tracked. It is clear from these traces that ground separation can and does occur. The same conclusion was drawn from the tower studies. Ground separation generally occurs under unstable atmospheres with low winds. The conclusion to be drawn from this experience is that if ground measurement stations are to be sure to record aircraft plumes, they must be far enough from the source to assure that the plume has time to diffuse to the ground. This distance is probably of the order of one kilometer under worst conditions.

B. Modeling

The Air Force began its air base ambient air quality modeling program in 1972 with the adaption of the existing Airport Vicinity Model, developed by Argonne National Laboratory for the Federal Aviation Administration, to military flying operations. The resulting model, called the Air Quality Assessment Model (AQAM) and also developed at Argonne, is one of the most comprehensive air quality models available. It provides for up to fifty aircraft types and a complete array of mobile and stationary ground sources. It uses Gaussian point, line and area source dispersion equations to compute the concentrations of the five principal

TABLE 2. WILLIAMS AFB FIELD STUDY

PARAMETER MEASURED	METHOD
NO, NO_x	Dual reaction chamber chemiluminescent analyzer
Total hydrocarbon, CH_4, and CO	Gas chromatograph with flame ionization detector
Nephelometric visible light scattering	Integrating nephelometer
Wind speed and wind direction	Propeller vane anemometer
*Mixing depth	Monastatic acoustic sounder
*Isolation	Pyranometer
*Vertical winds	UVW propeller anemometer

*Measured at only one location

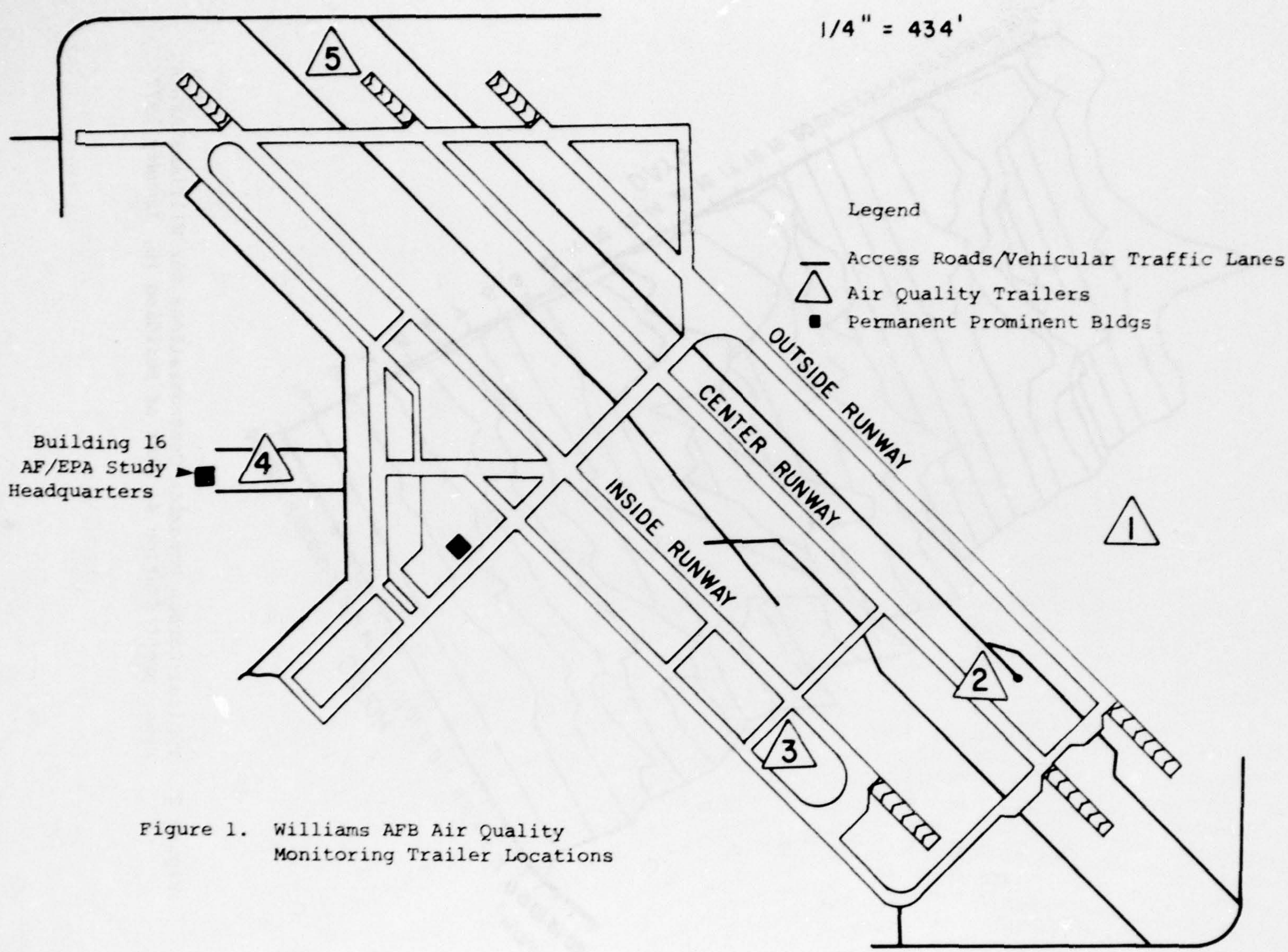

Figure 1. Williams AFB Air Quality Monitoring Trailer Locations

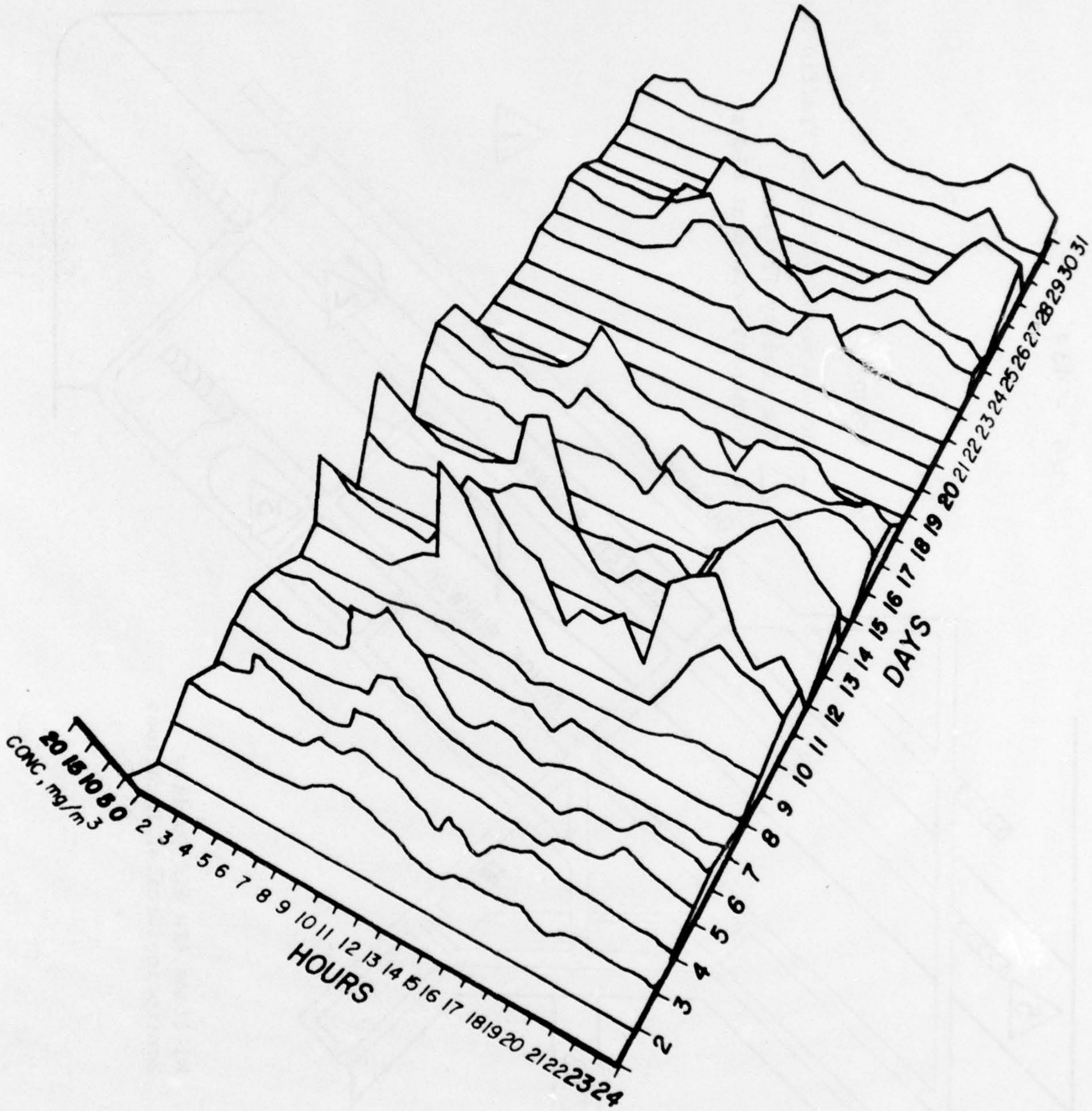

Figure 2. Typical Carbon Monoxide Concentrations for Williams AFB AZ Measurement Station 4, East of Building 16, January 1977

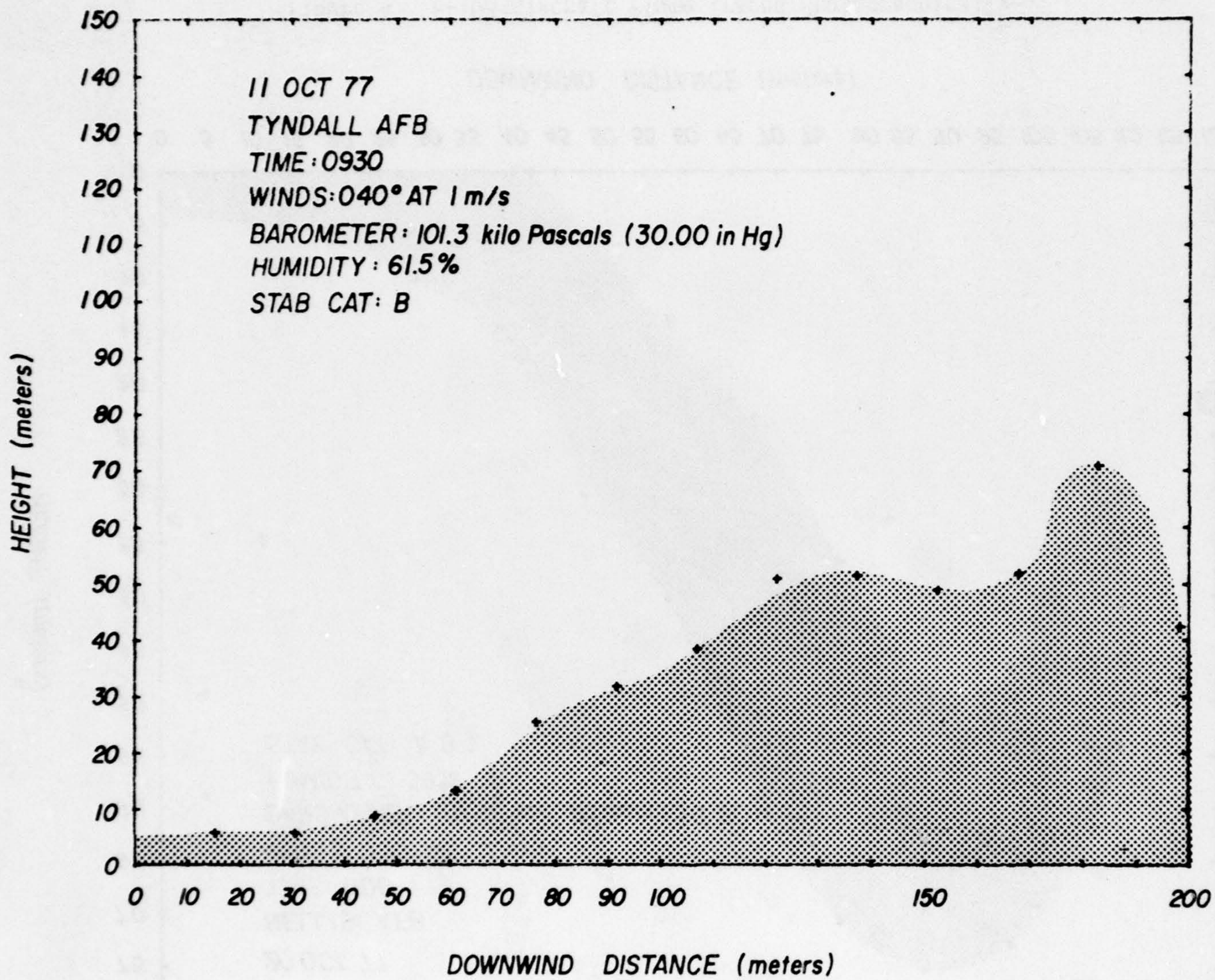

Figure 3. T-38 Aircraft Plume Traced Photographically

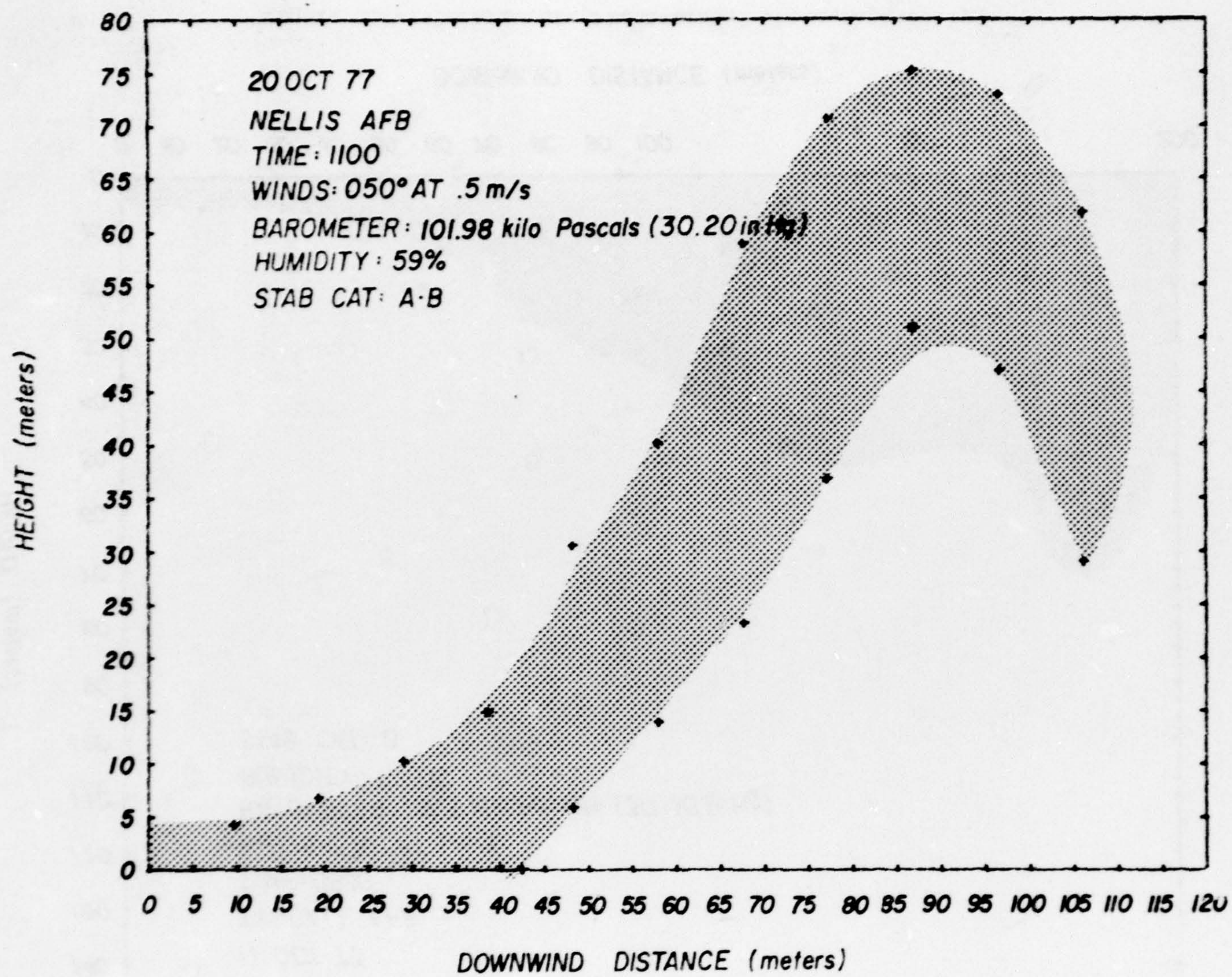

Figure 4. F-102 Aircraft Plume Traced Photographically

pollutants (SO, NO_x, hydrocarbons, carbon monoxide, and particulate matter) at up to 389 points. This array can then be used to plot concentration contours; Figure 5 is an example of nitrogen oxide isopleths. Hourly concentration predictions can be made for any given set of meteorological conditions for an entire year through the use of a meteorological subroutine.

The AQAM was used to evaluate the impact of AF flying operations on air quality (References 4, 5) and to evaluate the air pollution benefit obtainable by reducing emissions of state-of-the-art engines to established Air Force emission goals (Reference 7). To put the different pollutants in perspective in these studies, all concentrations were reduced to PSIs, the EPA Pollution Standards Index (Reference 6). Since PSI equivalents were not available for nitrogen oxides or hydrocarbons, the California one-hour NO_x standard of 470 $\mu g/m^3$ and the National Ambient Air Quality (3 hour) Hydrocarbon Standard of 160 $\mu g/m^3$ were arbitrarily set to a PSI of one-hundred with linear interpolation between zero and one hundred.

The A-10 and F-15 aircraft were selected as typical state-of-the-art aircraft in the emission goals study. The A-10 is powered by two General Electric TF 34-100 engines and the F-15 by two Pratt and Whitney F-100 engines. The former is an advanced version of the older TF-34 turbofan series, and the latter is the Air Force's most recently developed production turbofan engine and power the F-16 in addition to the F-15.

Plotted in Figure 6 are "worst case" PSIs (1 m/s tail wind, "F" stability and 115 m mixing depth), for positions 5 and 10 km downwind along the runway centerline. The solid symbols represent emissions from current engines and the dotted symbols, the PSIs that would be predicted if the AF were to retrofit the engines to meet the USAF Turbine Engine Emission Goals (Reference 7). The goals cannot be compared easily with the recently proposed revisions to commercial aircraft engine emission standards (Reference 8) because the latter assume a specific landing-takeoff cycle whereas the former are based on engine efficiency (CO and HCs) and combustor temperature (NO_x). The goals, when applied to typical A-10 and F-15 operations, will exceed the EPA standards for smoke and NO_x but not those for hydrocarbons and carbon monoxide. Future revisions of the goals will probably make them more restrictive for these latter two pollutants, however. Returning to Figure 6, it is clear that the only significant improvement to be obtained through application of the goals is in the area of reactive hydrocarbon (RHC) control. For SO_2 there is no goal, and TSP (Total Suspended Particulate matter) and CO emissions are already so low that their contributions to air pollution is inconsequential. For nitrogen oxides, the contribution to air pollution from the F-15 aircraft is relatively high, but the improvement obtainable through achieving the goals is small. It is interesting to note that the nitrogen oxide air

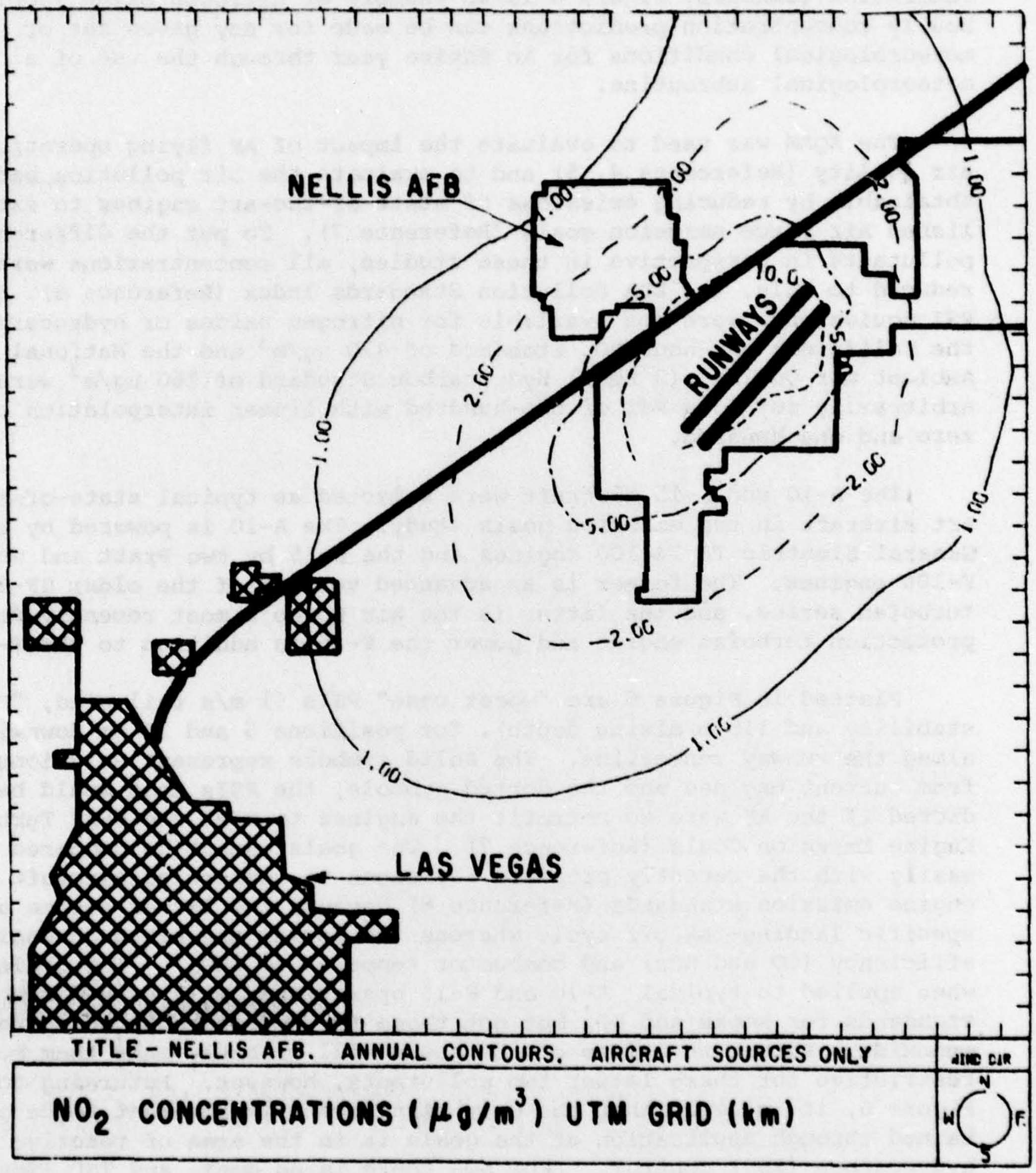

Figure 5. Nellis AFB Annual NO_x Concentrations

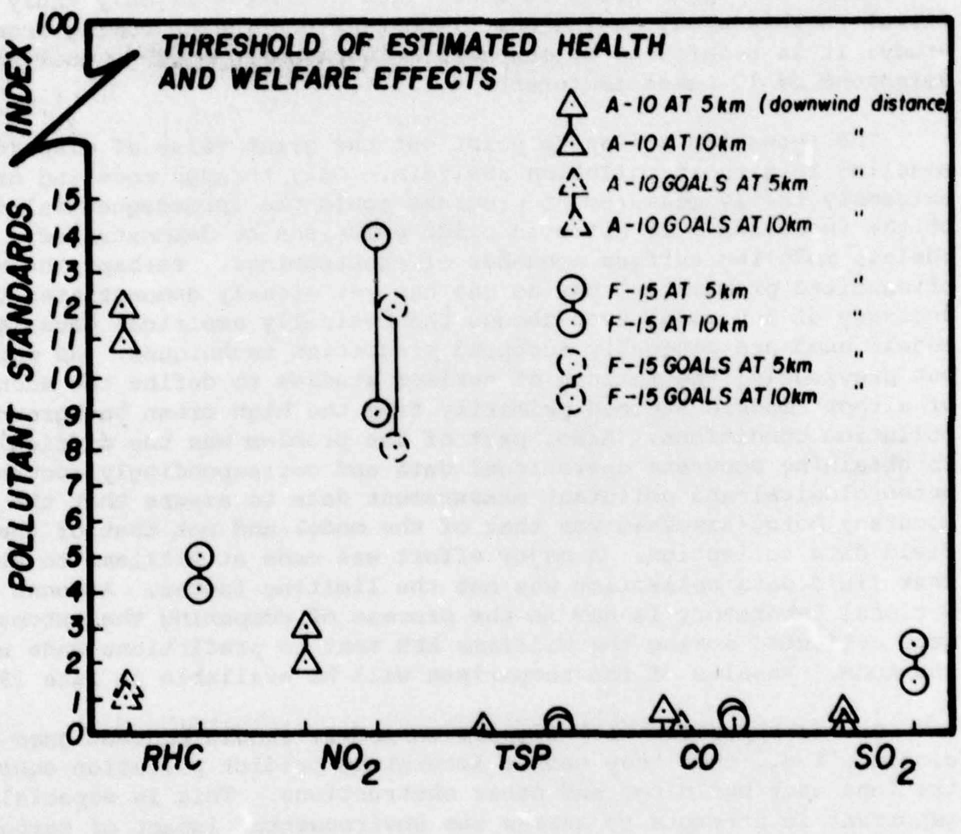

Figure 6. Changes in PSI Levels Through Application of USAF Emission Goals

pollution contribution from the F-15 aircraft is essentially the same as that of the much older F-4 it replaces in spite of the much higher F-100 engine pressure ratio. This is because the higher NO_x emission factor (mass of pollutant per unit mass of fuel) is compensated by the greatly improved performance (shorter time on take-off roll and climb out) of the F-15. Note that no improvement in hydrocarbon emissions is shown for the F-15 because the present engine meets the goals. The earlier conclusion regarding the dominant importance of hydrocarbon emissions, i.e., that the application of more rigid standards is only truly beneficial in this area, is the most important conclusion coming from this study; it is reinforced by our earlier work using AQAM to analyze the emissions of 10 bases (Reference 4, 5).

The foregoing serves to point out the great value of dispersion modeling in airport pollution analysis. Only through modeling or extremely costly measurement programs could the inconsequential impact of the increased F-15 nitrogen oxide emissions be demonstrated. Nonetheless modeling suffers a number of shortcomings. Perhaps the most often cited problem is that no one has yet clearly demonstrated the accuracy of any model even though the basically empirical Gaussian models used are generally accepted prediction techniques. As pointed out previously, the failure of earlier studies to define the accuracy of airport models stemmed primarily from the high urban background pollution conditions. Also, part of the problem was the difficulty in obtaining accurate operational data and correspondingly accurate meteorological and pollutant measurement data to assure that the accuracy being assessed was that of the model and not that of the field data collection. A major effort was made at Williams to assure that field data collection was not the limiting factor. Argonne National Laboratory is now in the process of comparing the extensive data collected during the Williams AFB test to predictions made using the AQAM. Results of the comparison will be available in late 1978.

One last problem with dispersion models should be mentioned before closing, i.e., that they cannot accurately predict pollution concentrations near buildings and other obstructions. This is especially important in attempts to assess the environmental impact of carbon monoxide in the vicinity of air terminals. The plume rise observations discussed earlier aggravate the problem further since most existing aircraft models do not include plume rise computations. No reasonable solution to this problem exists, and measurement appears to be the only practical method to assess airport air pollution close to the terminal.

SECTION II

CONCLUSIONS

The Air Force is engaged in a variety of studies to aid in the assessment of the airport pollution problems. The Williams AFB pollution measurement and modeling study now being completed will provide the first extensive airport measurements in the absence of obscuring background pollution. Comparison of the results with dispersion modeling predictions will provide a valuable measure of the ability of Gaussian models to predict airport pollution.

The application of the Air Force Air Quality Assessment Model (AQAM) to the analysis of air base pollution has shown that the most beneficial air pollution control investment the Air Force can make is in the field of hydrocarbon emission control. The use of the Pollutant Standards Index (PSI) as a common base to compare predicted concentrations of various pollutants was instrumental in reaching this conclusion and could greatly facilitate analysis of the commercial aviation pollution problem.

In the area of exhaust plume tracking, Air Force studies have shown that rise of a turbine engine plume due to thermal buoyancy can cause ground pollutant measurement stations close to the aircraft to completely miss a passing plume. This, together with the inability of Gaussian models to predict concentrations close to obstructions, limits their applicability to pollution prediction in the vicinity of airport terminals.

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