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Air Pollution by Jet Aircraft at Seattle-Tacoma Airport

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Western Region

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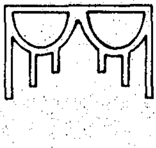

A western Indian symbol for rain. It also symbolizes man's dependence on weather and environment in the West.

U. S. DEPARTMENT OF COMMERCE
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
WEATHER BUREAU

Weather Bureau Technical Memorandum WR-58

AIR POLLUTION BY JET AIRCRAFT AT SEATTLE-TACOMA AIRPORT

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Seattle-Tacoma, Washington

WESTERN REGION
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AIR POLLUTION BY JET AIRCRAFT AT SEATTLE-TACOMA AIRPORT

I. INTRODUCTION

Most pollution problems we face today are a direct result of advances in technology. In the aircraft industry this is particularly true. As the airplane increased in size and power, more pollution was produced. The advent of the commercial jet aircraft attracted the attention of the public through the visible smoke plume and noise.

The rapid expansion of air transportation brought other problems to airlines and airport operators. There were lawsuits over violation of individual air space, complaints over falling objects and nasty letters written to the editor concerning TV and radio interference. At local airports there were strong kerosene odors, soot fallout, and occasional occurrences of eye irritating smogs.

The sprawling major airports with ever-increasing numbers of large, more powerful jet aircraft are the result of technological developments which in turn contribute air pollution.

At the 62nd annual meeting of the Air Pollution Control Association in New York on June 26, 1968, a paper was presented by George, Verssen, and Chass (1). This paper was one of the first studies of jet aircraft pollution in the United States. Ideas and data in this paper suggested the format for the Seattle study.

In the pages that follow, some of the problems of the jet engine are discussed along with some effects on the environment. Proposals to help to reduce the pollution problem are also discussed.

II. TRANSPORTATION GROWTH PATTERNS

Figure 1 depicts a 30-year pattern of public transportation covering domestic intercity travel. The rapid increase in air passenger miles, after the advent of the jet aircraft in 1958, is very apparent. Data for Figure 1 was taken from information gathered by the National Academy of Engineering (2). A projected period of data extends from 1970 to 1977.

III. TECHNOLOGY INTERACTIONS

Figure 2 represents a system of social and technological activities centered around the airplane. The interaction between the environment and the elements of the system are shown by the arrows.

Most of the technological interactions of Figure 2 apply to all modes of transportation and not exclusively to the airplane. The aircraft industry, however, is an excellent example (3).

IV. PUBLIC RESISTANCE TO JET AIRCRAFT

Two features of jet aircraft operation cause most criticism by the public: noise and the very obvious smoke plume. This paper will deal with the problem of air pollution and discuss contaminants found in the jet engine exhaust.

V. A HISTORY OF THE SEATTLE-TACOMA AIRPORT

The Seattle-Tacoma Airport was constructed in 1944 as an alternate airport to nearby busy Boeing Field. It was expected to be relatively fog-free due to its higher elevation, 400 feet above sea level as compared to near sea level at Boeing Field (4). The original terminal building was completed in late 1949 and most commercial carriers transferred their operations to the new location at that time. As the air transportation business boomed in the twenty-year period following the opening of the airport,many physical changes took place on the field. The original main runway was doubled in length and a new parallel one is in the process of being completed. The airport administration building, which had been previously expanded many times, is now in the process of massive expansion.

VI. AIR TRAFFIC STATISTICS FOR SEATTLE-TACOMA AIRPORT 1960 TO 1969

The number of commerical flights from Seattle-Tacoma Airport has nearly doubled between the years 1960 to 1969. Except for the years 1969 and 1963, traffic figures climbed steadily from year to year. These figures do not include itinerant or military traffic (5). The latter types of air traffic, while not inconsequential, are too variable to be included in this study. Figure 3 is a graph of commercial air traffic at Seattle-Tacoma Airport during this period.

VII. EMISSION CHARACTERISTICS OF JET AIRCRAFT ENGINES

Jet aircraft engines emit the same type of atmospheric contaminants as car, truck and bus engines. Gaseous emissions are composed principally of carbon monoxide and hydrocarbons. Other major gaseous pollutants are oxygenated organic compounds and oxides of nitrogen. Levels of the latter vary during similar operating modes. Carbon is an important particulate emission, which is found in the form of smoke, the major particulate emission in jet engine exhaust (6). Engine smoke is composed for the most part of fine particles of nearly pure carbon with diameters of 0.6 micron or less. The combination of size and composition gives substantial light-scattering properties to the exhaust plume. Aerosol emissions in the form of water droplets, unburned fuel, and soot particles are difficult to measure because of possible sampling variations (7).

Fuels contain sulfur impurities which cause sulfur compounds in the combustion products of motor vehicles and aircraft. Since these sulfur compounds are present only in very small quantities in the engine exhaust, they are only of minor concern in the transportation-related air pollution problem (6).

VIII. TURBINE ENGINE ODORS

There are certain characteristic odors produced by the operation of turbine powered aircraft. However, it has not been possible so far to relate these odors to specific chemical compounds or classes of compounds isolated from samples of the turbine exhaust.

IX. COMPARISON OF AUTOMOBILE AND AIRCRAFT ENGINE EMISSIONS

Table I shows a comparison of automobile and aircraft engine emissions. The emission index represents the number of pounds of pollutant per thousand pounds of fuel. The radial piston engine produces considerably more carbon monoxide and hydrocarbons than the automobile engine. The jet engine produces only about 5% of the carbon monoxide and 17% of the hydrocarbons produced by the automobile engine on the average.

The automobile engine emits the maximum amount of oxides of nitrogen, nearly 10 times as much as the jet engine and radial piston engine. All three engine types produce similar amounts of particulate matter.

X. COMPARISONS OF DAILY CONTAMINANT EMISSIONS IN LOS ANGELES COUNTY

Table 2 compares average contaminant emissions from combustion of fuels by motor vehicles, power plants, and jet engines in Los Angeles County for 1969 (I). Under power plants, period I represents data for the seven-month period between April 15 and November 15 inclusive. Period 2 represents data for the remainder of the year (winter). Average daily emissions are listed in tons per day.

Daily average totals indicate that jet aircraft emission is about 1% of the motor vehicle and about 1/2 that of power plant emission. If carbon monoxide emissions are disregarded, jet aircraft emissions are 3.5% those of the automobile engine and 37% of power plant totals. Highest emission ratios occur under particulates, with the jet aircraft reaching 25% of the motor vehicle total and over 3 times the power plant average. The figures show a wide variability in pollutant emissions by each engine type. This suggests a closer examination of each individual pollutant.

XI. AIR FORCE COMPARISONS OF JET ENGINE AIR POLLUTION EMISSIONS

At the request of the National Center for Air Pollution Control, Public Health Service, and at the direction of the Surgeon's Office of the Environmental Health Laboratory, Kelly Air Force Base, Air Force Logistics Command conducted tests to measure and characterize exhaust products of three representative Air Force jet engines which have counterparts in civilian airlines (8). The three engines tested were the T-56 turboprop engine used to power the C-130 (Lockheed) and the Lockheed Electra, the J-57 conventional jet engine (Pratt and Whitney) used on the B-52 and Boeing 707, and the TF-33 fan jet engine (Pratt and Whitney) used on the Boeing 707, 720, and Douglas DC-8.

Tests were conducted in engine test cells operated by the Air Force. The information was intended for use in preparing estimates of pollution emissions from jet engine aircraft operation. JP-4 type fuel was used in all of the tests.

Table 3 shows a breakdown of pollution emissions for each engine type using power settings for take-off, cruise and approach, and idle. Oxygen and carbon dioxide pollutants are expressed in percentages while the remaining pollutants are expressed in parts per million. Table 4 shows a similar breakdown except that pollutants are measured in pounds per hour.

Data values obtained for all contaminants in Tables 3 and 4 represent average emission rates over a period of 10- to 30-minute intervals. Samples were not taken during acceleration or deceleration modes because large variations in exhaust composition were observed during these periods. Oxide of nitrogen emissions mainly take the form of nitric oxide. In TF-33 exhaust the volume-percent of nitric oxide in the total nitrogen oxides varied from 82 to 93%, while in J-57 exhaust the percent composition varied from 62 to 76% depending upon engine power setting. Percent composition of nitric oxide was greatest at take-off power setting and lowest at idle power setting.

Olefin and aromatic characterizations of exhaust hydrocarbons were performed at idle setting only, since analysis at other power settings involved analytical measurements beyond the lower limits of the flame ionization detector. Photochemically reactive hydrocarbon content (olefins and aromatics) of T-56, J-57, and TF-33 exhaust represented 35, 51, and 40% respectively of the total hydrocarbons emitted. Olefin content was significantly greater than aromatic content in TF-33 exhaust. Emissions of reactive hydrocarbons are particularly important to emission studies related to photo-chemical type smog problems.

The principal aldehyde present in jet engine exhaust is formaldehyde. From Table 3, it can be seen that the formaldehyde content of the aldehydes measured was greater than 70% in J-57 and T-56 engines, except at take-off setting in the T-56 exhaust when the formaldehyde content was 27%. Carbon monoxide and hydrocarbon concentrations in exhaust products generally increased with decreasing engine power settings, while nitrogen oxide concentrations generally increased with increasing power settings.

Odor dilution threshold* for jet engine exhaust varied from 15 to 1000, depending upon engine type and power setting. Odor dilution threshold is greatest for the fan-jet engine at idle power setting.

Data obtained on particulate emissions from jet engines during this study are limited, especially those obtained from T-56 and J-57 engines. Sufficient data to provide a representative value were obtained only for the TF-33 engine. The irregular nature of particulate emissions resulting from deposition of soot on burner cans and subsequent sporadic discharge complicated collection of representative samples. Further tests on emissions of particulates from TF-33 engines would be desirable, and further tests on the other two engines are necessary to obtain particulate emission factors.

XII. COMMERCIAL AIR TRAFFIC FIGURES FOR SEATTLE-TACOMA AIRPORT IN 1969

In 1969, there were 108,111 commercial take-offs and landings at Seattle-Tacoma Airport. These figures do not include light, itinerant, or military aircraft (9). Port of Seattle aircraft landing records (10) for 1969 were examined to determine types of aircraft used. Ninety percent of the total commercial traffic at the airport during 1969 was jet-type aircraft. The remainder of the traffic consisted of Electras and Viscounts with a few Hercules and an occasional Constellation. Aircraft traffic counts were compiled every 3 months for purposes of classifying aircraft types. Table 5 presents air traffic figures for the airport in 1969.

XIII. JET AIRCRAFT TIME STUDY COMPARISONS

One hundred twenty aircraft landings and departures at Seattle-Tacoma were clocked with a stopwatch to obtain representative figures for air pollution computations. Average times were computed for taxiing, holding, landing run, climb-out to 3500 feet and approach from the same altitude. Radio contacts, radar contacts, and turning patterns were used along with visual contact. Table 6 is a comparison of time

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*The beginning point at which the odor is being diluted by other gases.

studies from the Los Angeles data (1), the Air Force study (8), and the Seattle-Tacoma figures.

Average times of the Air Force study are estimated, and are based upon a climb to or a descent from 2500 feet. Times for the other two studies are computed times and are averaged over a series of operations. Taxiing and holding times at Seattle are appreciably lower than at Los Angeles, while take-off and climb and approach to touchdown are slightly higher.

Airplane types used to compute average times in the Los Angeles and the Seattle studies are identical. Aircraft types in the Air Force study are limited to the B-707, the B-720, and the DC-8. The Douglas DC-9, which was used in the Los Angeles study, has had only limited use at the Seattle-Tacoma airport and was not considered in the Air Force study at all. The total number of observations ranged from 70 in the Los Angeles study (1) to 120 in the Seattle study.

XIV. ESTIMATED POLLUTION EMISSIONS FROM JET OPERATIONS

Lozano, **Melvin**, and Hochheiser estimated pollution emissions for certain jet engines (8). These emissions were based on estimated times for taxiing, take-off, climb-out, approach, and landing run. Average estimated departure (taxiing, take-off, climb-out) times were 6.5 minutes based upon a climb to 2500 feet. Arrival times (approach, landing run, taxiing) were estimated at 9.5 minutes for a descent from 2500 feet to arrival at terminal. Table 7 shows estimated total pollutant emitted in pounds. Note the increase in pollutant emission for arrivals as compared to departures.

XV. LOCAL POLLUTION DISPERSION AREAS

Heavier aircraft pollutants are dispersed in a fan shaped area from each end of the main runway. Maximum distances from the end of the runway at which pollution was detected were 6 miles for take-offs and 12 miles for approaches.

On southbound departures from Seattle-Tacoma (Figure 4), pollution will be dispersed over an area bounded by the city limits of Kent to the southeast, Star Lake to the south, and the northern tip of Maury Island to the southwest. On approach to touchdown from the south, limits of pollution will extend from Auburn to Lake Killarney to Dash Point.

For northbound departures, pollution will be dispersed over an area bounded by Arbor Heights to the northwest, Boeing Field to the north, and Renton to the northeast. Approaches from the north will disperse pollution over an area bounded by Eastgate, the original Lake Washington floating bridge, and northwestward to the Alki Point lighthouse.

XVI. AREA FUEL CONSUMPTION

Aircraft fuel consumption in the United States for the year 1967 is estimated at 19×10^6 gallons (11). The largest user area is the northeast section of the county where an estimated 7.4×10^6 gallons will be consumed. The second largest user area is the far West, including Alaska, Hawaii, California, Oregon, Nevada, Arizona, and Washington. Consumption in this area is expected to be 5.5×10^6 gallons of aircraft fuel. Since 68% of fuel consumption falls into these two areas, it would be reasonable to expect to find a high rate of air pollution as well.

Table 8 depicts average fuel consumption rates in pounds per minute for each jet engine model. Table 9 shows annual fuel consumption for various airports (12).

Table 10 compares arrival and departure fuel consumption at Los Angeles with that of Seattle for the three most common engine types for the years 1968-69. Note that consumption is greater at Seattle for JT3D-3B and JT8D-7 engines, but averages slightly lower for the 501-D13 engine. Differences are due to variations in elapsed arrival and departure times at the two airports for aircraft using the engines in question.

XVII. AIRCRAFT EMISSION COMPARISONS

Data from Table 10 provide the necessary information for computation of average rates of emission of air contaminants for the Seattle-Tacoma Airport based upon the Los Angeles study. These are shown in Table 11.

When allowances for faster taxi times are considered (see Table 6), an aircraft departing from or arriving at Seattle-Tacoma uses on the average about 6% more fuel than the same aircraft at Los Angeles. Air contaminant emissions shown in Table 11 have been adjusted to show this increase in fuel consumption. Traffic figures also show a slightly higher percentage of aircraft at Seattle to be of the jet type than at Los Angeles. Planes arriving or departing at Seattle had an average of 3.57 engines while the corresponding Los Angeles figure is 3.44.

XVIII. FUEL GRADES AND ADDITIVES

Tests were made in Los Angeles using fuel additive, JP-4 fuel and "clean" burner cans. The fuel additive to Turbine A fuel (CI-2) did not decrease contaminants to any degree. Use of JP-4 fuel reduced particulate matter by 35%, hydrocarbons and organic gases by 79%, and sulfur dioxide by 30%. However, there was a 33% increase in carbon monoxide and a 3% increase in oxides of nitrogen to offset these gains. The use of "clean" or smokeless burner cans produced the lowest number of contaminants, with a total of 14 pounds of contaminants for a turbo-fan JT8D-7 engine per average flight, using turbine "A" fuel.

XIX. VISIBLE EMISSIONS

The visible smoke plume is responsible for the largest number of complaints of jet aircraft air pollution. The Boeing 727, with three engines in close proximity, puts out a concentrated smoke plume that is visible for miles. Although it is both necessary and desirable to reduce these smoke plumes, it is also important to reduce other air contaminants as well.

The use of smokeless burner cans on the JT8D jet engine, the engine used in the Boeing 727, will reduce visible smoke drastically. Tests in Los Angeles revealed decreases of hydrocarbons and organic gases of 99%, while particulates and carbon monoxide were reduced by 23% each. The one undesirable effect was a 40% increase in nitrogen oxides. Some means of reducing this pollutant must also be found.

Figure 5 shows newspaper clippings that reflect the problem with visible smoke. These are typical of the type of article that is appearing with greater frequency in local press.

It has been pointed out recently that absence of a black smoke plume will make it difficult to see jet aircraft (13). This article infers that not only will it be more difficult to spot an approaching jet aircraft but that more and more planes will find themselves in the wake turbulence of passing aircraft because they will be unable to see them. This is a serious problem that requires prompt solution; however, continued air pollution does not appear to be the proper answer.

XX. CONCLUSIONS

The operation of jet aircraft engines produce air pollution. This is a real problem to people who work at or reside near major airports. The approach to control of this pollution is similar to ones used in the control of many other pollution sources.

Aircraft engine pollution can best be controlled through engine modification and fuel substitution. Some success has already been achieved by these means. Goals should include a reduction in the amount of all pollutants. A control which provides small reductions in all pollutants is superior to one which reduces the concentration of one pollutant but increases another.

Progress in the solution of jet engine air pollution problems will not come overnight. Costs are high and new developments are slow. Unfortunately, high air quality is no longer free; it is one of the costs of doing business.

XXI. REFERENCES

1. Jet Aircraft, A Growing Pollution Source, R. E. George, J. A. Verssen and R. L. Chass, June 1969.
2. Statistics from National Academy of Engineering 1941-1977.
3. Scientific American, February 1970, pages 13 through 21.
4. Terminal Forecasting Reference Manual Seattle-Tacoma Airport, February 1968.
5. Port of Seattle traffic count 1960 through 1969.
6. Department of Health, Education, and Welfare, Nature and Control of Aircraft Engine Exhaust Emissions, December 1968.
7. Aircraft Engine Exhaust Emissions, Brian E. Bates, University of Washington, CE451, 1968.
8. Air Pollution Emissions from Jet Engines, JAPCA, June 1968, Volume 18, No. 6.
9. Federal Aviation Agency Air Traffic Figures 1969.
10. Port of Seattle Landing records 1969.
11. Airline Management and Marketing, September 1969, page 72.
12. Aircraft Air Pollution, Thomas Hanna, University of Washington, CE461, November 1969.
13. Flying Magazine, May 1970, page 18.

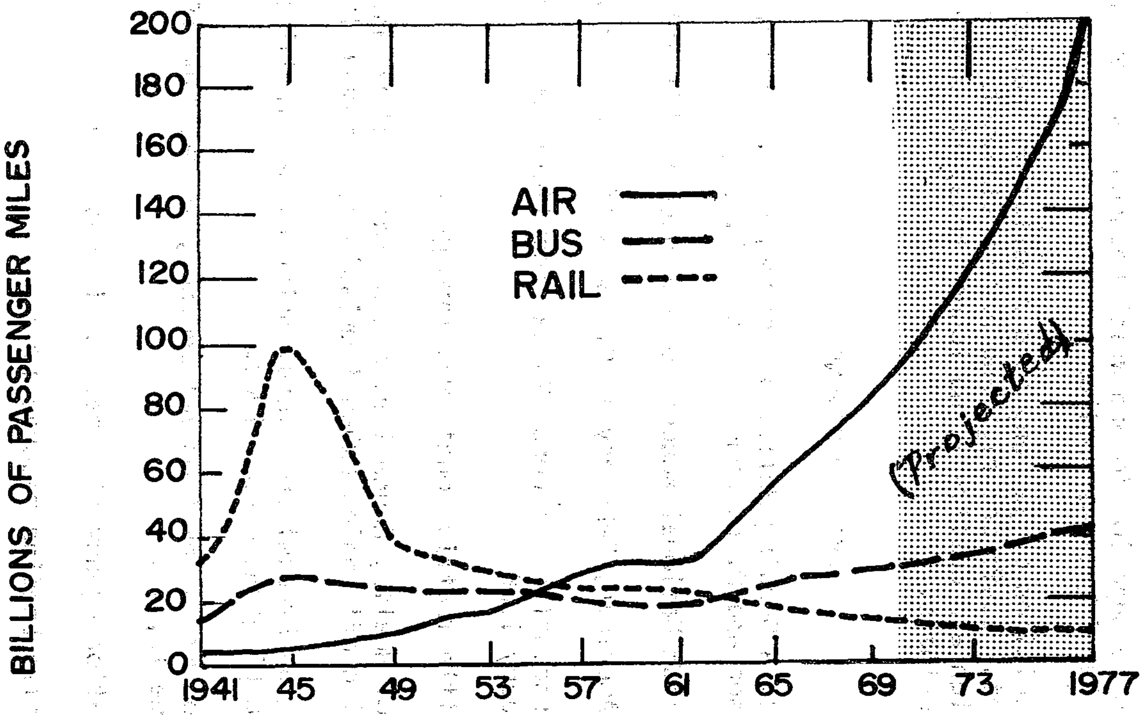

FIGURE 1. PASSENGER MILES FOR RAIL, AIR, AND BUS INTERCITY TRAVEL. 1970-77 CURVES ARE PROJECTED.

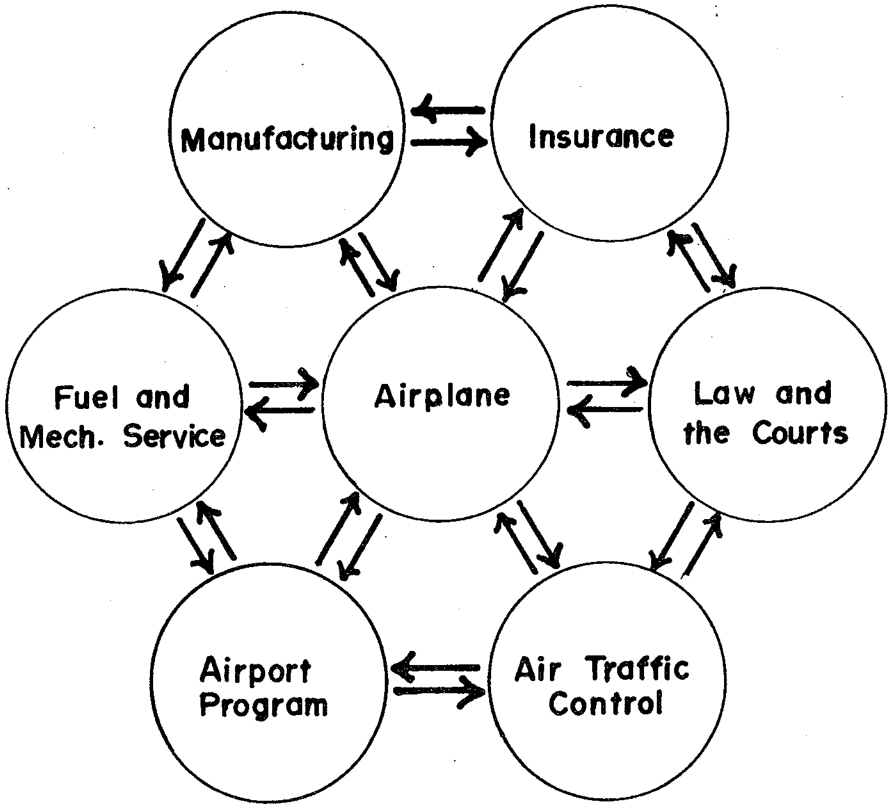

FIGURE 2. SOCIAL AND TECHNOLOGICAL ACTIVITIES RELATED TO THE AIRCRAFT INDUSTRY.

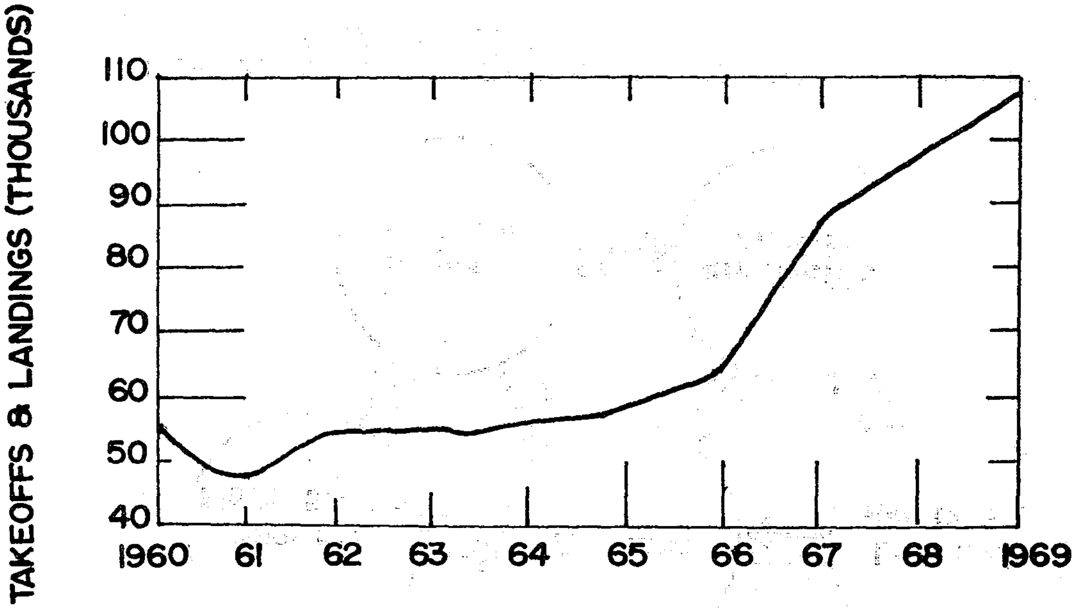

FIGURE 3. COMMERCIAL AIR TRAFFIC AT THE SEATTLE-TACOMA AIRPORT.

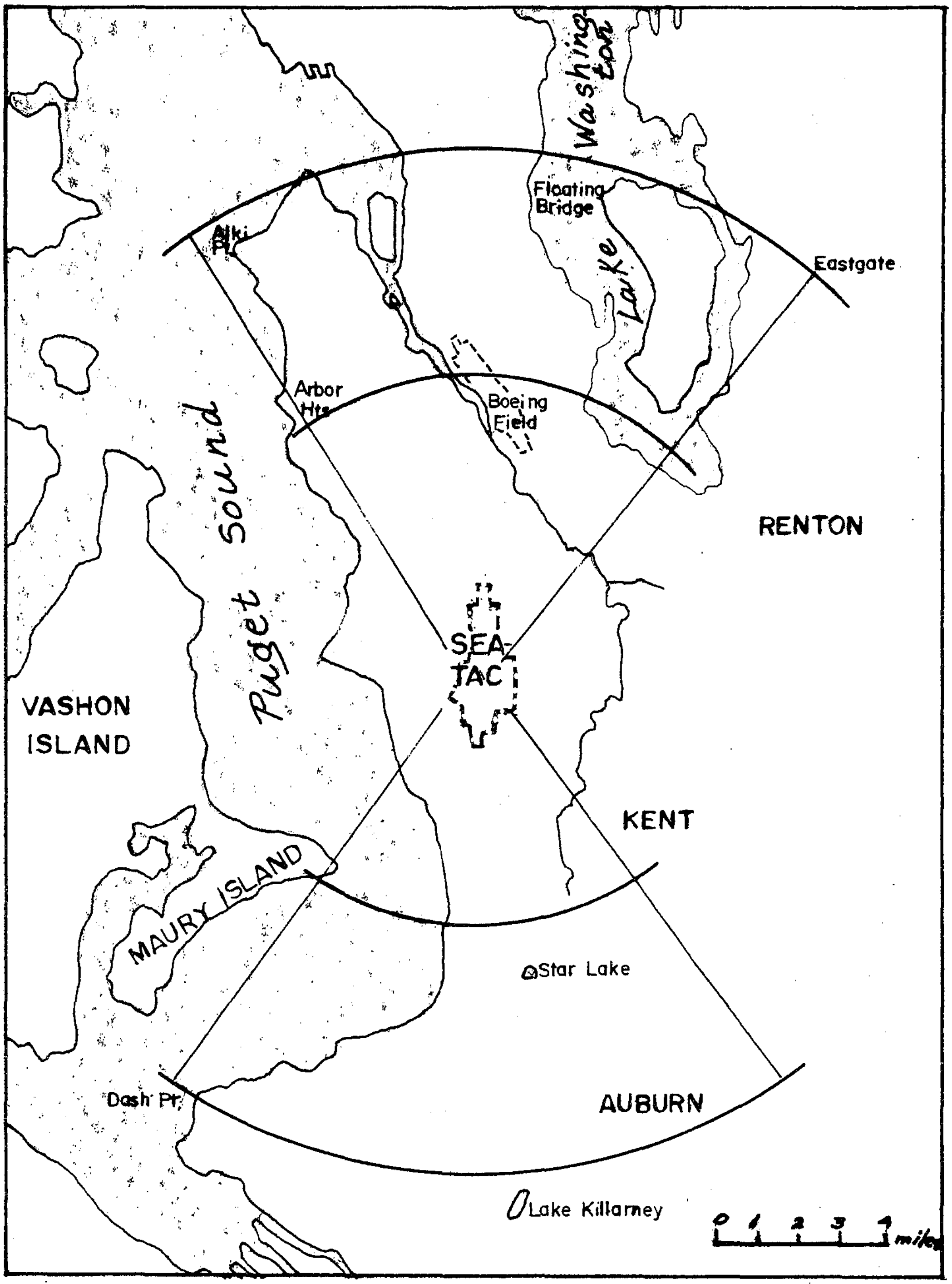

FIGURE 4. MAP OF SEATTLE-TACOMA AIRPORT VICINITY.

20 R Thurs., Feb. 26, 1970 Seattle Post-Intelligencer

United to Reduce Smoke Emission Of Jet Engines

United Air Lines will modify the engines on 225 of its jets to reduce smoke, George Keck, president, announced Tuesday.

The action was taken after the government said it would issue new rules about aircraft smoke emissions.

The planes involved in United's fleet are Boeing-built 737 twinjets and 727 trijets. They are equipped with Pratt & Whitney JT8D engines.

Keck said the job of fitting them with smoke-preventing equipment would cost about $3 million.

The project will begin this spring at the airline's San Francisco maintenance base. Keck said it will be completed by the end of 1972. The executive said:

"Although aircraft contribute less than one per cent of total atmospheric pollutants, we are acting on our corporate responsibility to participate in the solution of environmental problems."

The anti-smoke equipment will cost $8,000 for each 737 and $12,000 for each 727.

Representatives of 31 domestic airlines, including United, met with members of the U.S. Departments of Transportation and Health, Education and Welfare on January 20 and agreed to install smoke-reduction devices.

THE 727 WITH THE STANDARD JT8D ENGINE

Unburned carbon poured out black smoke

—AP Photos.

BOEING 727 TRIJET WITH MODIFIED ENGINE

Virtually no smoke emitted during takeoff

Seattle Times 12-7-69

Airline Timetable Ordered To End Pollution at Newark

NEWARK, N. J. — (UPI) — A Superior Court judge, rejecting airline arguments for delay, ordered nine major carriers Friday to produce a firm timetable for ending pollution produced by some 3,000 planes using Newark Airport.

Judge Nelson K. Mintz warned the airlines that if the timetable for converting pollution-producing planes is not ready by February 9, he will hold a summary hearing on the state's complaint that their planes are polluting the atmosphere.

Airline attorneys stated Friday it might be the mid-1970s before pollution could be eliminated.

Boston Explores Smokeless Engines

BOSTON — (UPI) — Gov. Francis W. Sargent, in a move to curb air pollution, has requested the Massachusetts Port Authority to discuss with the airlines at Logan International Airport the possibility of installing smokeless engines on their jets.

Sargent pointed out Friday that seven major airlines had agreed to use smokeless engines at Newark Airport after New Jersey brought a suit against them.

FIGURE 5

Engine	Operating Mode	Emission Index CO	Hydro-carbons	Oxides of Nitrogen	Particulates
Turbofan M/R Jet	Idle, Taxi	50	9.6	2.0	0.6
	Approach	6.6	1.4	2.7	2.7
	Takeoff	1.2	0.6	4.3	2.5
Radial Piston Transport	Idle	600	160	0	2
	Approach	800	60	5	2
	Takeoff	1250	190	0	2
Average auto. engine	Average overall modes	405	71	21	2

TABLE 1. COMPARISON OF AUTOMOBILE AND AIRCRAFT ENGINE EMISSIONS (POUNDS OF POLLUTANT PER THOUSAND POUNDS OF FUEL)

	Motor Vehicles	Power Plants Period 1	Period 2	Jet Aircraft
PARTICULATES	43	1	6	11
CARBON MONOXIDE	9,282	Neg.	Neg.	24
NITROGEN OXIDES	624	135	145	7
HYDROCARBONS	1,677	4	6	61
SULFUR DIOXIDE	31	30	115	3
TOTALS	11,657	170	272	106

TABLE 2. AVERAGE DAILY EMISSIONS, TONS PER DAY, LOS ANGELES COUNTY.

	POWER SETTING AND ENGINE TYPE								
	Take-off			Cruise and Approach			Idle		
POLLUTANT	T-56	J-57	TF-33	T-56	J-57	TF-33	T-56	J-57	TF-33
Oxygen (%)		16.7	17.1		17.5	18.0		19.0	19.6
Carbon Dioxide (%)	4.1	2.3	2.7	3.2	1.5	2.1	2.4	1.0	0.9
Carbon Monoxide (ppm)	34	32	7	40	55	30	109	130	195
Oxides of Nitrogen as NO_2 (ppm)	43	59	27	27	39	15	12	13	11
Nitric Oxide (ppm)	37	44	25		30	13		8	9
Total Hydrocarbons (as C atoms) (ppm)	5.5	5	7	2.5	5	42	101	152	700
Olefins as C atoms (ppm)							25	38	220
Aromatics as C atoms (ppm)							10	39	60
Total Aldehydes as HCHO (ppm)	4.1	0.8	.06	2.0	0.8	0.3	4.8	2.5	21
Formaldehyde (ppm)	1.1	0.5		1.9	0.5		3.5	2.4	

TABLE 3. POLLUTION EMISSIONS FROM JET AIRCRAFT.

	POWER SETTING AND ENGINE TYPE								
(lb/hr.) Pollutant	Take-off			Cruise and Approach			Idle		
	T-56	J-57	TF-33	T-56	J-57	TF-33	T-56	J-57	TF-33
Carbon Dioxide	6800	20,000	27,900	5300	12,000	14,000	3100	2500	2100
Carbon Monoxide	3.6	17.5	3.0	4.7	27.6	12.7	6.2	20.9	28.1
Oxides of Nitrogen (NO_2)	7.5	53.8	28.4	34.6	32.1	10.4	1.1	3.4	2.6
Nitric Oxide	6.4	44.2	26.3	--	24.6	9.0	--	2.1	1.4
Total Hydrocarbons	0.3	1.2	2.4	0.1	1.1	9.3	3.0	10.5	43.2
Olefins (C atoms)	--	--	--	--	--	--	0.7	2.6	13.6
Aromatics (C atoms)	--	--	--	--	--	--	0.3	2.7	3.7
Total Aldehydes (as HCHO)	--	0.5	.04	0.2	0.4	.14	0.2	0.4	3.2
Formaldehyde	0.2	0.4	--	0.2	0.3	--	0.2	0.4	--
Particulates	--	--	16.2	--	--	10.8	--	--	2.4
Odor Dilution Threshold	100	600	75	--	600	15	--	600	1000

TABLE 4. A COMPARISON SIMILAR TO TABLE 3 EXCEPT THAT THE POLLUTANTS ARE MEASURED IN LB/HR.

Aircraft Type	Landings	Take-Offs	% of Total
DC-8	7,875	7,875	14
Boeing 720	13,839	13,839	26
Boeing 727	19,581	19,581	36
Boeing 737	741	741	1+
B 707 (100 & 200)	2,289	2,289	4+
B 707 (300 series)	4,512	4,512	8+
Electras and Viscounts	5,218	5,219	10

TABLE 5. SEATTLE-TACOMA AIRPORT TRAFFIC, 1969.

Operation	Air Force	Los Angeles	Seattle
Taxi and Holding	4.0	6.8	4.8
Take-off and Climb to 3500'	2.5	2.6	3.0
Approach to Touchdown from 3500'	4.5	4.1	4.7
Landing Run and Taxi to Terminal	5.0	6.2	5.8

TABLE 6. OPERATIONAL TIME-STUDIES FOR AIR FORCE, LOS ANGELES, AND SEATTLE-TACOMA AIRPORT IN MINUTES.

	POLLUTANTS* (LB.)				
	CO	Nitrogen oxides (as NO_2)	Hydro-carbons (as CH_4)	Aldehydes as (HCHO)	Particulates
Departure					
T-56 (Electra)	2.4	1.9	1.0	0.14	
J-57 (B 707)	8.4	9.9	3.0	0.19	
TF-33 (B 707, B 720, DC-8)	8.0	5.2	12.0	1.00	3.4
Arrival					
T-56 (Electra)	3.5	2.2	1.2	0.13	
J-57 (B 707)	15.2	10.7	3.8	0.25	
TF-33 (B 707, B 720, DC-8)	12.6	4.0	17.0	1.20	4.0

*For four-engine aircraft (reduce by 25% for 3 engines and by 50% for 2 engines).

No water injection used in J-57 during take-off.

TABLE 7. ESTIMATED POLLUTION EMISSIONS FROM JET AIRCRAFT DURING DEPARTURE AND ARRIVAL.

JET ENGINE MODEL #	TYPE OF ENGINE	COMMENTS	TYPE OF FUEL USED IN TEST	AVERAGE FUEL CONSUMPTION RATES POUNDS PER MINUTE*			
				TAXIING	APPROACH	CLIMBOUT	TAKE-OFF
JT3D-3B	Turbofan	No additive	Turbine A	18	48	132	161
JT3D-3B	Turbofan	CI-2 Added	Turbine A	18	49	131	160
JT8D-1	Turbofan		Turbine A	16	72	117	123
JT8D-7	Turbofan	Smokeless	Turbine A	18	66	121	142
JT8D-1	Turbofan		JP-4	20	63	105	125
CJ805-3B	Turbojet	Dry	Turbine A	20	62	134	148
JT3C-6	Turbojet	Water Injection	Turbine A	28	100	155	200
501-D13	Turboprop		Turbine A	16	24	27	34

*Based on metered fuel usage rates obtained during APCD tests.

TABLE 8. FUEL CONSUMPTION RATES OF GAS TURBINE ENGINES BASED ON LOS ANGELES STUDY.

AIRPORT	RANK	1968	1969	1970 (Projected)	1976 (Projected)
JFK	1	1,057,399	1,184,695	1,298,432	1,451,771
LAX	2	765,514	916,522	1,147,219	1,144,492
ORD	3	736,633	854,086	958,988	1,036,902
SFO	4	560,734	634,909	696,033	758,673
MIA	5	409,572	476,880	540,314	602,459
DAL	6	259,716	287,829	327,268	361,137
ATL	7	228,835	290,478	337,345	371,030
SEA	8	203,054	243,466	283,610	312,932
DEN	9	197,118	249,399	296,483	310,658
EWR	10	160,954	208,307	231,034	250,701

TABLE 9. ANNUAL FUEL CONSUMPTION FOR VARIOUS AIRPORTS (GALLONS).

ENGINE MODEL	TOTAL FUEL CONSUMPTION IN POUNDS PER ENGINE					
	DEPARTURE		ARRIVAL		AVERAGE	
	LAX	SEA	LAX	SEA	LAX	SEA
JT3D-3B	494.6	511.4	308.4	330.0	401.5	420.7
JT8D-7	458.0	470.4	382.2	414.6	420.1	442.5
501-D13	186.0	164.8	197.6	205.6	191.8	185.2

TABLE 10. FUEL CONSUMPTION COMPARISON BETWEEN LOS ANGELES AND SEATTLE-TACOMA AIRPORTS (1968-69).

GAS TURBINE AIRCRAFT ENGINE TYPE USING TURBINE "A" FUEL	NUMBER OF JET ENGINES	AIR CONTAMINANT EMISSIONS, IN POUNDS PER AVERAGE FLIGHT					
		PARTICULATE MATTER	CARBON MONOXIDE	OXIDES OF NITROGEN AS NO_2	HYDROCARBONS AND ORGANIC GASES	OXIDES OF SULFUR AS SO_2	TOTAL (ROUNDED)
PRATT & WHITNEY TURBOFAN JT8D-1	4	20.4	27.9	13.2	183.7	4.3	250
	3	15.3	20.9	9.9	137.8	3.2	187
	2	10.2	13.9	6.6	92.0	2.2	125
	1	5.1	7.0	3.3	45.9	1.1	62
GENERAL ELECTRIC TURBOJET (DRY) CJ805-3B	4	21.0	35.5	10.4	123.9	4.7	196
	3	15.7	26.6	7.9	92.9	3.5	147
	2	10.4	17.7	5.2	62.0	2.3	98
	1	5.2	8.8	2.7	31.0	1.2	49
PRATT & WHITNEY TURBOFAN JT3D-3B	4	15.5	53.3	12.0	34.2	4.2	119
	3	11.7	39.8	9.0	25.7	3.2	89
	2	7.8	26.7	5.9	17.1	2.1	60
	1	3.9	13.3	3.0	8.6	1.1	30
PRATT & WHITNEY TURBOJET (WET) JT3C-6	4	24.4	42.7	10.2	9.6	6.8	94
	3	18.3	32.0	7.6	7.2	5.1	70
	2	12.2	21.3	5.1	4.8	3.4	47
	1	6.2	10.6	2.5	2.4	1.7	23
GENERAL MOTORS-ALLISON TURBOPROP 501-D13	4	12.3	3.9	10.2	5.6	2.1	34
	3	9.2	3.0	7.7	4.2	1.6	26
	2	6.2	2.0	5.1	2.9	1.1	17
	1	3.1	1.0	2.6	1.4	0.5	9
SEA JET MIX	.57	17.9	38.0	11.5	96.9	4.0	168

TABLE II. AVERAGE RATES OF EMISSION OF AIR CONTAMINANTS PER AVERAGE FLIGHT FROM GAS TURBINE ENGINE POWERED AIRCRAFT AT THE SEATTLE-TACOMA INTERNATIONAL AIRPORT.

Western Region Technical Memoranda: (Continued)

No. 28** Weather Extremes. R. J. Schmidli. April 1968. (PB-178 928)
No. 29 Small-Scale Analysis and Prediction. Philip Williams, Jr. May 1968. (PB-178 425)
No. 30 Numerical Weather Prediction and Synoptic Meteorology. Capt. Thomas D. Murphy, U.S.A.F. May 1968. (AD-673 365)
No. 31* Precipitation Detection Probabilities by Salt Lake ARTC Radars. Robert K. Belesky. July 1968. (PB-179 084)
No. 32 Probability Forecasting in the Portland Fire Weather District. Harold S. Ayer. July 1968. (PB-179 289)
No. 33 Objective Forecasting. Philip Williams, Jr. August 1968. (AD-680 425)
No. 34 The WSR-57 Radar Program at Missoula, Montana. R. Granger. October 1968. (PB-180 292)
No. 35** Joint ESSA/FAA ARTC Radar Weather Surveillance Program. Herbert P. Benner and DeVon B. Smith. December 1968. (AD-681 857)
No. 36* Temperature Trends in Sacramento--Another Heat Island. Anthony D. Lentini. February 1969. (PB-183 055)
No. 37 Disposal of Logging Residues Without Damage to Air Quality. Owen P. Cramer. March 1969. (PB-183 057)
No. 38 Climate of Phoenix, Arizona. R. J. Schmidli, P. C. Kangieser, and R. S. Ingram. April 1969. (PB-184 295)
No. 39 Upper-Air Lows Over Northwestern United States. A. L. Jacobson. April 1969. (PB-184 296)
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No. 45/2 Precipitation Probabilities in the Western Region Associated with Spring 500-mb Map Types. Richard P. Augulis. January 1970. (PB-189 434)
No. 45/3 Precipitation Probabilities in the Western Region Associated with Summer 500-mb Map Types. Richard P. Augulis. January 1970. (PB-189 414)
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* Out of Print
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