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AIRPORT EMISSION INVENTORY METHODOLOGY

by

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ABSTRACT

This report describes a methodology for performing emission inventories at airports, with specific focus on the airports in the St. Louis AQCR. This work was performed in support of EPA's RAPS program. Within the basic methodology, three submethodologies are presented corresponding to municipal, military, and civilian airports. Data collection and handling requirements are discussed, and data for the airports in the St. Louis AQCR are presented. The sensitivity of emission estimates to improved knowledge of data inputs is discussed.

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SECTION I

INTRODUCTION

Under the charges of the Clean Air Act of 1970, the Environmental Protection Agency is assisting state and local pollution control agencies in developing implementation strategies to meet the established air quality standards. A basic premise of these efforts is that operationally a cause and effect relationship between pollution sources and air quality can be accurately specified. The EPA is conducting the Regional Air Pollution Study (RAPS) in St. Louis to determine the current reliability of this premise, and to provide for improvements where accuracy is less than adequate.

To achieve this goal, RAPS will engage in extensive analysis of the atmospheric dispersion and transformation process modeling links between emissions and air pollution levels.[1] The cause and effect data required to analyze these modeling links include detailed temporal and spatial emission inventories; atmospheric data such as wind fields and temperature profiles for dispersion calculations, and insolation data for transformation process modeling; and air pollutant concentration data against which modeling results will be compared.

A crucial phase of this program is the adequate and accurate specification of emission inventories at least to the level of detail engaged by the models - the results of these deterministic links can be no more comprehensive and consistent than the initial input values. Emissions inventories have been made by county in the St. Louis Air Quality Control Region according to the Nation Emissions Data System (NEDS). Air-

Aircraft operations were surveyed for yearly landing and takeoff cycle volumes for each type of airport, and a single emission factor based on type of airport was applied to each to calculate annual emissions. The spatial and temporal detail involved is insufficient for uses other than trend estimates of emissions. This report describes techniques for inventorying airport emissions from aircraft and ground support vehicles and processes as an aid to achieve the RAPS goals.

SECTION II

EMISSION INVENTORY NEEDS FOR RAPS

The St. Louis Interstate Air Quality Control Region is subdivided into a grid system for the RAPS study. The smallest grid side is 1 km, so that an airport may not be wholly enclosed in a single grid. This, and the requirement of hourly average emissions data, dictates the development of more spatially and temporally detailed emission inventory data and methodologies than are currently available.

This report describes the available data and techniques and outlines further refinements of methodologies for inventorying airport emissions. The sources involved include aircraft operations and engine maintenance testing, ground support vehicles, and fuel storage and handling. For these sources there needs to be described:

- emission rate
- emission location
- emission duration

The task of developing and analyzing emission inventory methodologies for these sources can be divided into three sub-tasks based on the type of airport in question; that is, inventories for municipal, civilian, and military airports. The methods for inventorying each are similar and reduce to finding the three factors listed above. However, the types of sources and their significance is a function of the type of airport. The municipal airport has principally commercial jets, ground support vehicles for servicing and fueling these aircraft, jet fuel handling and storage, and testing of jet engines. Civil airports primarily carry private and charter piston aircraft, ground support to the extent of fueling trucks (absent at the smaller airports), gasoline storage and handling (with some jet fuel at larger airports), and testing of piston engines. The military airport operations consist mainly of jet aircraft, fueling trucks, jet fuel handling and storage, and jet engine testing.

SECTION III

FACTORS CONTRIBUTING TO AIRPORT EMISSIONS

The purpose of this section is to outline the factors contributing to airport emissions and to discuss how they are interrelated. This is presented to provide an overview of the inventory problem for airports and to provide a basis from which to examine alternative levels of inventory detail.

The factors contributing to airport emissions are those involved with the previously listed sources of aircraft operation, ground support vehicles, fuel storage and handling, and engine maintenance testing. These factors are discussed for each type of airport in the following sections.

FACTORS AFFECTING FLIGHT OPERATION EMISSIONS

Flight operations consist of the modes listed in Table 1. To determine emissions, two basic factors must be known: (1) the time spent in each mode, and (2) the emission rate for each mode. The interacting factors determining these basic factors are outlined below.

Municipal Airport Flight Operations

Figure 1 is a diagram showing the interactions of factors affecting emission production at a municipal airport. These will be sorted according to significance of contribution and availability of information when levels of emission inventory detail and relative emission contributions are discussed.

Table 1. AIRCRAFT OPERATING MODES [2]

Mode	Engine operating time included in mode
Taxi	Transit times between ramp and apron, apron and runway and time required for turning and alignment between taxiway and runway.
Idle	Push back from gate; waiting for signal to begin taxiing; waiting at taxiway intersections; runway queuing; gate queuing.
Landing	Touchdown to beginning of taxi on taxiway.
Takeoff	After alignment with runway to liftoff.
Approach	3000 ft altitude to touchdown.
Climb-out	Liftoff to 3000 ft altitude.

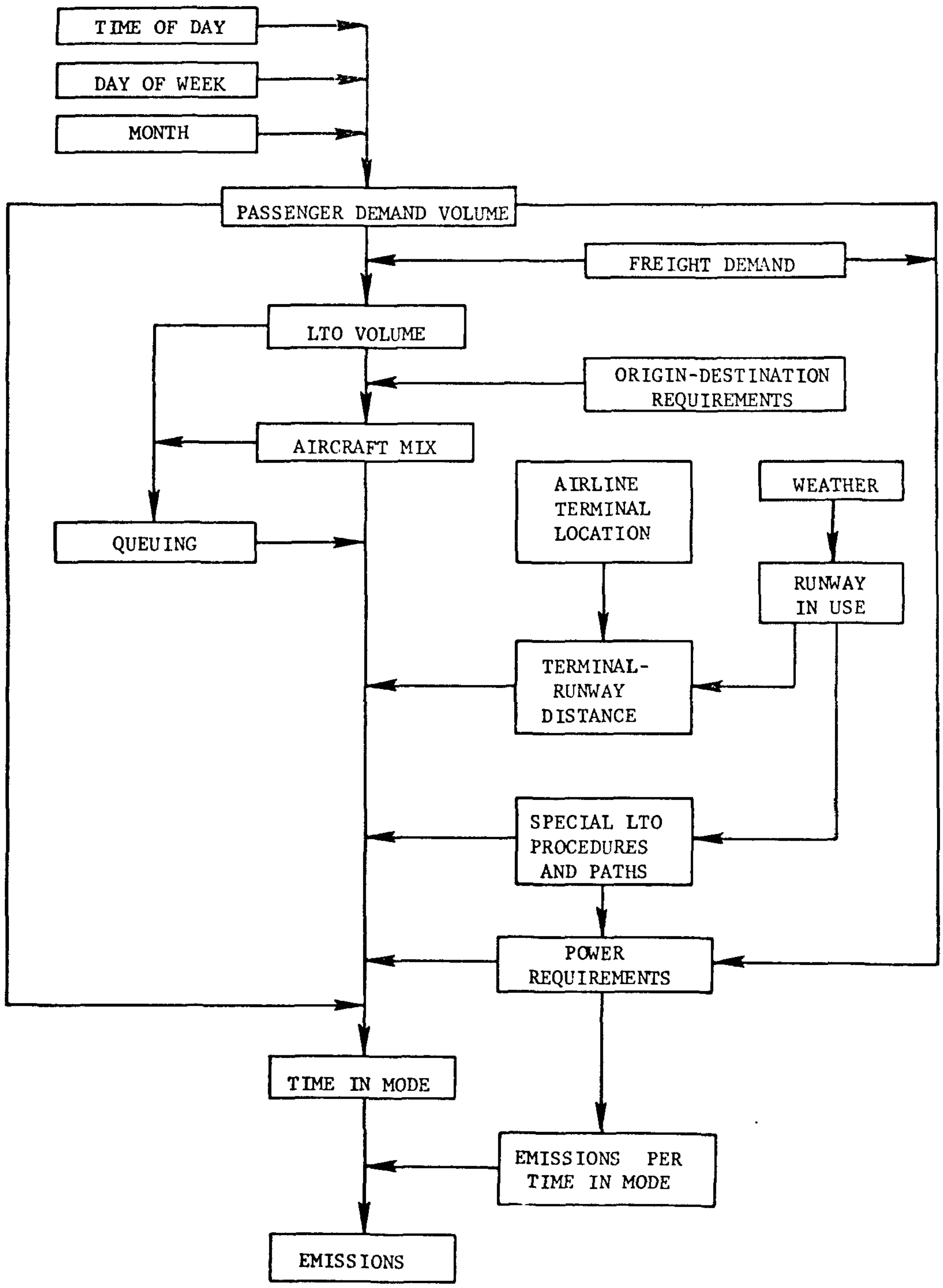

Figure 1. Interacting factors affecting emissions production at a municipal airport

The major impetus to flight operations is the passenger demand volume. Fluctuations in demand volume occur with time of day, the day of the week, and the month. Figure 2 shows the hourly percent of the total LTO volume for a typical airport. Airline schedules and schedule changes reflect these fluctuations. Freight demands are shown in Figure 1 as being secondary to passenger demands as cargo needs are usually accommodated on passenger flights.

Landing and takeoff cycle volume is then determined by passenger demand. Origin-destination requirements and LTO volume determine the mix of equipment, which in turn feeds back to LTO volume. Short, low passenger demand trips will be made by medium and short range aircraft; longer, high demand trips will use long range and jumbo jets. The aircraft classes and representative aircraft within each class are listed in Table 2.

If the LTO volume is greater than some number characteristic of the airport and runway in use queues will form. The EPA report, "Air Pollution Impact Methodology for Airports," (APTD-1470)[2] recommends adding extra idle time due to queuing as $T = (N-30)/10$ when the LTO volume exceeds 30 per hour. T is the time queued in minutes and N is the LTO volume. This relationship assumes the use of two parallel runways and is empirically based on experience at Chicago's O'Hare airport. For more nearly accurate idle mode emission calculations, similar relationships should be determined for St. Louis, since in addition to LTO volumes, queue times can depend on airport configuration and runway in use, approach path radio aids, weather, and even the air traffic controller.

The LTO volume affects queuing which affects the time spent in the idle mode. Other "times in modes" are influenced by additional factors as shown in Figure 1.

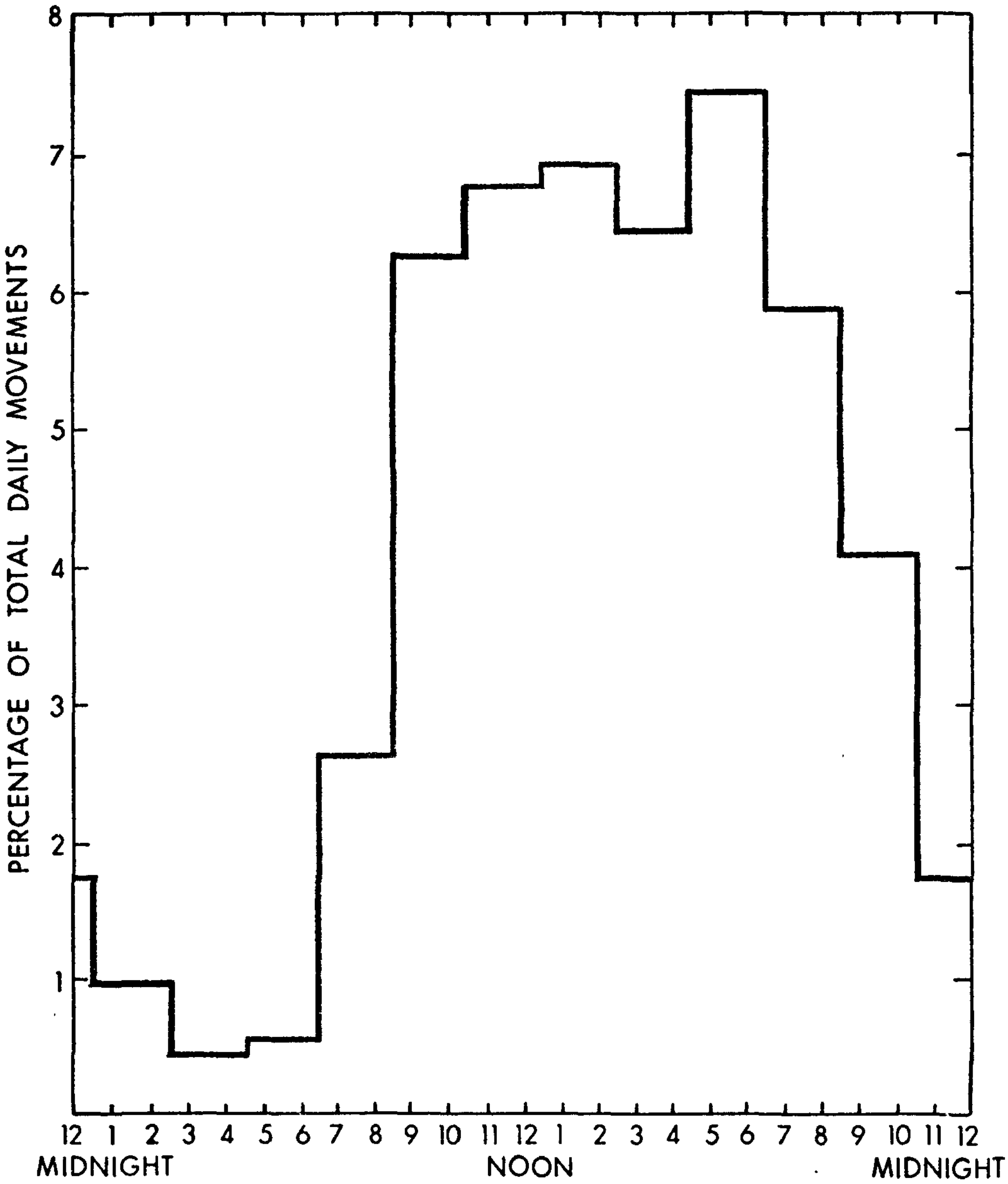

Figure 2. Hourly percent of total daily LTO volume for a typical municipal airport

Table 2. AIRCRAFT CLASSIFICATIONS AND REPRESENTATIVE AIRCRAFT[3]

Aircraft class	Representative aircraft
Jumbo jet	Boeing 747 Lockheed L-1011 McDonald Douglas DC-10
Long-range jet	Boeing 707 McDonald Douglas DC-8
Medium-range jet	Boeing 727 Boeing 737 McDonald Douglas DC-9
Air carrier turboprop	Convair 580 Electra L-188 Fairchild Hiller FH-227
Business jet	Gates Learjet Lockheed Jetstar
General aviation turboprop	-
General aviation piston	Cessna 210 Piper 32-300
Piston transport	Douglas DC-6
Helicopter	Sikorksy S-61 Vertol 107
Military turboprop	
Military jet	
Military piston	

Meteorological conditions of wind direction and visibility determine the runway in use. Generally, it will be the longest runway or the one most nearly parallel to wind direction, although low visibility or night flight might require the use of an instrument landing system equipped or lighted runway which does not give the best alignment with wind direction. The terminal location and the runway in use determine the time spent in taxi mode before takeoff and after landing.

Time in takeoff and landing modes is affected by the component of wind velocity parallel to the runway and by the temperature as well as type of aircraft. Takeoff and landing times are shorter the higher the wind speed and the lower the temperature. These times become longer as the aircraft carries more mass to be accelerated and lifted, or decelerated after landing.

The same factors affect climbout and approach, with potential modifications if nearby populated areas require special noise reduction procedures and flight paths. These may include techniques such as climbing at reduced power and immediate turns away densely populated areas.

After the time spent in the different modes are determined they can be multiplied by the modal emission rates to calculate emissions. The emission rates depend basically on power requirements and engine type, which are in turn related to passenger and freight volume, amount of fuel carried for origin-destination requirements, weather, and special LTO procedures.

Civilian Airport Flight Operations

Figure 3 is a diagram of the interacting factors involved in emission production at a civilian airport. Weather is a dominant factor in civilian flight operations. The level of activity falls as the weather deteriorates, since much of the flying done is for instruction and pleasure, and since pilot qualifications often exclude flying during

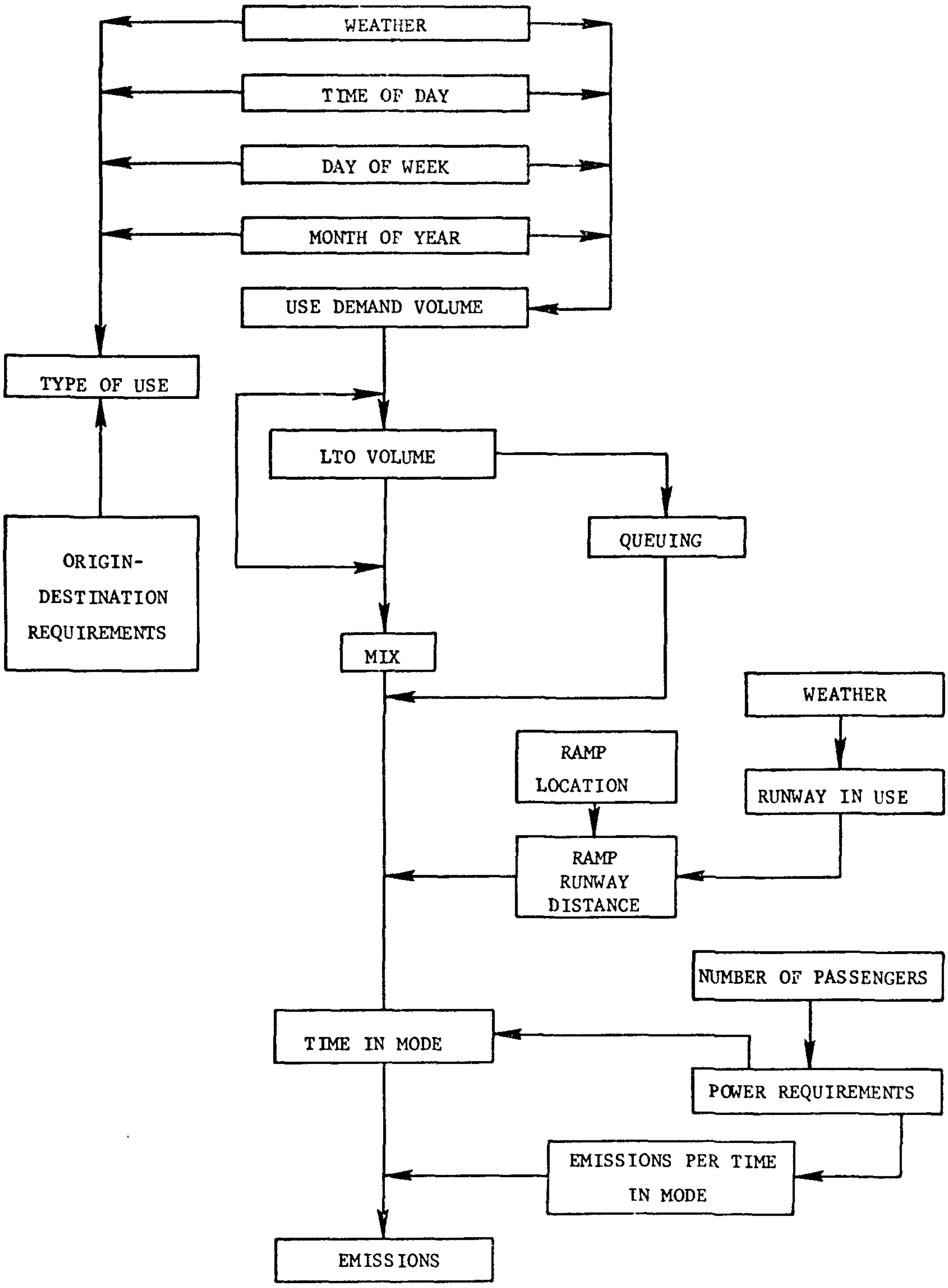

Figure 3. Interacting factors affecting emissions production at a civilian airport

inclement weather. Further, the airport may not be equipped with the radio navigation aids needed for foul weather flying.

The traffic volume also varies with time of day, day of week, and month. It is generally heavier in the evening, on weekends, and in the summer when private pilots have the time and weather offers more incentive to fly.

These factors determine the air traffic volume and, to some extent, the mix. Commercial charter and business flights are less affected by weather than private flights. When there is a large percentage of private flights the mix will have a greater percentage of small, single engine aircraft.

Time in mode is affected by the same factors as at the municipal airport, only in this case the aircraft are at ramp or tie-down locations. Aircraft rental, instruction, and charter companies generally have a specific portion of the ramp area for their use which is rented from the airport authority. These locations can be determined from a visit to the airport.

Time in mode, and also power requirements, are further affected by the number of passengers, especially in light, two or four-place planes where passenger weight is a significant fraction of aircraft weight. Climbout time is reduced with fewer passengers, reducing time in this mode, while approach time is increased because of reduced downward weighting force.

When emission rates as functions of mode and power requirements are known, they can be multiplied by the times in the various modes to find emissions.

Military Airport Flight Operations

These operations are influenced by the factors common to all airport operations; however, they are not dependent on passenger demands, as at the municipal airport, nor are they strongly affected by weather, as for civilian flights. The level of activity is determined mainly by training, proficiency, and defense requirements. Weather determines the runway used and taxi times.

FACTORS AFFECTING GROUND SUPPORT VEHICLE EMISSIONS

Municipal Airport

The municipal airport has by far the most ground service vehicle operations. A listing of the types of service vehicles is given in Table 3. The extent of use of each vehicle is directly related to LTO volume and aircraft mix. Emissions can be calculated from published data on service times and emission rates. Emissions from service vehicle travel around the airport can be found knowing the airport layout, the activity, and the proper emission factors.

Civilian Airports

Service vehicles at civilian airports are almost exclusively fueling trucks, and even these may be absent at the smaller airports. Other support vehicles may include tractors, etc. for grass cutting and snow removal.

Military Airport

Service vehicles at the military airport also include fueling trucks and many of the vehicles found at municipal airports. Emissions from these sources are dependent on flight activity.

Table 3. SERVICE VEHICLES USED AT A MUNICIPAL AIRPORT[2]

Vehicle
1. Tractor
2. Belt loader
3. Container loader
4. Cabin service
5. Lavatory truck
6. Water truck
7. Food truck
8. Fuel truck
9. Tow tractor
10. Conditioner
11. Airstart
Transporting engine
Diesel power unit
12. Ground power unit
Transporting engine
Gasoline power unit
Diesel power unit
13. Transporter

FUEL HANDLING AND STORAGE EMISSIONS

These emissions are of two types: (1) working losses, and (2) breathing losses. The former type occurs when vapors in fuel tanks are displaced during fueling, and when there is spillage and evaporation. The latter type is due to diurnal temperature variations, wind speeds, and fuel vapor pressure among other factors. It may be controlled by tank vapor recovery systems.

Municipal Airport

By far the largest use is of jet fuel with a much smaller volume of gasoline used for service vehicles and piston aircraft. Actual volumes of each are a function of LTO activity, passenger volumes, and origin-destination distances.

Civilian Airport

Here, gasoline comprises the larger volume of fuel use. Jet fuel is available at the larger airports. Gasolines of different octane ratings at these airports will have slightly different emission characteristics because of volatility differences. Actual use will be determined by LTO activity and the factors affecting it.

Military Airport

Jet fuel comprises the larger use for military airport operations. Gasoline is used for service vehicles.

ENGINE MAINTENANCE TESTING

The emissions from this source depend on the test cycle power settings and times spent at each setting for the various types of engines. The municipal and military airports will handle mostly jet engine testing, while the civilian airports will test piston engines. Emissions from this source at the smaller civilian airports will be negligible, if not non-existent.

SECTION IV

LEVELS OF EMISSION INVENTORY DETAIL

The ideal emissions inventory would consider all the interrelating factors described in Section III. Of course, the time and economic costs would be prohibitive. The purpose of this study is to consider alternative levels of detail for making inventories on a "cost-benefit" basis, determining the significance of emissions sources and the sensitivity of an inventory in return for added data collection and analysis efforts. In this section, levels of detail are outlined with comments on efforts and benefits.

EMISSIONS INVENTORY FROM PUBLISHED DATA

Features:

- NEDS data on annual LTO volumes by airport type and county
- Uses average emission factor for LTO cycle based on type of airport
- Annual LTO activity data available from FAA
- Time resolution - annual average
- Spatial resolution - countywide area source

Comments:

- Easily calculated from readily available data
- Insufficient resolution and specificity by source.

TYPE OF AIRCRAFT DETAIL

Features:

- Emission factor for type of aircraft
- Percent of total LTO's for type of aircraft
- Emission factor for service vehicle use by type of aircraft
- Emission factor for fuel handling and storage by aircraft mix and total LTO's
- Emission factor for maintenance testing by type of aircraft
- Data available from FAA, airport records, airline schedules
- Time resolution - by type of data collected
- Spatial resolution - by source locations at airport

Comments:

- More extensive data collection effort
- Easily calculated once necessary data are known
- Time resolution variable

TIME-IN-MODE DETAIL

Features:

- Emission factors by mode required
- Average times in mode required

Comments:

- Average time in mode data available from EPA publication "An Air Pollution Impact Methodology for Airports - Phase I," (APTD-1470)
- No additional data collection needed
- Relatively little added effort over type of aircraft detail

HOURLY EMISSION ESTIMATES

Features:

- LTO activity by time of day, day of week, month, type of aircraft
- Data available from airline schedules, airport records, FAA

Comments:

- Extensive effort required for data collection and analysis over time-in-mode detail
- Hourly resolution for aircraft operations, support vehicles, fuel handling

REFINED HOURLY EMISSIONS ESTIMATES

Features:

- To include meteorological effects, special LTO procedures, aircraft loading, terminal-runway distances, queuing

Comments:

- Long-term, extensive effort required for data collection
- Computer analysis of data
- Degree of refinement not initially required

RELATIVE EMISSIONS CONTRIBUTIONS BY SOURCE AT AIRPORTS

Table 4 shows the relative emissions contributions of the airport sources at O'Hare airport in 1970. Aircraft operations account for well over 60 percent of carbon monoxide and hydrocarbon emissions, and about 90 percent of these emissions occurs during taxi and idle modes. This indicates a good sensitivity return for improved data on time in mode and emission rates for these modes.

Table 4. PERCENT EMISSIONS CONTRIBUTION BY SOURCE AT O'HARE AIRPORT - 1970

Source	CO	HC	NO_x	Particulate
Aircraft	69	79	86	96
Service vehicles	31	13	14	4
Fuel handling	0	8	0	0

Aircraft operations contribute 86 percent to total NO_x emissions, indicating good leverage from improved information on the factors involved. Most of these emissions occur during the high power operations of takeoff and climbout.

SECTION V

EMISSION ESTIMATION METHODOLOGY FOR LAMBERT FIELD

This section and the following two sections describe the hourly emission estimation techniques. This section applies to Lambert Field, the next one applies to Scott AFB, and Section VII describes the methodology for the civilian airports. The three types of airports are discussed separately, since data availability and the complexity of the required methodology is different for each. Four emission sources are included in the methdologies:

- Aircraft flight operations
- Ground service vehicles
- Fuel handling and storage
- Engine testing and maintenance.

EMISSIONS FROM AIRCRAFT FLIGHT OPERATIONS

To estimate hourly emissions from aircraft flight operations five parameters must be known:

- Temporal activity patterns
- Spatial activity patterns
- Percent volume distribution of aircraft types
- Time spent in the different operating modes
- Emission factors.

The following sections discuss the availability of data for each of these five parameters, and the use of these data in a methodology for emission estimation.

Temporal Activity Patterns

Ideally, hourly landing and takeoff volumes and type of equipment would be known for the best predictions of emissions. However, this information is not compiled and estimates must be made from available data.

For Lambert Field there are three sources of data:

- Federal Aviation Administration Air Traffic Control Tower, Mr. Jerome C. Moonier
- Lambert Field, Manager's Office, Mr. Arthur K. Muchmore, Assistant Airport Manager, Operations and Maintenance
- Official Airline Guide[4] listings for air carrier traffic at St. Louis

The FAA maintains daily totals of traffic volumes under the classifications shown in Table 5. Local traffic has its origin and destination at Lambert, and it mainly involves "touch and go" landing and takeoff practice. Itinerant operations have their origin or destination at another airport. These classifications are further divided for itinerant traffic into air carrier, air taxi, general aviation, and military categories. For local operations they are subdivided into civilian and military categories. The FAA also compiles average hourly activity totals for May and November. The November totals are presented in Table 6.

The airport manager's office receives its flight activity information from the FAA in the form described. This office is an alternative source of this information.

Table 5. FAA CLASSIFICATION OF DAILY AIR TRAFFIC OPERATIONS

	Itinerant air traffic					Local air traffic			Total air traffic
DAY	AIR CARRIER	AIR TAXI	GENERAL AVIATION	MILITARY	TOTAL	CIVIL	MILITARY	TOTAL	

Table 6. AVERAGE HOURLY AIR TRAFFIC VOLUMES AT LAMBERT FIELD, ST. LOUIS, FOR MAY AND NOVEMBER, 1972

Hour	Volume
0000-0100	12
0100-0200	11
0200-0300	10
0300-0400	3
0400-0500	4
0500-0600	5
0600-0700	13
0700-0800	36
0800-0900	55
0900-1000	64
1000-1100	68
1100-1200	66
1200-1300	64
1300-1400	66
1400-1500	65
1500-1600	57
1600-1700	67
1700-1800	64
1800-1900	50
1900-2000	43
2000-2100	40
2100-2200	26
2200-2300	30
2300-2400	13

The Official Airline Guide lists flight schedules semi-monthly for the air carriers. These listings show scheduled departure and arrival times and type of aircraft used. Scheduled flight activity to St. Louis is listed in one section of the Guide, while flights from St. Louis to other cities are listed under the destination city headings.

Table 6 lists hourly totals of flight activity at Lambert Field. To complete the temporal data, the total volumes by month and by the day of the week for the four aircraft categories are given in Tables 7 and 8. The itinerant and local volumes have been combined for both general aviation and military flights in these Tables.

In order to prepare a methodology for estimating emissions, the volumes given in Tables 6, 7, and 8 were converted to percentages totaling 100 percent for each category of aircraft. The computed percentages for monthly, daily, and hourly air traffic are given in Tables 9, 10, and 11.

To compute the volume of traffic for category i for a given hour, day, and month we start from the relationship:

$$V_i = \frac{A_i' \cdot M_i \cdot D_i \cdot H_i}{(OD_m)\ (10^6)}$$

where i indicates the category (e.g. air carrier), A_i' is the annual volume, and M_i, D_i, and H_i are the percents of the annual volume for the month, day, and hour of interest. The factor OD_m is the average occurrence of the day of the week for the month. It equals 4.43 for months having 31 days, 4.29 for 30 day months, and 4 for February (4.14 in a leap year). The factor of 10^6 converts the percentages to decimals. This relationship can be entered at any point. For example, if the monthly total is known,

Table 7. MONTHLY AIR TRAFFIC AT LAMBERT FIELD, ST. LOUIS, FOR DECEMBER 1972 AND JANUARY - NOVEMBER 1973

Month	Air carrier	Air taxi	General aviation	Military	Total
January	16,006	1,985	9,112	1,008	28,111
February	14,316	1,744	8,957	1,013	26,030
March	15,655	2,052	9,300	1,071	28,078
April	13,955	2,078	11,305	1,363	28,701
May	12,236	2,606	13,106	1,576	29,524
June	12,363	2,648	12,618	1,293	28,922
July	15,703	2,492	12,137	963	31,295
August	16,721	2,812	12,420	1,187	33,140
September	15,934	2,474	10,509	1,106	30,023
October	16,658	2,724	11,985	1,353	32,720
November	11,004	2,488	11,110	878	25,480
December	15,234	1,590	6,691	861	24,376
Category Total	175,785	27,693	129,250	13,672	346,400

Table 8. AIR TRAFFIC VOLUMES BY DAY OF WEEK AT LAMBERT FIELD, ST. LOUIS, FOR DECEMBER 1972 AND JANUARY - NOVEMBER 1973

Day	Air carrier	Air taxi	General aviation	Military	Total
Sunday	23,385	1,907	15,851	1,096	42,239
Monday	25,037	3,229	15,369	1,219	44,854
Tuesday	25,499	4,801	18,424	2,266	50,990
Wednesday	25,965	5,115	20,772	2,532	54,384
Thursday	26,259	5,040	21,326	2,390	55,015
Friday	26,718	5,280	20,499	2,505	55,002
Saturday	22,922	2,321	17,009	1,664	43,916
Category Total	175,785	27,693	129,250	13,672	346,400

Table 9. PERCENT OF TOTAL ANNUAL AIR TRAFFIC BY MONTH AT LAMBERT FIELD

Month	Air carrier	Air taxi	General aviation	Military	Total
January	9.11	7.17	7.05	7.37	8.18
February	8.14	6.30	6.93	7.41	7.57
March	8.91	7.41	7.20	7.83	8.16
April	7.94	7.50	8.75	9.97	8.07
May	6.96	9.41	10.14	11.53	8.52
June	7.03	9.56	9.76	9.46	8.38
July	8.93	9.00	9.39	7.04	8.98
August	9.51	10.15	9.61	8.68	9.64
September	9.06	8.93	8.13	8.09	8.73
October	9.48	9.84	9.27	9.90	9.52
November	6.26	8.98	8.60	6.42	7.40
December	8.67	5.74	5.18	6.30	6.86

Table 10. PERCENT OF TOTAL AIR TRAFFIC BY DAY OF WEEK FOR LAMBERT FIELD, ST. LOUIS

Day	Air carrier	Air taxi	General aviation	Military	Total
Sunday	13.30	6.89	12.26	8.02	12.19
Monday	14.24	11.66	11.89	8.92	12.95
Tuesday	14.51	17.34	14.25	16.57	14.72
Wednesday	14.77	18.47	16.07	18.52	15.70
Thursday	14.94	18.20	16.50	17.48	15.88
Friday	15.20	19.07	15.86	18.32	15.88
Saturday	13.04	8.38	13.16	12.17	12.68

Table 11. PERCENT OF TOTAL DAILY MOVEMENTS BY HOUR AT LAMBERT FIELD

Hour	Air carrier	Air taxi	General aviation	Military
0000-0100	1.15	2.05	2.05	2.05
0100-0200	1.00	1.33	1.33	1.33
0200-0300	1.00	1.33	1.33	1.33
0300-0400	0.26	0.24	0.24	0.24
0400-0500	0.42	0.24	0.24	0.24
0500-0600	0.42	0.00	0.00	0.00
0600-0700	1.36	0.97	0.97	0.97
0700-0800	3.67	2.54	2.54	2.54
0800-0900	6.02	4.83	4.83	4.83
0900-1000	6.81	5.92	5.92	5.92
1000-1100	6.97	6.88	6.88	6.88
1100-1200	6.86	7.49	7.49	7.49
1200-1300	6.71	6.52	6.52	6.52
1300-1400	7.12	6.88	6.88	6.88
1400-1500	6.60	9.42	9.42	9.42
1500-1600	5.92	8.33	8.33	8.33
1600-1700	7.23	6.76	6.76	6.76
1700-1800	7.18	6.52	6.52	6.52
1800-1900	5.97	5.43	5.43	5.43
1900-2000	5.40	4.35	4.35	4.35
2000-2100	4.71	4.23	4.23	4.23
2100-2200	3.04	3.62	3.62	3.62
2200-2300	2.88	2.66	2.66	2.66
2300-2400	1.31	1.45	1.45	1.45

$$V_i = \frac{M_i' \cdot D_i \cdot H_i}{(OD_m)\ (10^4)}$$

where M_i' is the monthly total volume of aircraft category i.

Suppose it is required to estimate the air carrier activity between 10 am. and 11 am. on a Wednesday in June. The arrival total $A_i' = 175{,}785$; from Table 9, $M_i = 7.03$; $D_i = 14.77$ from Table 10, and $H_i = 6.97$ from Table 11. Hence

$$V_i = \frac{(175{,}785)\ (7.03)\ (14.77)\ (6.97)}{(4.29)\ (10^6)}$$

= 30 air carrier movements (takeoff plus landing).

This method assumes equal numbers of landings and takeoffs, and also that the distribution of activity by month, day of the week, and hour remains constant from year to year. The exact landing and takeoff split by hour for air carriers can be extracted from the Official Airline Guide. This has been done for "average" day, and the results are shown in Table 12. For other categories it is assumed that half the movements are takeoffs and half are landings.

The relationship for calculating hourly volumes can be entered at any point for which a volume is known. The actual volume for the year, month, or day of interest can be used when making an emission inventory retrospectively. These data are available from the FAA Air Traffic Control Tower at Lambert.

The percent volumes presented in Tables 9, 10 and 11 are for December 1972 and January-November 1973. In future years the latest figures could be used to revise these tables either by replacement, or by averaging. The former revision of replacement may become especially

Table 12. PERCENT OF DEPARTURES AND ARRIVALS FOR AIR CARRIER TRAFFIC BY HOUR OF THE DAY[4]

Hour	Departures (%)	Arrivals (%)
0000-0100	25.00	75.00
0100-0200	66.67	33.33
0200-0300	100.00	0
0300-0400	0	100.00
0400-0500	0	0
0500-0600	100.00	0
0600-0700	33.33	66.67
0700-0800	58.33	41.67
0800-0900	52.94	47.06
0900-1000	37.84	62.16
1000-1100	60.53	39.47
1100-1200	40.63	59.37
1200-1300	43.59	56.41
1300-1400	32.26	67.74
1400-1500	62.86	37.14
1500-1600	32.00	68.00
1600-1700	42.11	57.89
1700-1800	50.00	50.00
1800-1900	40.63	59.37
1900-2000	51.43	48.57
2000-2100	41.67	58.33
2100-2200	15.38	84.62
2200-2300	20.00	80.00
2300-2400	57.14	42.86

important if economic or other factors change the distribution as well as the total volume of air traffic.

Spatial Patterns of Aircraft Flight Activity

Aircraft flight activity consists of the six modes described in Table 1. These modes occur at different locations on the airport, and the emissions estimates must reflect this spatial variation. Lambert Field lies in eight grid elements of 1 kilometer squared according to the grid network designed for RAPS. Table 13 displays the grid numbers, the grid coordinates, and the aircraft operations in each grid according to the runway being used. Figure 4 shows the grids overlaid on the airport. No grids are listed for climbout or approach; these are listed later with times in mode. Lambert Field requests that aircraft maintain a constant heading away from or towards the runway when flying below 1500 feet. The approach glide path is about 2.5 or 3 degrees, so an approach heading is maintained within a distance of about 5 miles from the airport. The FAA indicates good compliance with this request. Above 1500 feet the aircraft may fly in any direction.

As an example, consider the emissions from the hourly volume of 30 air carrier movements. For the 1000-1100 hour, approximately 60 percent of these aircraft are departing. Generally these aircraft will move from the terminal area to the runway by the most direct taxiway when departing, and they will move from the runway to the terminal area by the shortest taxi distance after landing. In this example, it is assumed that runway 30L is the active runway. Referring to Figure 4, two thirds of the terminal area, or ramp, is in grid 523, while the other third is in grid 492. Aircraft will taxi out to take off in grids 492, 523, and 559, and take off in grids 560, 523, and 559. (See Table 13.) Of the 18 aircraft taking off, 12 will have idle mode emissions in grid 523, and 6 will emit during idle in grid 492. The simplest method of distributing the taxi and takeoff emissions would be to divide them equally

Table 13. OPERATING MODES FOR EACH GRID BY ACTIVE RUNWAY AT LAMBERT FIELD, ST. LOUIS

Runway	Grid	X-Coord	Y-Coord	Size	Idle	Taxi	Takeoff	Climbout	Approach	Landing	Taxi
30L	560	4291	730	1	x		x			x	
	559	4290	730	1	x	x	x				
	523	4291	729	1	x	x	x			x	x
	493	4292	728	1			x			x	x
	492	4291	728	1	x	x				x	x
	452	4292	727	1							
30R	560			1	x	x	x			x	
	524	4292	729	1		x	x			x	
	523			1		x	x			x	x
	493			1	x	x	x			x	x
	492			1	x	x					x
	452			1							
12R	560										
	523				x	x	x			x	x
	493				x	x	x			x	x
	492				x	x	x			x	x
	452				x	x	x			x	
12L	560										
	524					x	x			x	
	523					x	x			x	x
	493				x	x	x			x	
	492										
35	524					x	x			x	x
	523				x	x	x			x	x
	493				x	x					x
17	524				x	x	x			x	
	523					x	x			x	x
	493				x	x					x

Table 13 (continued). OPERATING MODES FOR EACH GRID BY ACTIVE RUNWAY AT LAMBERT FIELD, ST. LOUIS

Runway	Grid	X-Coord	Y-Coord	Size	Idle	Taxi	Takeoff	Climbout	Approach	Landing	Taxi
6	524					x					
	523										
	493				x	x	x			x	
	492				x	x					x
	452				x	x					x
	451	4291	727			x	x			x	
24	524				x	x	x			x	
	523					x					x
	493				x	x	x			x	x
	492				x	x					x
	451				x		x			x	x

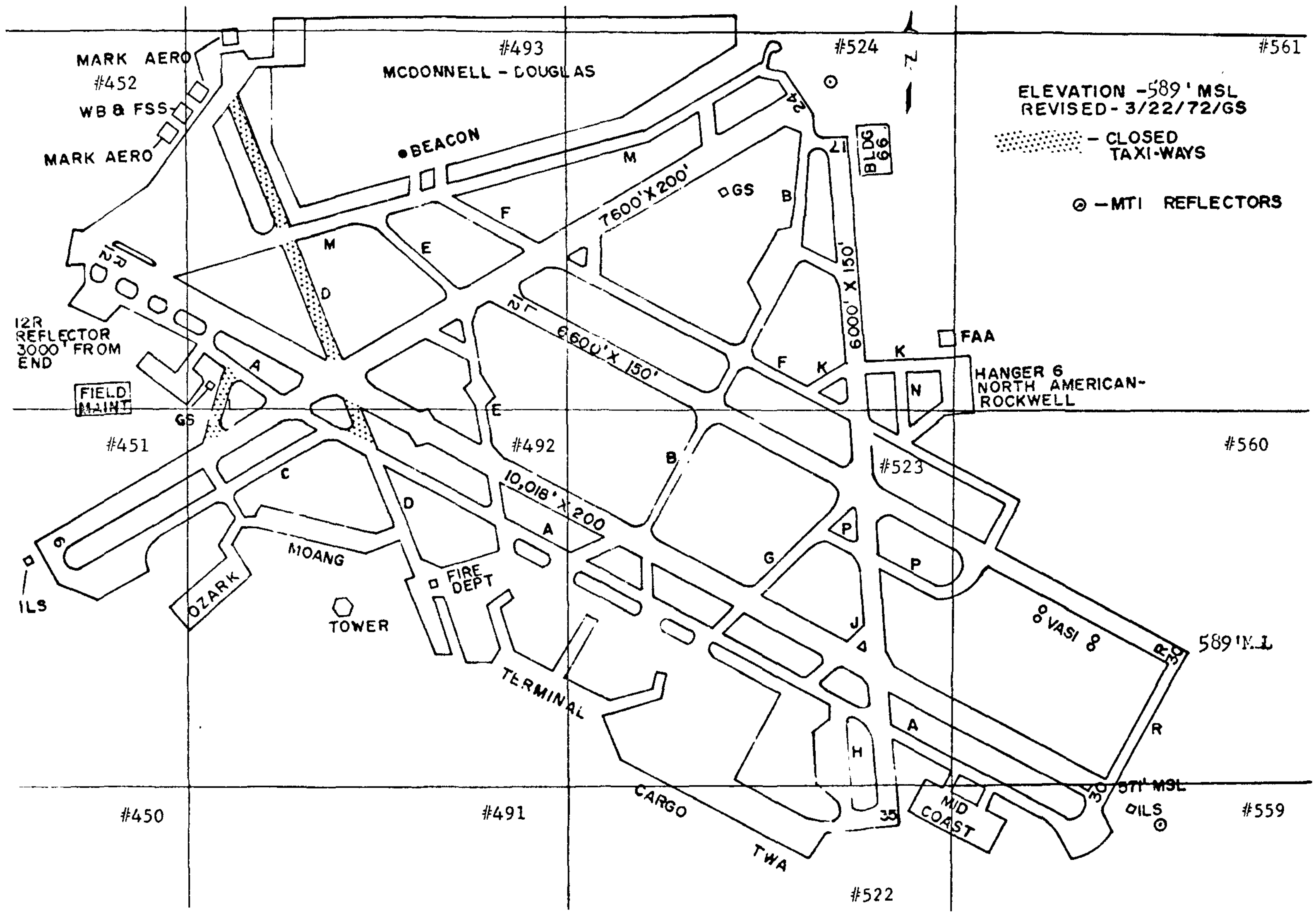

Figure 4. Lambert - St. Louis International Airport

among the grids involved. A more refined yet still simple method would be weight them according to the percent of the total taxi or takeoff time spent in each grid. This method is described here.

Table 14 shows the times in mode in each grid for air carriers taxiing to and taking off from runway 30L. To calculate emissions for each grid, the idle emissions are added to grids 492 and 523 for the six and 12 aircraft, respectively, the taxi emissions are distributed by the times in Table 14 for the six aircraft starting from grid 492 and the 12 starting from 523, and the takeoff emissions from all 18 aircraft are distributed in the grids containing runway 30L. This same method is used for landing and taxiing to the terminal area and for other runways and ramp destinations. Tables 15 through 21 list the times in mode by grid and by mode for the aircraft categories using the remaining runways.

A complicating factor is the queuing of aircraft waiting to take off during periods of heavy volume. The EPA report APTD-1470 recommends adding extra idle time due to queuing as T = (N-30)/10 when the landing and takeoff volume exceeds 30 per hour. T is the time queued (minutes) and N is the LTO volume. This relationship is based on data from Chicago's O'Hare airport and assumes the use of two parallel runways. Observation at Lambert Field indicate, however, that no extensive queuing occurs ever during periods of heaviest volume.

Emission Rates

Most emission rate data for aircraft have been gathered by the Cornell Aeronautical Laboratory. These are compiled in the report "Analysis of Aircraft Exhaust Emission Measurements," (PB-204-879)[5] and summarized in the EPA report "Compilation of Air Pollutant Emission Factors," (AP-42).[3] Emission rates for SO_2 are not given, possibly because of variation with fuel sulfur content, but they can be estimated by the product of the fuel use rate and the percent of sulfur in the fuel.

Table 14. TIMES IN MODE BY GRID BY MODE FOR AIR TRAFFIC USING RUNWAY 30L (seconds)

	Air carrier						Military					
Grid	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach
2187	0	0	0	0	35	0	0	0	0	0	10	0
683	0	0	0	0	0	26	0	0	0	0	0	15
654	0	0	0	0	0	26	0	0	0	0	0	15
653	0	0	0	0	0	26	0	0	0	0	0	15
616	0	0	0	0	0	26	0	0	0	0	0	15
589	0	0	0	0	0	26	0	0	0	0	0	15
588	0	0	0	0	0	26	0	0	0	0	0	15
560	20	0	10	0	0	3	0	0	10	4	0	2
559	45	15	2	0	0	7	130	30	0	0	0	4
524	0	0	0	0	0	0	0	0	0	0	0	0
523	540	130	30	20	3	0	150	120	14	20	0	0
522	0	0	0	0	0	0	0	0	0	0	0	0
493	0	0	0	0	15	0	0	0	0	0	8	0
492	520	230	0	15	5	0	200	150	0	0	0	0
452	0	0	0	0	15	0	0	0	0	0	2	0
451	0	0	0	0	0	0	0	0	0	0	0	0
389	0	0	0	0	35	0	0	0	0	0	10	0

Table 15. TIMES IN MODE BY GRID BY MODE FOR AIR TRAFFIC USING RUNWAY 12R
(seconds)

	Air carrier						Military					
Grid	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach
2187	0	0	0	0	0	68	0	0	0	0	0	45
683	0	0	0	0	13	0	0	0	0	0	0	0
654	0	0	0	0	13	0	0	0	0	0	6	0
653	0	0	0	0	13	0	0	0	0	0	0	0
616	0	0	0	0	13	0	0	0	0	0	6	0
589	0	0	0	0	13	0	0	0	0	0	6	0
588	0	0	0	0	13	0	0	0	0	0	0	0
560	0	0	0	0	4	0	0	0	0	0	2	0
559	0	0	0	0	10	0	0	0	0	0	4	0
524	0	0	0	0	0	0	0	0	0	0	0	0
523	524	210	2	10	15	0	0	40	8	8	6	0
522	0	0	0	0	0	0	0	0	0	0	0	0
493	15	45	20	5	0	5	60	70	8	8	0	0
492	520	110	10	20	0	0	420	50	8	8	0	0
452	45	15	10	0	0	5	0	0	0	0	0	6
451	0	0	0	0	0	0	0	0	0	0	0	0
389	0	0	0	0	0	68	0	0	0	0	0	45

Table 16. TIMES IN MODE BY GRID BY MODE FOR AIR TRAFFIC USING RUNWAY 30R (seconds)

	Air taxi						General aviation					
Grid	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach
560	150	0	0	15	0	273	100	0	0	9	0	360
559	0	0	0	0	0	0	0	0	0	0	0	0
524	0	80	13	0	0	0	0	80	8	0	0	0
523	0	80	20	18	0	0	0	80	20	18	0	0
522	0	0	0	0	0	0	0	0	0	0	0	0
493	600	320	0	0	200	0	500	320	0	0	250	0
492	0	0	0	0	0	0	0	0	0	0	0	0
452	0	0	0	0	25	0	0	0	0	0	50	0
451	0	0	0	0	0	0	0	0	0	0	0	0

Table 17. TIMES IN MODE BY GRID BY MODE FOR AIR TRAFFIC USING RUNWAY 12L (seconds)

	Air taxi						General aviation					
Grid	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach
560	0	0	0	0	225	0	0	0	0	0	300	0
559	0	0	0	0	0	0	0	0	0	0	0	0
524	0	90	17	17	0	0	0	90	10	9	0	0
523	0	90	16	16	0	0	0	90	8	9	0	0
522	0	0	0	0	0	0	0	0	0	0	0	0
493	750	300	0	0	0	123	600	300	0	0	0	160
492	0	0	0	0	0	0	0	0	0	0	0	0
452	0	0	0	0	0	150	0	0	0	0	0	200
451	0	0	0	0	0	0	0	0	0	0	0	0

Table 18. TIMES IN MODE BY GRID BY MODE FOR AIR TRAFFIC USING RUNWAY 35 (seconds)

	Air taxi						General aviation					
Grid	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach
560	0	0	0	0	0	0	0	0	0	0	0	0
559	0	0	0	0	0	0	0	0	0	0	0	0
524	0	160	0	0	225	0	0	160	0	0	300	0
523	250	160	33	33	0	0	50	160	18	18	0	0
522	0	44	0	0	0	273	0	44	0	0	0	360
493	500	300	0	0	0	0	450	300	0	0	0	0
492	0	0	0	0	0	0	0	0	0	0	0	0
452	0	0	0	0	0	0	0	0	0	0	0	0
451	0	0	0	0	0	0	0	0	0	0	0	0

Table 19. TIMES IN MODE BY GRID BY MODE FOR AIR TRAFFIC USING RUNWAY 17 (seconds)

	Air taxi						General aviation					
Grid	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach
560	0	0	0	0	0	0	0	0	0	0	0	0
559	0	0	0	0	0	0	0	0	0	0	0	0
524	250	100	30	30	0	273	50	100	15	15	0	360
523	0	100	3	3	40	0	0	100	0	0	50	0
522	0	0	0	0	185	0	0	0	0	0	250	0
493	500	380	0	0	0	0	450	380	0	0	0	0
492	0	0	0	0	0	0	0	0	0	0	0	0
452	0	0	0	0	0	0	0	0	0	0	0	0
451	0	0	0	0	0	0	0	0	0	0	0	0

Table 20. TIMES IN MODE BY GRID BY MODE FOR AIR TRAFFIC USING RUNWAY 6 (seconds)

	Air taxi						General aviation						Military					
Grid	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach
560	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
559	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
524	0	0	0	0	125	0	0	0	0	0	175	0	0	50	0	0	25	0
523	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
522	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
493	300	290	13	11	100	0	250	290	8	6	125	0	0	0	20	20	5	0
492	0	10	10	11	0	0	0	10	5	6	0	0	400	200	2	2	0	0
452	300	10	0	0	0	0	250	10	0	0	0	0	0	0	0	0	0	0
451	150	10	10	11	0	273	100	10	5	6	0	360	80	50	2	2	0	96

Table 21. TIMES IN MODE BY GRID BY MODE FOR AIR TRAFFIC USING RUNWAY 24 (seconds)

	Air taxi						General aviation						Military					
Grid	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach
560	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
559	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
524	150	150	23	23	0	273	100	150	12	12	0	360	80	120	24	24	0	96
523	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0
522	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
493	300	230	10	10	40	0	250	230	6	6	40	0	0	0	0	0	5	0
492	0	0	0	0	0	0	0	0	0	0	0	0	400	100	0	0	0	0
452	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
451	300	0	0	0	185	0	250	0	0	0	260	0	0	0	0	0	25	0

Table 22 lists the air carrier aircraft and engines used at Lambert Field as compiled from the Official Airline Guide. The numbers of each type of engine were used to weight the emission factors for each to prepare a single, composite set of weighted emission factors for air carriers. The emission factors for each engine type and the weighted factors are presented in Table 23.

Table 22. AIRCRAFT AND ENGINE VOLUMES FOR LAMBERT FIELD, ST. LOUIS

Aircraft	Engine type							
	Number	JT3D	JT4A	JT8D	CJ805	JT9D	T56-A7	RRMK511
DC9	110			220				
727	76			228				
707	24	96						
CV5	25						50	
320	2		8					
880	2				8			
DC10	3					9		
737	5			10				
BAC111	5							10
TOTAL	252	96	8	458	8	9	50	10

Composite emission factors were also prepared for the other three aircraft categories. For air taxi the weighting factors are 100 T56-A7 engines and 20 RRMK511 engines. General aviation was given an equal distribution of 0-320, 0-360, and 0-200 engines. Military aircraft were half J79 and half J57 engines. The composite emission factors by pollutant and by mode are listed in Table 24. The SO_2 emission factors presented in this report are for an assumed 0.05 percent sulfur content fuel.[3]

Table 23. EMISSION FACTORS BY ENGINE TYPE AND MODE FOR AIR CARRIERS (kg/hr)

Mode	Pollutant	JT3D	JT4A	JT8D	CJ805	JT9D	T56-A7	RRMK511	Weighted factors
Idle	CO	49.4	28.5	15.2	28.9	46.3	6.94	27.3	20.66
	HC	44.7	29.4	3.71	12.4	12.4	2.93	30.0	10.77
	NO_x	0.649	1.23	1.32	0.712	2.75	0.98	0.385	1.19
	SO_2	0.396	0.631	0.435	0.454	0.788	0.249	0.300	0.42
	Particulate	0.20	0.54	0.16	0.59	1.0	0.73	0.077	0.23
Taxi	CO	49.4	28.5	15.2	28.9	46.3	6.94	27.3	20.66
	HC	44.7	29.4	3.7	12.4	12.4	2.93	30.0	10.77
	NO_x	0.649	1.23	1.32	0.712	2.75	0.98	0.385	1.19
	SO_2	0.396	0.631	0.435	0.454	0.788	0.249	0.300	0.42
	Particulate	0.2	0.54	0.16	0.59	1.0	0.73	0.077	0.23
Takeoff	CO	5.6	8.53	3.40	13.2	3.76	0.975	6.44	3.78
	HC	2.11	0.306	0.353	0.252	1.34	0.195	-----	0.61
	NO_x	67.1	107.0	89.8	50.3	327	10.40	69.4	82.92
	SO_2	4.915	7.051	3.971	4.518	7.735	1.943	3.459	3.97
	Particulate	3.7	95	1.7	6.8	1.7	1.7	7.3	2.25
Landing	CO	33.9	21.1	11.3	23.6	31.1	4.66	20.76	14.88
	HC	27.9	18.0	2.4	7.7	8.0	1.84	18.31	6.78
	NO_x	18.1	29.0	24.6	13.8	84.1	3.649	19.10	22.66
	SO_2	0.662	0.545	0.248	0.275	0.379	0.076	0.222	0.30
	Particulate	1.6	3.0	0.61	2.4	1.2	1.07	1.91	0.88
Climbout	CO	6.94	8.30	4.03	13.1	5.31	1.37	6.94	4.49
	HC	2.23	0.576	0.418	0.264	1.20	0.216	0.110	0.68
	NO_x	43.6	70.3	59.4	33.6	208	9.62	52.2	54.13
	SO_2	4.062	5.939	3.328	3.760	6.494	0.865	2.883	3.32
	Particulate	3.9	9.1	1.2	6.8	1.8	1.4	4.5	1.85
Approach	CO	18.0	11.9	8.26	19.4	14.8	1.66	17.7	9.63
	HC	3.56	1.74	0.794	1.10	1.36	0.235	1.91	1.21
	NO_x	9.89	16.3	14.0	8.07	24.5	3.53	13.8	12.66
	SO_2	1.877	2.724	1.546	1.713	2.361	0.478	1.384	1.54
	Particulate	3.6	2.7	0.68	2.3	1.0	1.4	0.68	1.23

Table 24. COMPOSITE EMISSION FACTORS FOR AIR TAXI, GENERAL AVIATION, AND MILITARY AIRCRAFT AT LAMBERT FIELD (kg/hr)

Mode	Pollutant	Air taxi	General aviation	Military
Idle	HC	7.442	0.428	24.0
	CO	10.333	4.779	36.0
	NO_x	0.881	0.006	1.5
	SO_2	0.258	0.005	0.509
	Particulate	0.621	0.0	10.0
Taxi	HC	7.442	0.428	24.0
	CO	10.333	4.779	36.0
	NO_x	0.881	0.006	1.5
	SO_2	0.258	0.005	0.509
	Particulate	0.621	0.0	10.0
Takeoff	HC	0.195	0.642	3.5
	CO	1.886	32.923	224.0
	NO_x	20.233	0.143	56.0
	SO_2	2.196	0.031	8.916
	Particulate	2.633	0.0	73.5
Landing	HC	4.585	0.451	24.0
	CO	7.343	12.764	36.0
	NO_x	6.224	0.044	1.5
	SO_2	0.100	0.012	0.509
	Particulate	1.210	0.0	10.0
Climbout	HC	0.198	0.488	1.5
	CO	2.298	28.393	6.0
	NO_x	16.717	0.157	42.5
	SO_2	1.201	0.027	3.898
	Particulate	1.917	0.0	48.0
Approach	HC	0.514	0.249	1.5
	CO	4.333	12.471	7.5
	NO_x	5.242	0.037	30.5
	SO_2	0.629	0.012	3.548
	Particulate	1.280	0.0	54.5

GROUND SERVICE VEHICLE OPERATIONS

The activity of ground service vehicles and the vehicles used depend on the type of aircraft being serviced. For Lambert Field, a composite time for servicing was computed for each of the various types of vehicles for the air carrier equipment mix. Table 25 presents a summary of ground service vehicle usage and times for the different types of aircraft.[2] The composite service time was computed using the aircraft volumes that were also used to compute composite emission factors. Table 26 lists the fuel consumption rates, while Table 27 gives the emission factors for each.[2] Emission factors for SO_2 can be computed from Table 27 and the sulfur content of the fuel. The hourly emissions from ground service vehicles are found by multiplying the times in Table 25, the consumption rates in Table 26, and the emission factors in Table 27 by half the hourly volume computed for aircraft activity.

FUEL HANDLING AND STORAGE

The Allied Aviation Fueling Company of St. Louis, Inc., is the major supplier of fuel at Lambert. The fuel is stored on a hill outside the airport boundary and is piped underground to the ramp area of the airline terminal. The majority of aircraft fueling is done directly from outlets on the ramp, although fueling trucks are used at a few locations.

The fuel storage tanks are equipped with vapor recovery systems and the cartridges are serviced regularly. Any fuel spillage during fueling is promptly washed away.

Approximately 12 million gallons of fuel are pumped per month.[6] The working loss of hydrocarbons varies with temperature, and Table 28 lists the 94 year average high, medium, and low temperatures for each month as compiled in the Climatic Atlas of the U. S.[7] The average low

Table 25. SERVICE TIMES OF AIRCRAFT GROUND SERVICE VEHICLES

Aircraft / Vehicle	Time in vehicle-minutes								Composite times
	DC-10	B-707	B-727	DC-9	B-737	C-880	F-227	C-580	
1. Tractor	148	66	66	48	85	40	55	50	56
2. Belt Loader	40	37	28	15	30	40	0	25	23
3. Container Loader	80	12	6	0	0	0	0	0	3
4. Cabin Service	25	12	12	0	15	0	0	0	5
5. Lavatory Truck	18	15	15	15	15	20	10	10	15
6. Water Truck	10	0	0	10	0	0	10	10	5
7. Food Truck	20	20	17	17	20	20	10	10	17
8. Fuel Truck	45	37	20	15	15	20	10	20	19
9. Tow Tractor	10	10	10	5	5	15	5	5	8
10. Conditioner	0	30	0	0	0	0	0	0	3
11. Airstart									
Transporting Engine	0	10	0	0	0	15	0	0	2
Diesel Power Unit	0	8	0	0	0	11	0	0	2

Table 25 (continued). SERVICE TIMES OF AIRCRAFT GROUND SERVICE VEHICLES

Vehicle \ Aircraft	Time in vehicle-minutes								Composite times
	DC-10	B-707	B-727	DC-9	B-737	C-880	F-227	C-580	
12. Ground Power Unit									
Transporting Engine	0	9	0	0	0	35	0	0	4
Gasoline Power Unit	0	4	0	0	0	15	0	0	2
Diesel Power Unit	0	4	0	0	0	15	0	0	2
13. Transporter	0	10	3	0	0	0	0	0	2
14. Auxiliary Power Unit	Yes	No	Yes	Yes	Yes	No	No	No	30

Table 26. GROUND SERVICE VEHICLE FUEL CONSUMPTION RATES

Vehicle	Rate of fuel consumption (gal/hr)
1. Tractor	1.80
2. Belt Loader	0.70
3. Container Loader	1.75
4. Cabin Service	1.50[a]
5. Lavatory Truck	1.50[a]
6. Water Truck	1.50[a]
7. Food Truck	2.00[a]
8. Fuel Truck	1.70[a]
9. Tow Tractor	2.35
10. Conditioner	1.75[a]
11. Airstart	
Transporting Engine	1.40
Diesel Power Unit	8.20
12. Ground Power Unit	
Transporting Engine	2.00
Gasoline Power Unit	5.00
Diesel Power Unit	7.10
13. Transporter	1.50
14. Auxiliary Power Unit	7.10

[a]Estimated values

Table 27. GROUND SERVICE VEHICLE EMISSION FACTORS

Vehicle	Pollutant emissions (grams/gal)			
	CO	HC	NO_x	Particulates
Gasoline Engines	999.0	223.2	57.0	1.8
Diesel Engines	147.6	29.5	154.4	11.4

Table 28. NINETY-FOUR YEAR AVERAGE HIGH, MEDIUM, AND LOW TEMPERATURES FOR ST. LOUIS (^{o}F)

Month	High	Medium	Low
January	40	32	23
February	44	35	25
March	53	43	32
April	66	55	44
May	75	64	53
June	85	74	63
July	89	78	67
August	87	77	66
September	81	70	58
October	70	59	47
November	59	49	35
December	43	35	27

temperature is used for the 8 p.m. to 8 a.m. period, the average medium is used for 8 a.m. to 1 p.m. and 3 p.m. to 8 p.m., and the average high is used for 1 p.m. to 3 p.m.

The hydrocarbon emission factors are calculated by using the method from the American Petroleum Institute publication API 2513.[8] Table 29 lists the working loss factors computed for each month for each time period.

The gallons of fuel pumped in any hour are computed by the same method used for aircraft volumes. Hence,

$$G_h = \frac{1}{2} \frac{(G_m)(D_i)(H_i)}{(OD_m)10^4} ,$$

where G_m is gallons/month (12 million) and the factor of 1/2 assumes an even distribution of landings and takeoffs. The mass emissions are then calculated by multiplying G_h by the emission factor appropriate to the hour of the day (Table 29), and then multiplying the result by the volume to mass factor of 2.8 kg/gal. These emissions are restricted to grids 492 (one third) and 523 (two thirds).

ENGINE TESTING AND MAINTENANCE

Engine testing and maintenance is done by McDonnell Douglas in association with their manufacturing facilities at Lambert. The details of their testing and maintenance are classified, since their production consists of military aircraft. Their production rate is "about" two aircraft per day, and hence this emission source will be excluded from the inventory

Table 29. WORKING LOSS FACTORS FOR THE THREE TIME PERIODS FOR EACH MONTH

Month	Working loss (gallons/1000 gallons throughput)		
	0800-1300 1500-2000	1300-1500	2000-0800
January	0.87	1.03	0.71
February	0.94	1.17	0.72
March	1.12	1.38	0.87
April	1.42	1.65	1.17
May	1.61	2.11	1.38
June	2.10	2.58	1.60
July	2.17	2.76	1.81
August	2.16	2.64	1.80
September	1.92	2.37	1.51
October	1.52	1.92	1.20
November	1.17	1.41	0.94
December	0.94	1.12	0.78

SECTION VI

SCOTT AIR FORCE BASE

Scott Air Force Base is an Air Medical and Airlift Wing of the Military Airlift Command. The air traffic is light; it averages approximately 40 flights per day.

AIRCRAFT FLIGHT ACTIVITY

The five months of data available from Scott[9] were not sufficient to determine the percent of traffic by month. Therefore, a monthly mean and standard deviation was calculated from the five months of data. This is used with the day of week and hour of the day percentages to find the hourly traffic. Since the flights are predominantly by military aircraft, the categories of jet and piston aircraft are used. Table 30 lists the monthly volumes and the five month means and standard deviations for the two categories.

Table 30. FIVE-MONTH AIR TRAFFIC VOLUMES, MEANS, AND STANDARD DEVIATIONS AT SCOTT AFB, 1973 - 1974

Month	Jet	Piston	Total
Sept.	1208	451	1659
Oct.	1088	470	1558
Nov.	788	400	1188
Dec.	461	281	742
Jan.	617	285	912
Mean	832	379	1212
Standard Deviation	313	87	397

Percentages by the day of the week are given in Table 31. Percentages by the hour of the day were obtained from percentages for 6-hour periods beginning at 0400. Thus, all hours within a 6-hour block are given the same percent of total daily traffic. These are shown in Table 32.

Table 31. PERCENT OF AIR TRAFFIC BY DAY OF WEEK AT SCOTT AFB

Day	Jet	Piston
Sunday	13.61	15.97
Monday	13.86	13.86
Tuesday	12.29	12.50
Wednesday	15.16	12.08
Thursday	14.58	15.93
Friday	15.75	14.11
Saturday	14.75	15.54

Scott Field lies in four grid elements as shown in Figure 5. There are only two runways at Scott, runways 13 and 31 (Figure 5). Hence the grid elements used for the different modes are easily defined, and these are implicit in Tables 33 and 34 which give the time in the various modes for each grid by runway and type of aircraft.

EMISSION FACTORS

Jet flights at Scott AFB are predominantly by C-9 and C-141 aircraft.[9] The C-9 has two JT8D engines, while the C-141 has four TF-33 engines.[10] The ratio of activity of the C-9 to C-141 is about 3.75 to 1.0, so the weighting by engine type is about 1.87 (JT8D) to 1.0 (TF-33). Composite emission factors based on these engines were calculated, and these are given in Table 35.

Table 32. PERCENT OF AIR TRAFFIC BY HOUR AT SCOTT AFB.

Hour	Jet	Piston
0000-0100	5.367	5.226
0100-0200	5.367	5.226
0200-0300	5.367	5.226
0300-0400	5.367	5.226
0400-0500	0.841	0.298
0500-0600	0.841	0.298
0600-0700	0.841	0.298
0700-0800	0.841	0.298
0800-0900	0.841	0.298
0900-1000	0.841	0.298
1000-1100	4.054	3.799
1100-1200	4.054	3.799
1200-1300	4.054	3.799
1300-1400	4.054	3.799
1400-1500	4.054	3.799
1500-1600	4.054	3.799
1600-1700	6.404	7.344
1700-1800	6.404	7.344
1800-1900	6.404	7.344
1900-2000	6.404	7.344
2000-2100	6.404	7.344
2100-2200	6.404	7.344
2200-2300	5.367	5.226
2300-2400	5.367	5.226

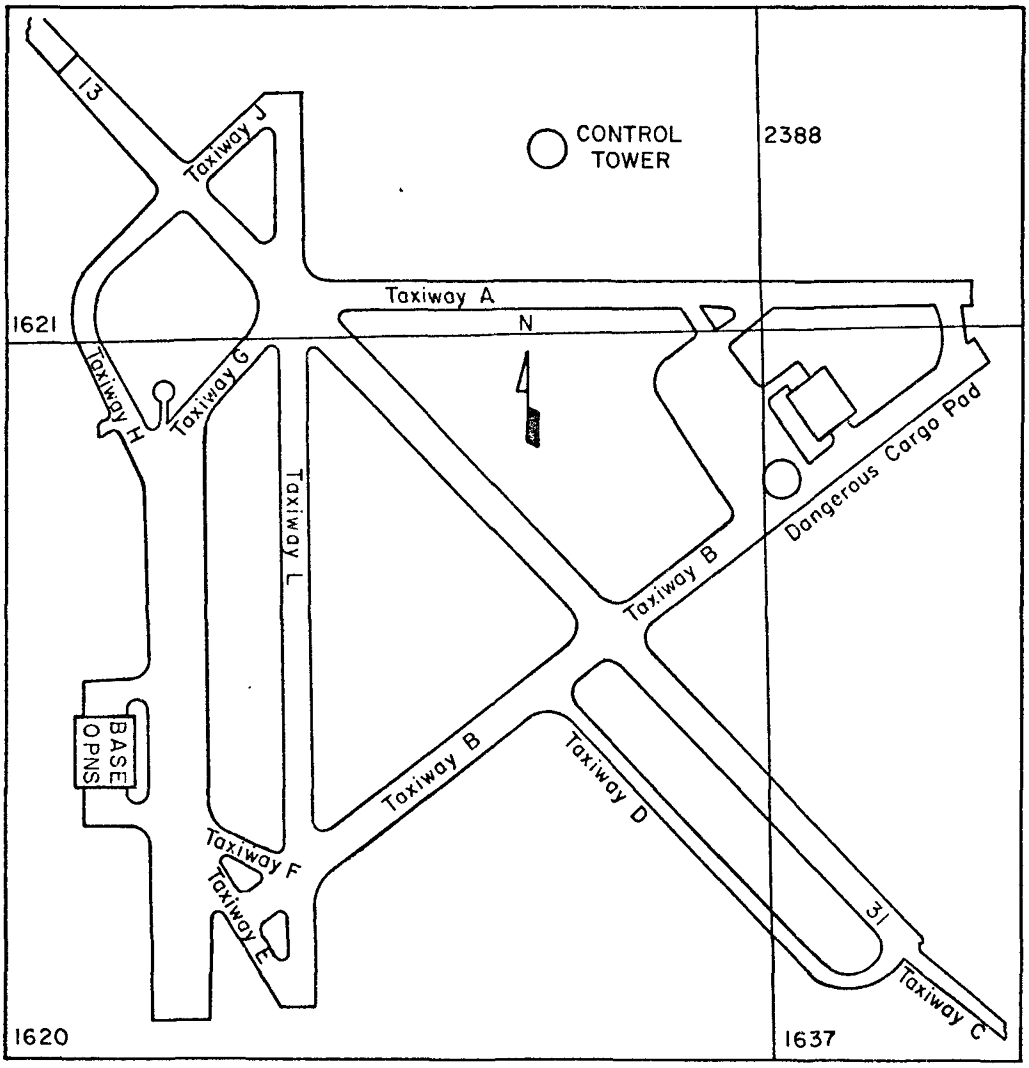

Figure 5. Runway layout and grid element overlay for Scott AFB

Table 33. TIME IN MODE BY GRID AND MODE FOR AIRCRAFT USING RUNWAY 13, SCOTT AFB (seconds)

Mode	2388		1637		1621		1620	
	Jet	Piston	Jet	Piston	Jet	Piston	Jet	Piston
Idle	0	0	20	0	40	80	420	720
Taxi	0	0	40	50	50	50	510	600
Takeoff	0	0	0	0	20	16	22	20
Landing	0	0	0	0	15	16	20	20
Climbout	0	0	108	300	0	0	0	0
Approach	110	100	0	0	56	176	0	0

Table 34. TIME IN MODE BY GRID AND MODE FOR AIRCRAFT USING RUNWAY 31, SCOTT AFB (seconds)

Mode	2388		1637		1621		1620	
	Jet	Piston	Jet	Piston	Jet	Piston	Jet	Piston
Idle	0	0	40	80	20	0	420	720
Taxi	0	0	20	50	20	50	800	700
Takeoff	0	0	10	16	0	20	32	0
Landing	0	0	5	10	0	26	30	0
Climbout	70	200	0	0	30	100	8	0
Approach	0	0	166	276	0	0	0	0

Table 35. EMISSION FACTORS FOR SCOTT AFB (kg/hr)

Mode	Pollutant	Jet	Piston
Idle	CO	31.70	59.00
	HC	22.51	10.30
	NO_x	1.17	0.08
	SO_2	0.470	0.072
	Particulate	1.60	NA
Taxi	CO	31.70	64.50
	HC	22.51	13.20
	NO_x	1.17	0.06
	SO_2	0.470	0.073
	Particulate	1.60	NA
Takeoff	CO	3.18	417.70
	HC	0.60	9.23
	NO_x	77.09	2.15
	SO_2	3.949	0.403
	Particulate	20.16	NA
Landing	CO	21.56	160.62
	HC	15.38	8.96
	NO_x	21.29	0.67
	SO_2	0.695	0.164
	Particulate	7.26	NA
Climbout	CO	4.07	305.80
	HC	0.71	5.43
	NO_x	50.91	1.85
	SO_2	3.388	0.309
	Particulate	18.19	NA
Approach	CO	10.95	156.10
	HC	10.96	3.50
	NO_x	12.96	0.64
	SO_2	1.600	0.152
	Particulate	9.15	NA

Piston aircraft flights are largely by T-29, C-118, and C-131 aircraft, all of which use Pratt Whitney R-2800 engines. Emission factors[11] for piston aircraft flights are also listed in Table 35.

GROUND SERVICE VEHICLE OPERATIONS

There are eight petroleum, oil, and lubricants trucks, or POL trucks used to service aircraft at Scott Field. These run an average of 3 hours 25 minutes each per day,[9] or a total of 27 hours 20 minutes in grid element number 1620.

In addition to the POL trucks, the fleet service vehicles listed in Table 36 are used. Their combined use accounts for approximately 15 gallons of fuel per day.[9] Emission factors for these vehicles are given in the previous Table 27. The hourly emissions are computed by distributing the daily emissions according to the average hourly percent of daily activity for piston and jet aircraft.

Table 36. GROUND SERVICE VEHICLES USED AT SCOTT AFB

Service vehicle	Number
Fork lift	2
Water truck	1
Multi-stop	2
High lift	1
Lavatory truck	2
Warehouse tug	2
Step van	2

Emissions from the POL trucks are found using the fuel consumption rate for fuel trucks given in Table 26 (1.70 gallons/hour) and the emission factors from Table 27. These total emissions are also distributed by the hourly percent of daily activity to find the emissions for a particular hour.

FUEL HANDLING AND STORAGE

The volume of fuel stored at Scott AFB is classified. The average use is 724,000 gallons of jet fuel and 82,000 gallons of avgas per month. Hourly volumes of fuel pumped can be calculated using the day of week and hour of day percentages used to find activity. The emissions are then calculated using the factors given in Table 29 for jet fuel and a factor of 5 kg/1000 gallons pumped for avgas.

ENGINE TESTING AND MAINTENANCE

Engine testing and maintenance activity does not follow a prescribed schedule and hence cannot be accurately accounted for on an hourly basis. Emissions could be computed as an average value for each hour, but the number of engine runups is so small (about 14 per week) that the emissions would be lost on an hourly basis.

SECTION VII

CIVILIAN AIRPORTS

INTRODUCTION

Civilian airports can be divided into those with control towers and those without. This division also applies to the degree of data availability, and to the volume and type of traffic. Two civilian airports in the St. Louis AQCR, Spirit of St. Louis and Civic Memorial, have control towers; the remainder do not.

FLIGHT ACTIVITY

More extensive data are available for Civic Memorial Airport from the FAA control tower. These data have been reduced in the same manner as those for Lambert Field. Table 37 gives the monthly percentages of annual traffic, Table 38 gives the percentages by the day of the week, and the percentages by the hour of the day are listed in Table 39. These data are used to compute hourly traffic by the same method described for Lambert Field.

Uncontrolled airports do not record air traffic volumes. However, FAA Forms 5010-1 list estimated annual volumes which can be used with the distribution of traffic found at Civic Memorial. Table 40 presents the annual volumes from FAA Forms 5010-1. Two exceptions are Civic Memorial and Spirit of St. Louis for which the volumes were obtained from control tower records.

Table 37. PERCENT OF AIR TRAFFIC BY MONTH AT CIVIC MEMORIAL AIRPORT

Month	Monthly percent
January	7.86
February	7.95
March	6.98
April	9.26
May	9.48
June	8.88
July	8.44
August	9.90
September	7.78
October	9.48
November	8.49
December	5.50

Table 38. PERCENT OF AIR TRAFFIC BY DAY OF WEEK AT CIVIC MEMORIAL AIRPORT

Day	Day percent
Sunday	17.47
Monday	11.14
Tuesday	12.54
Wednesday	13.30
Thursday	12.76
Friday	14.10
Saturday	18.69

Table 39. PERCENT OF AIR TRAFFIC BY HOUR OF THE DAY AT CIVIC MEMORIAL AIRPORT

Hour	Hourly percent
0700 - 0800	1.15
0800 - 0900	4.63
0900 - 1000	7.20
1000 - 1100	7.08
1100 - 1200	8.82
1200 - 1300	9.51
1300 - 1400	10.51
1400 - 1500	10.83
1500 - 1600	12.45
1600 - 1700	12.91
1700 - 1800	6.17
1800 - 1900	3.19
1900 - 2000	2.23
2000 - 2100	2.40
2100 - 2200	0.56
2200 - 2300	0.34

Table 40. ANNUAL AIR TRAFFIC VOLUMES AT CIVILIAN AIRPORTS IN THE ST. LOUIS AQCR

Airport	Annual volume
St. Clair	14,400
Wentzville	27,000
Arrowhead	60,500
Creve Coeur	63,100
St. Charles	63,000
St. Charles Smartt	27,000
Weiss	130,000
Festus	15,000
Gelhardt	14,183
Sparta	8,012
Highland	28,000
Greenville	38,734
Bi-State Parks	192,030
Civic Memorial	156,607
Spirit of St. Louis	114,426

SPATIAL DETAIL

Five of the general aviation airports lie in more than one grid element. These are Civic Memorial, Spirit of St. Louis, Bi-State Parks, St. Clair, and Creve Coeur Airports. The remaining ten are contained in one grid. Figures 6 through 10 show the layout of the multi-grid airports. The grids and the key operating modes for each grid for each active runway are listed in Tables 41 through 45.

The airports which lie in only one grid element are listed, along with the grid numbers and sizes, in Table 46. Figures 11 through 20 depict the layout of these remaining airports.

EMISSIONS FROM FLIGHT ACTIVITY

The emission factors for the civilian airports are those for general aviation listed in Table 24 for a mix of general aviation aircraft types. The average times in mode are given in Table 47. When an airport lies in more than one grid, the time for each mode is distributed equally among the grids identified for the mode (Tables 41 through 45). The emissions are computed by the same multiplication of volume, emission factors, and times in mode as described for Lambert Field.

GROUND SERVICE VEHICLES

Ground service vehicles at civilian airports are limited to fueling trucks, and even these are absent at all but the large civilian airports. Most of these airports provide fueling as at a gas station; airplanes are taxied to the gas pump for filling.

The fueling truck operation is erratic, depending on the amount of traffic, and it is not possible to pin down the actual operating characteristics.

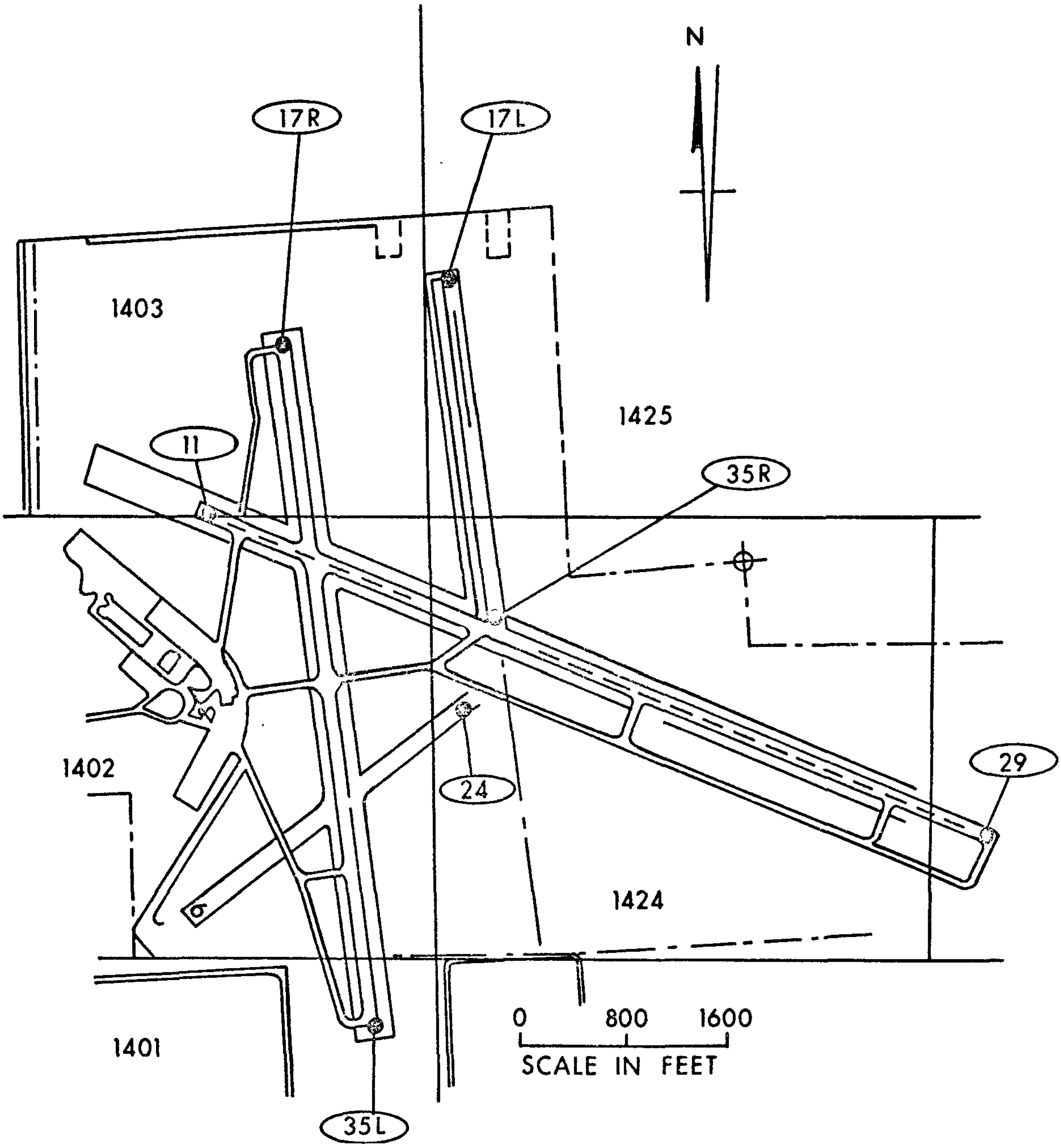

Figure 6. Diagram of Civic Memorial Airport sho‌w . grid element overlay

Table 41. OPERATING MODES FOR EACH GRID BY ACTIVE RUNWAY AT CIVIC MEMORIAL AIRPORT

Runway	Grid	X-coord	Y-coord	Size	Idle	Taxi	Takeoff	Climbout	Approach	Landing	Taxi
11	1402	4308	755	1		x	x			x	x
	1403	4309	755	1		x	x			x	
	1424	4308	756	1			x			x	x
	1444	4309	757	2			x			x	x
29	1402					x	x			x	x
	1403						x			x	
	1424					x	x			x	x
	1444					x	x			x	
17	1401	4307	755	1			x			x	x
	1402					x	x			x	x
	1403					x	x			x	
35	1401					x	x			x	
	1402					x	x			x	x
	1403						x			x	x

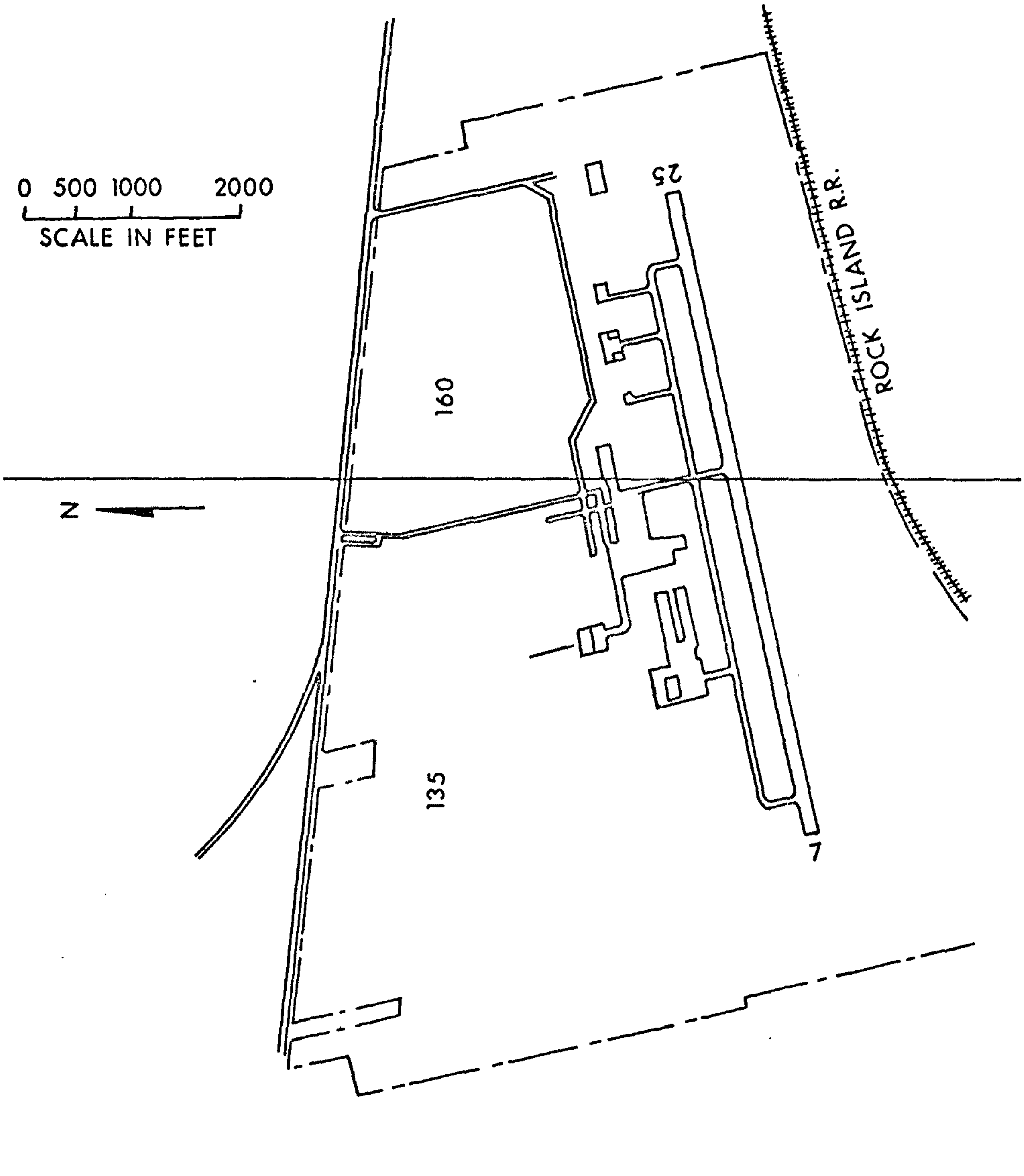

Figure 7. Diagram of Spirit of St. Louis Airport showing grid element overlay

Table 42. OPERATING MODES FOR EACH GRID BY ACTIVE RUNWAY AT SPIRIT OF ST. LOUIS AIRPORT

Runway	Grid	X-coord	Y-coord	Size	Idle	Taxi	Takeoff	Climbout	Approach	Landing	Taxi
8	135	4280	700	5		X	X			X	X
	160	4280	705	5		X	X			X	X
26	135					X	X			X	X
	160					X	X			X	X

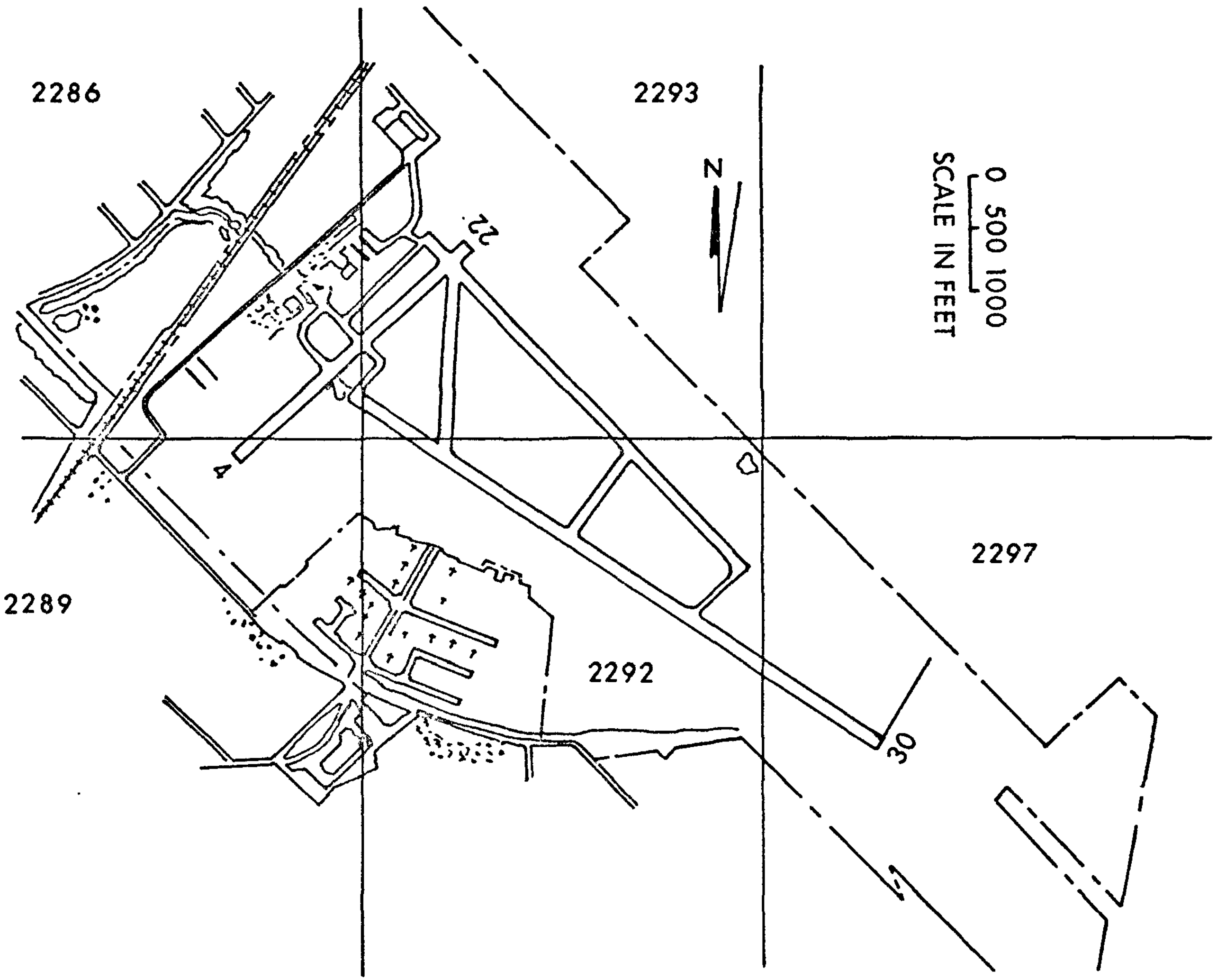

Figure 8. Diagram of Bi-State Parks Airport showing grid element overlay

Table 43. KEY OPERATING MODES FOR EACH GRID FOR EACH RUNWAY AT BI-STATE PARKS AIRPORT

Runway	Grid	Size	Idle	Taxi	Takeoff	Landing	Taxi
4	2286	2	X	X	X	X	X
	2293	1			X	X	X
	2289	1	X	X	X	X	
22	2286	2			X	X	X
	2293	1	X	X	X	X	
12	2286	2	X	X			
	2292	1			X	X	X
	2293	1			X	X	
	2297	1			X	X	
30	2292	1			X	X	
	2293	1	X	X	X	X	X
	2297	1		X	X	X	

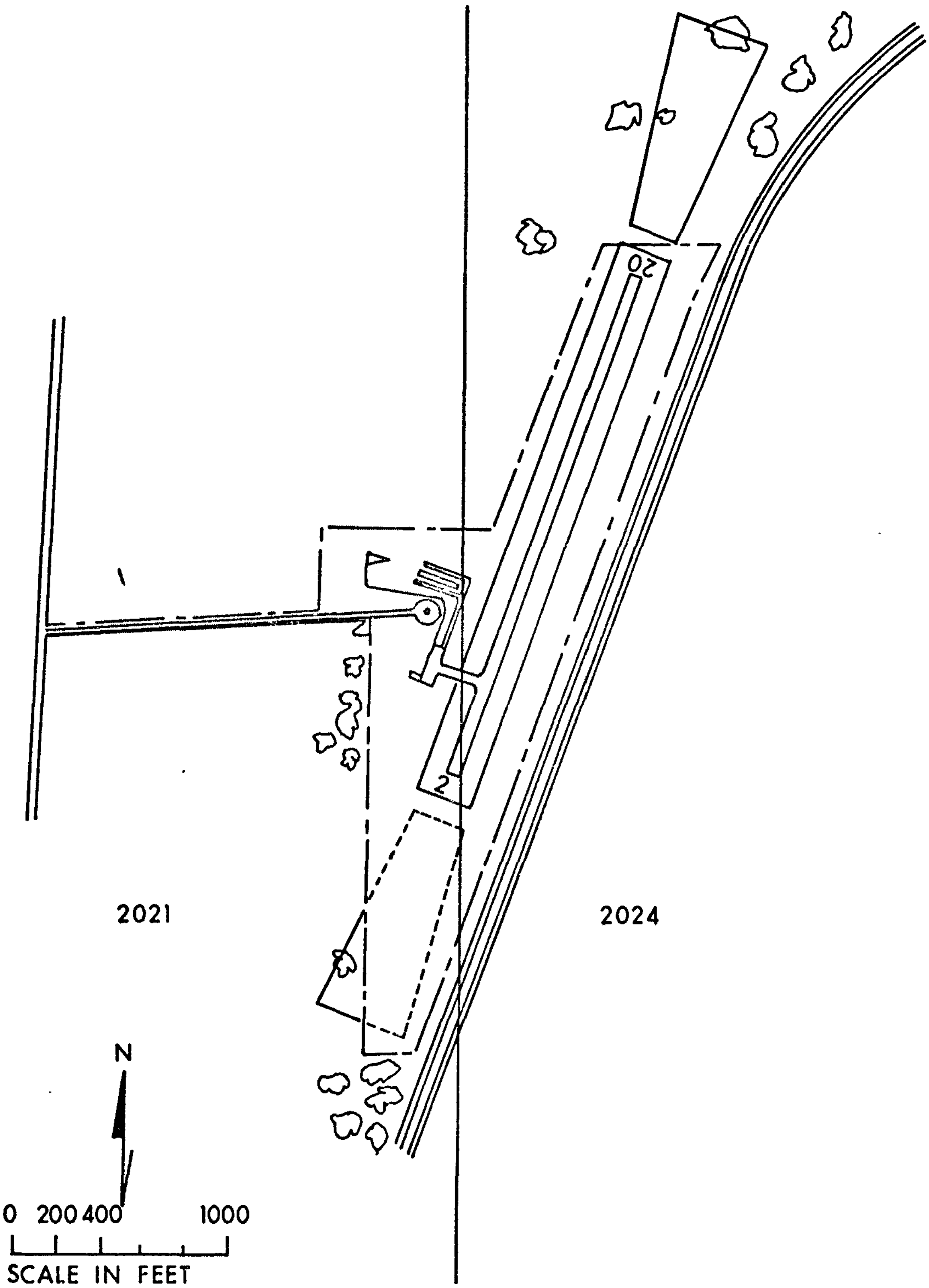

Figure 9. Diagram of St. Clair Airport showing grid element overlay

Table 44. KEY OPERATING MODES FOR EACH GRID FOR EACH RUNWAY AT ST. CLAIR AIRPORT

Runway	Grid	Size	Idle	Taxi	Takeoff	Landing	Taxi
2	2021	2	X	X			X
	2024	3		X	X	X	X
20	2021	2	X	X			X
	2024	3		X	X	X	X

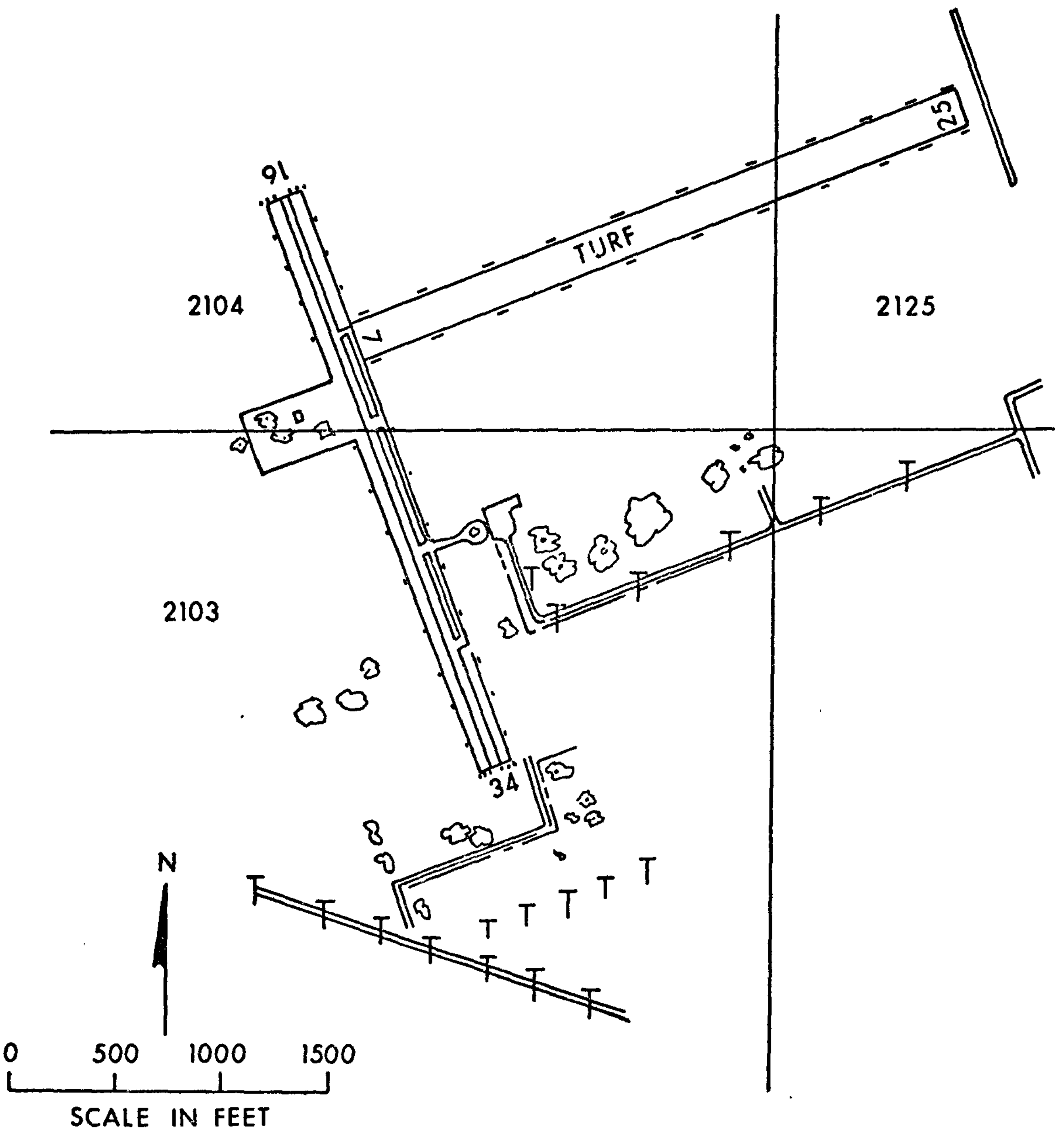

Figure 10. Diagram of Creve Coeur Airport showing grid element overlay

Table 45. KEY OPERATING MODES FOR EACH GRID FOR EACH RUNWAY AT CREVE COEUR AIRPORT

Runway	Grid	Size	Idle	Taxi	Takeoff	Landing	Taxi
16	2103	2	X	X	X	X	X
	2104	2		X	X	X	
34	2103	2	X	X	X	X	X
	2104	2			X	X	X
7	2103	2	X	X			X
	2104	2		X	X	X	X
	2125	2			X	X	X
25	2103	2	X	X			X
	2104	2		X	X	X	X
	2105	2		X	X	X	

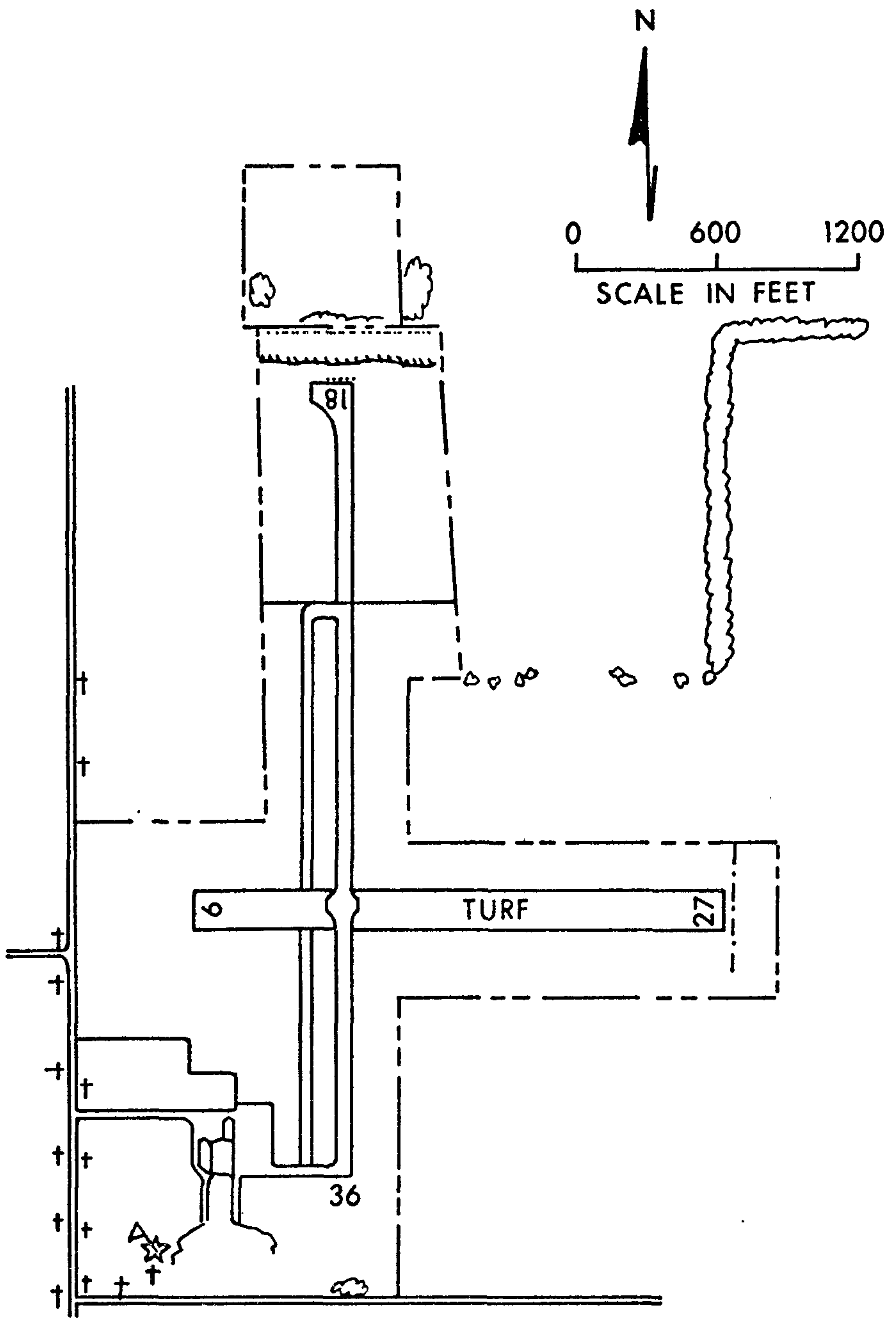

Figure 11. Diagram of Sparta Airport - grid element 1633

Table 46. GENERAL AVIATION AIRPORTS CONTAINED IN ONE GRID, ST. LOUIS AQCR

Airport	Grid number	Grid size (km)
Wentzville	76	10.0
Arrowhead	2102	2.0
St. Charles	241	5.0
St. Charles Smartt	242	10.0
Weiss	2161	4.0
Festus	467	2.0
Gebhardt	883	2.0
Sparta	1633	10.0
Highland	1709	10.0
Greenville	1815	10.0

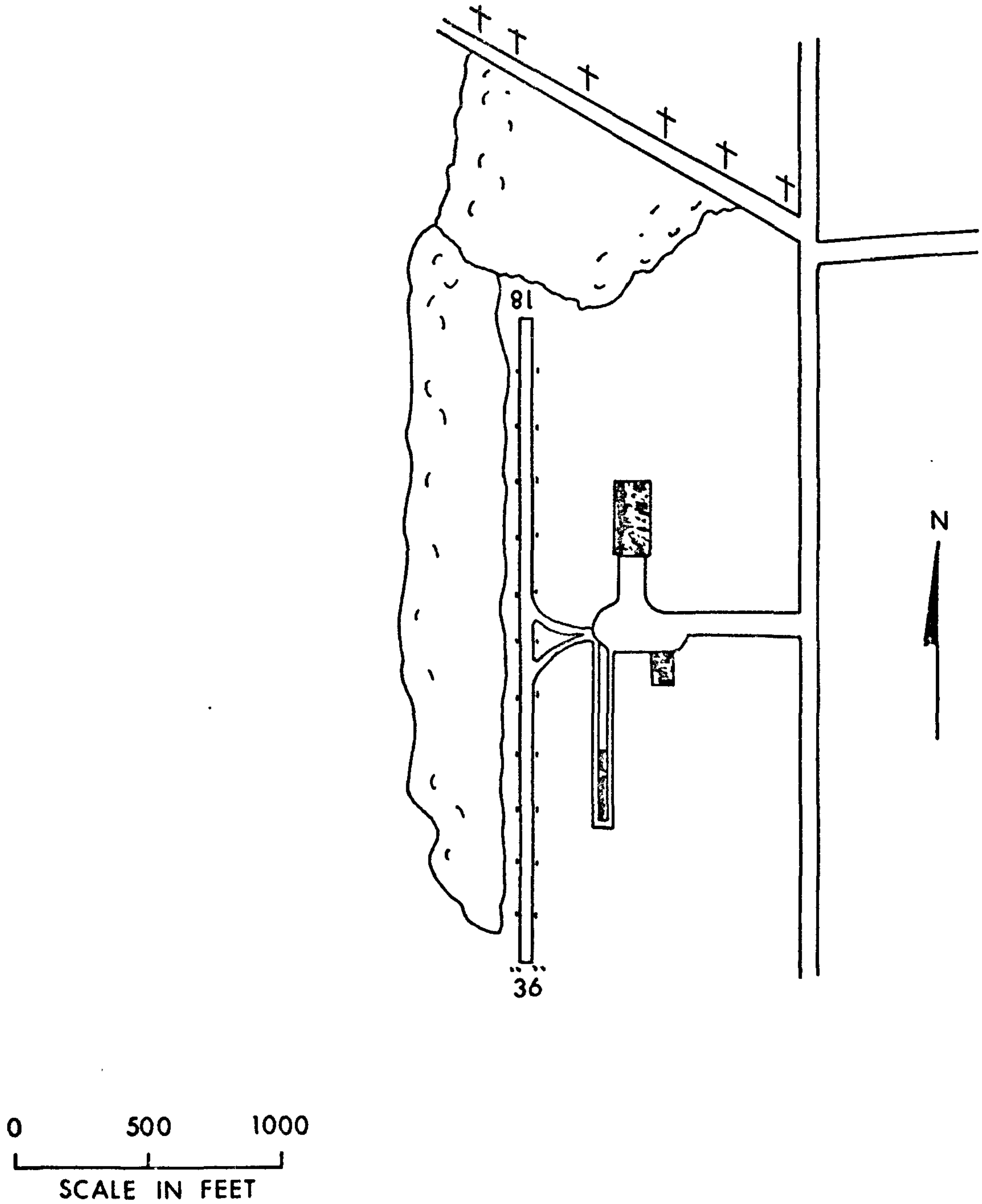

Figure 12. Diagram of Wentzville Airport - grid element 76

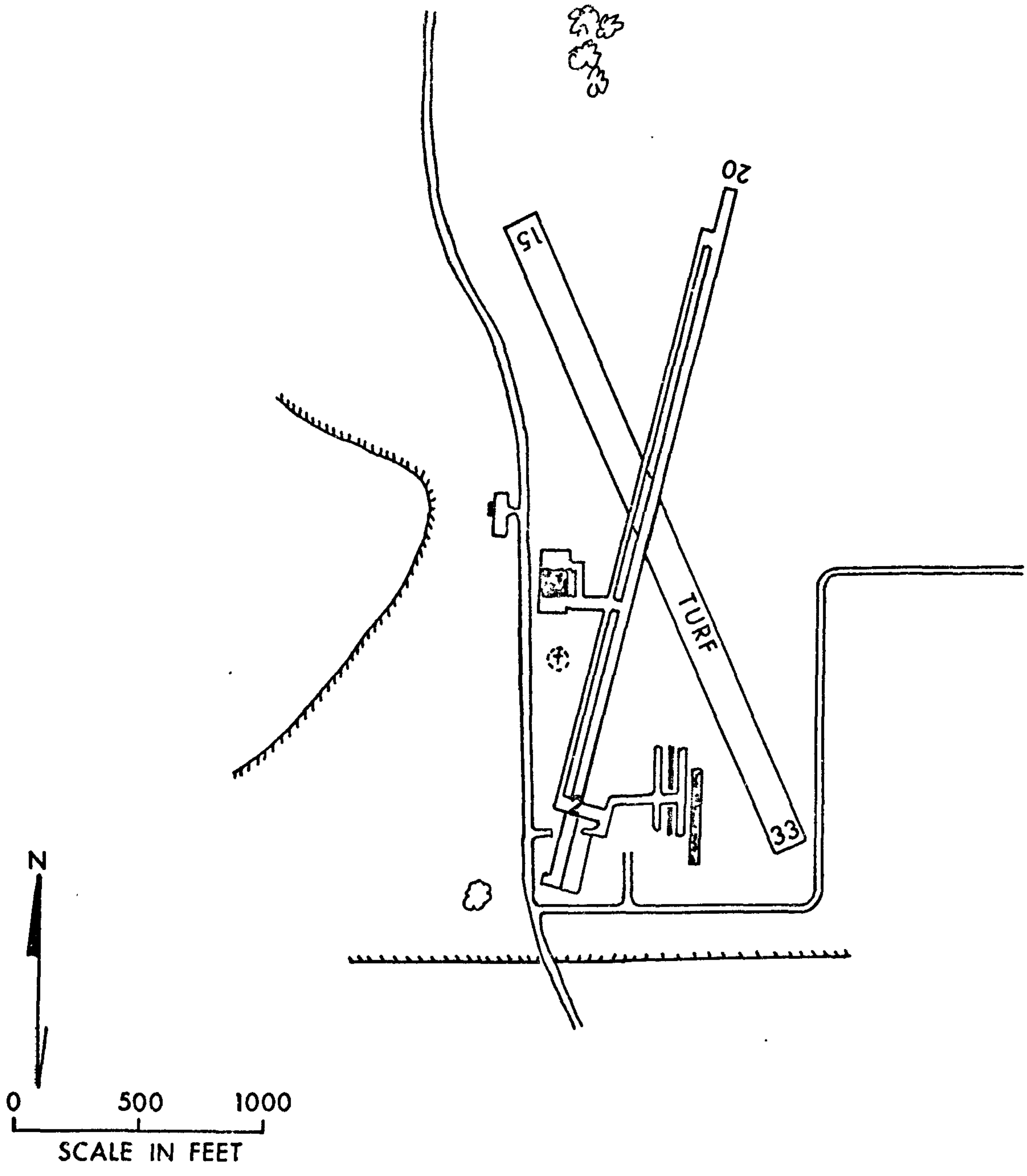

Figure 13. Diagram of Arrowhead Airport - grid element 2102

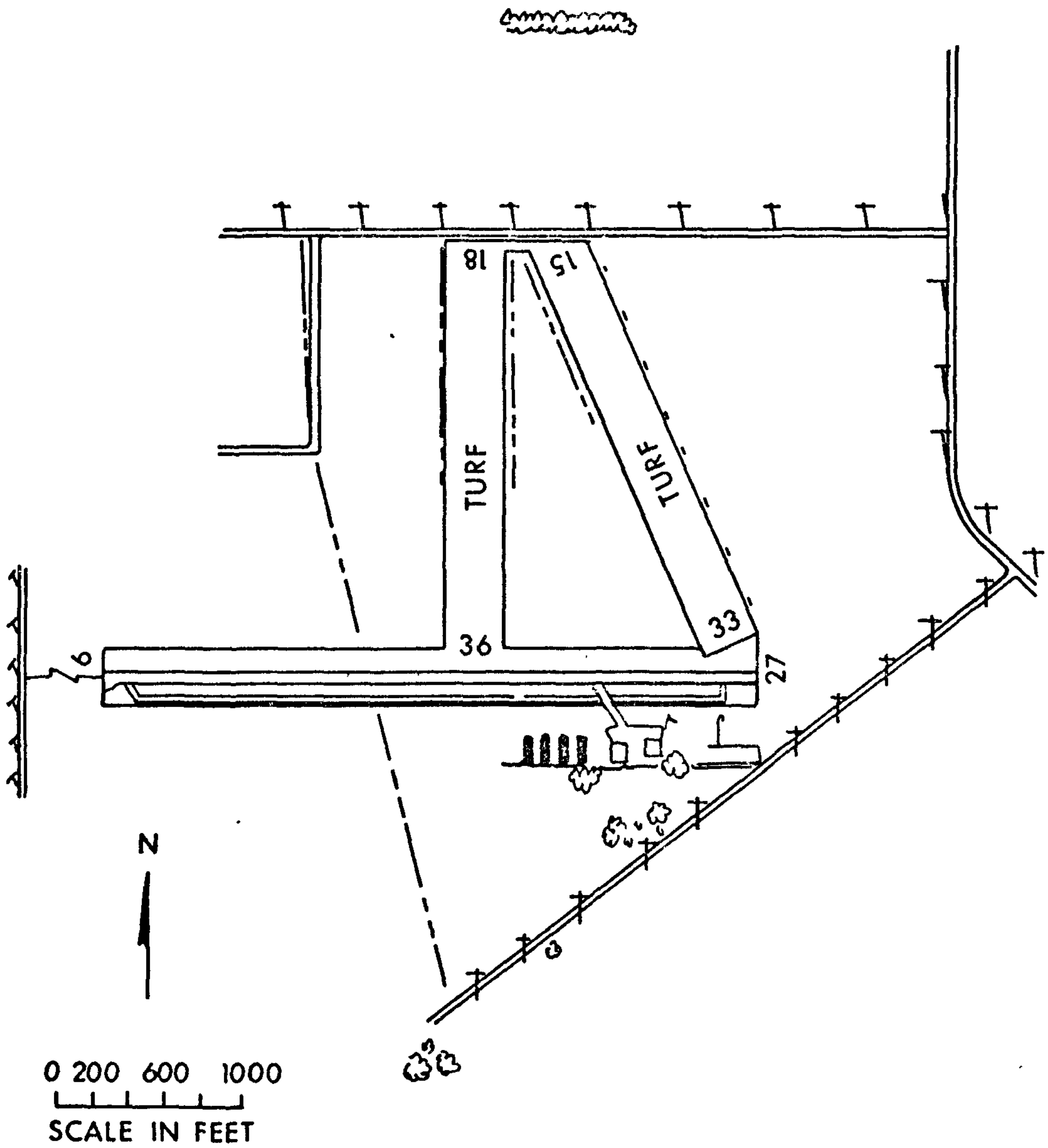

Figure 14. Diagram of St. Charles Airport - grid element 241

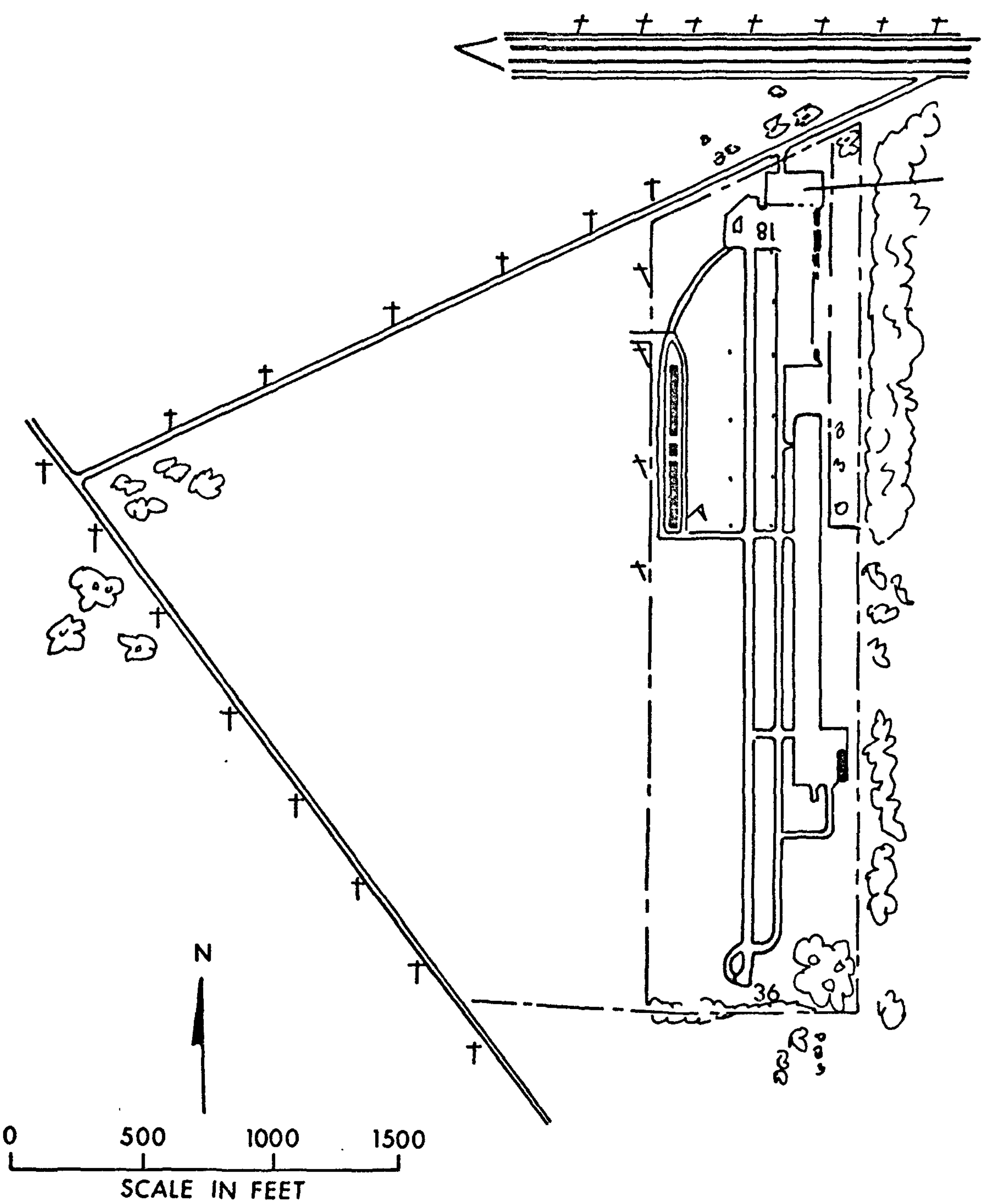

Figure 15. Diagram of Weiss Airport - grid element 2161

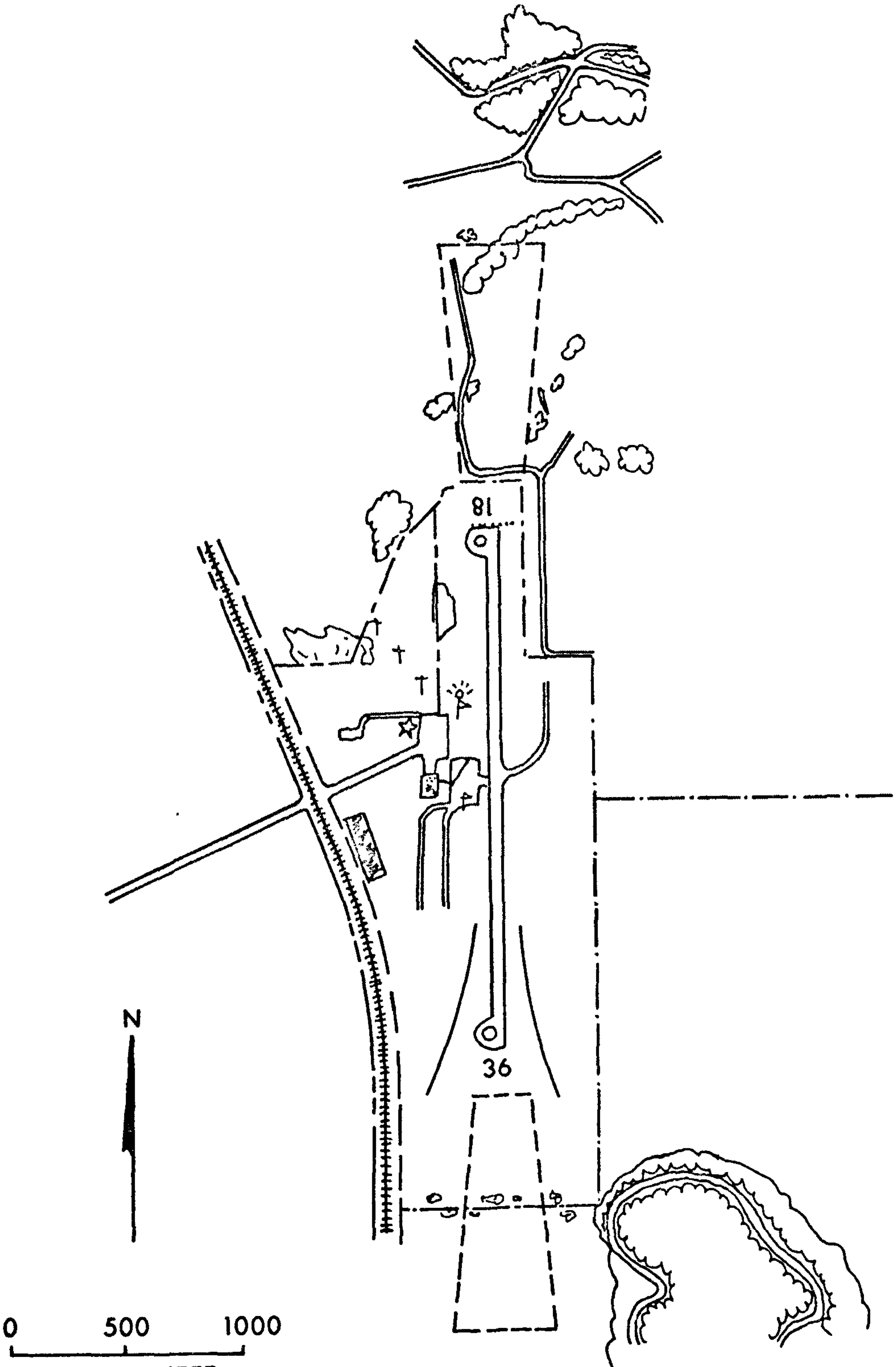

Figure 16. Diagram of Festus Airport - grid element 467

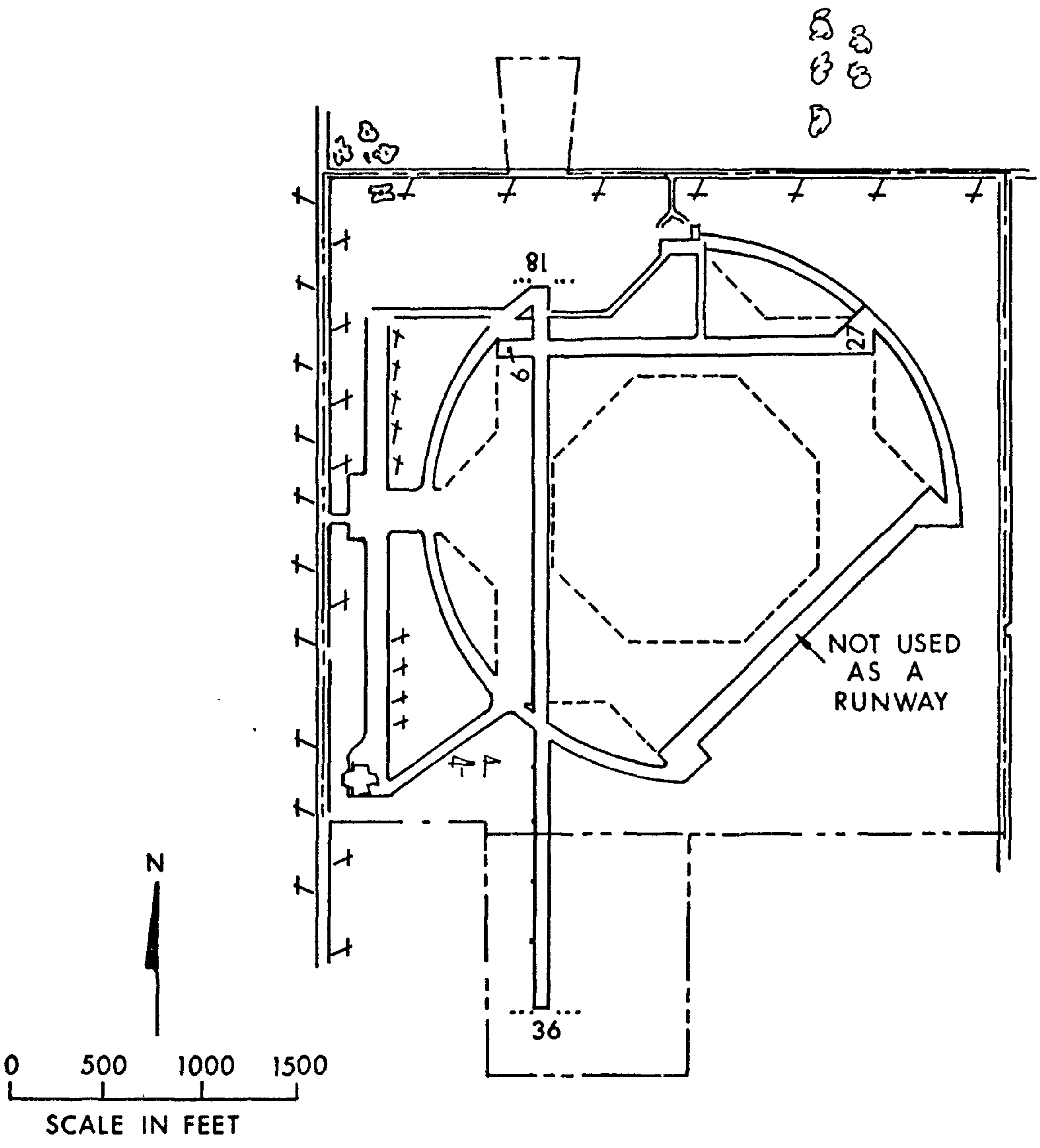

Figure 17. Diagram of St. Charles Smartt Airport - grid element 242

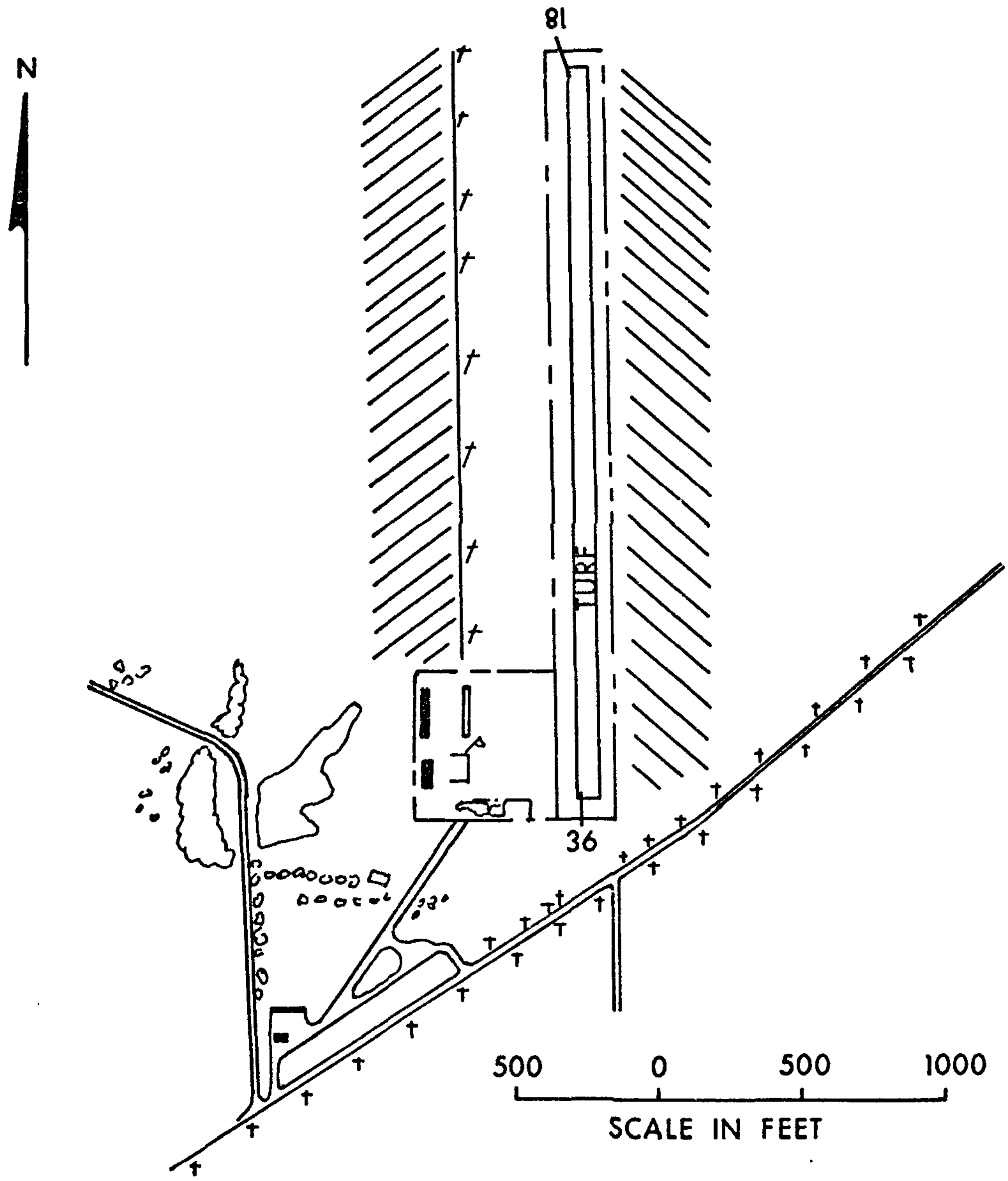

Figure 18. Diagram of Highland Airport - grid element 1709

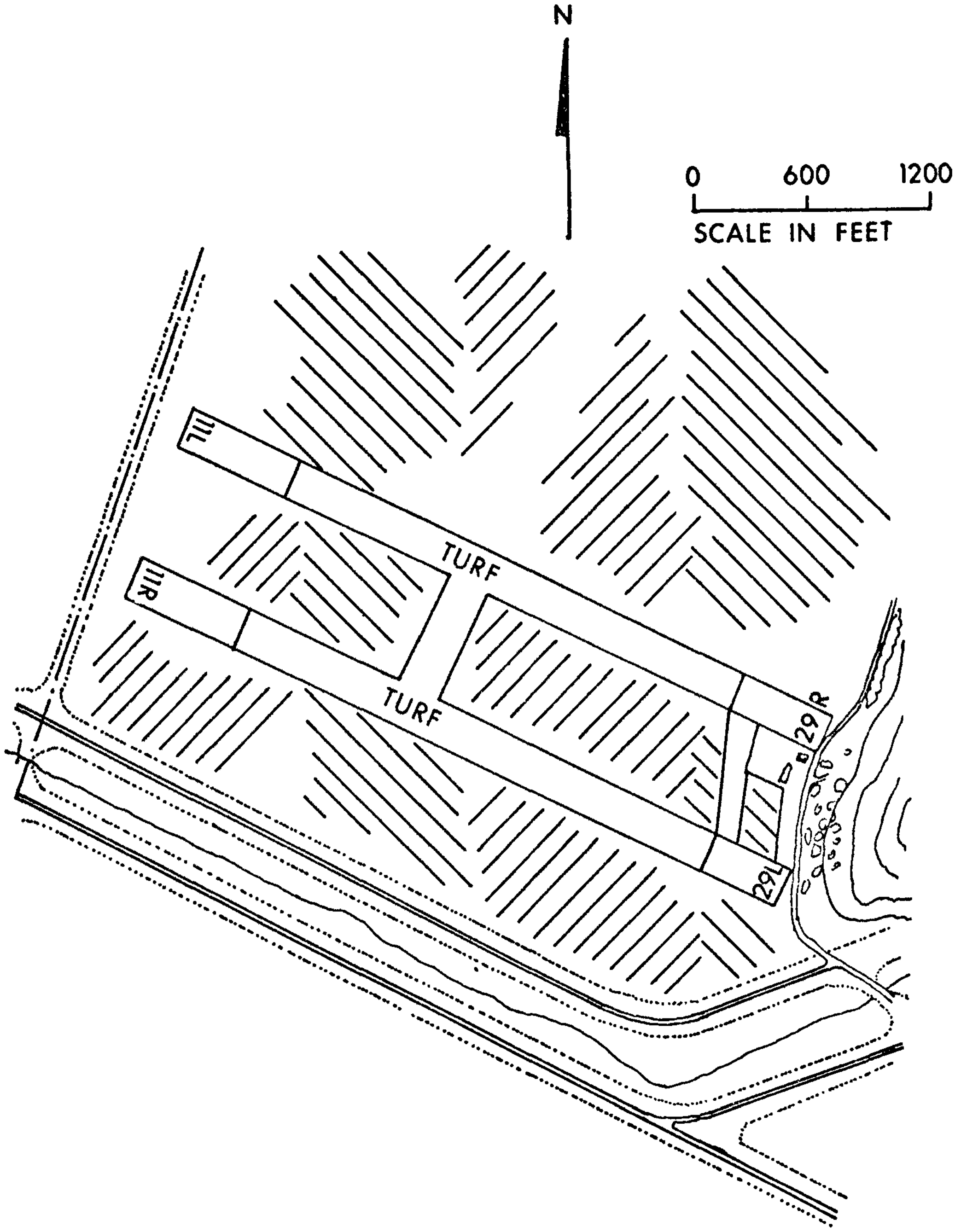

Figure 19. Diagram of Gebhardt Airport - grid element 883

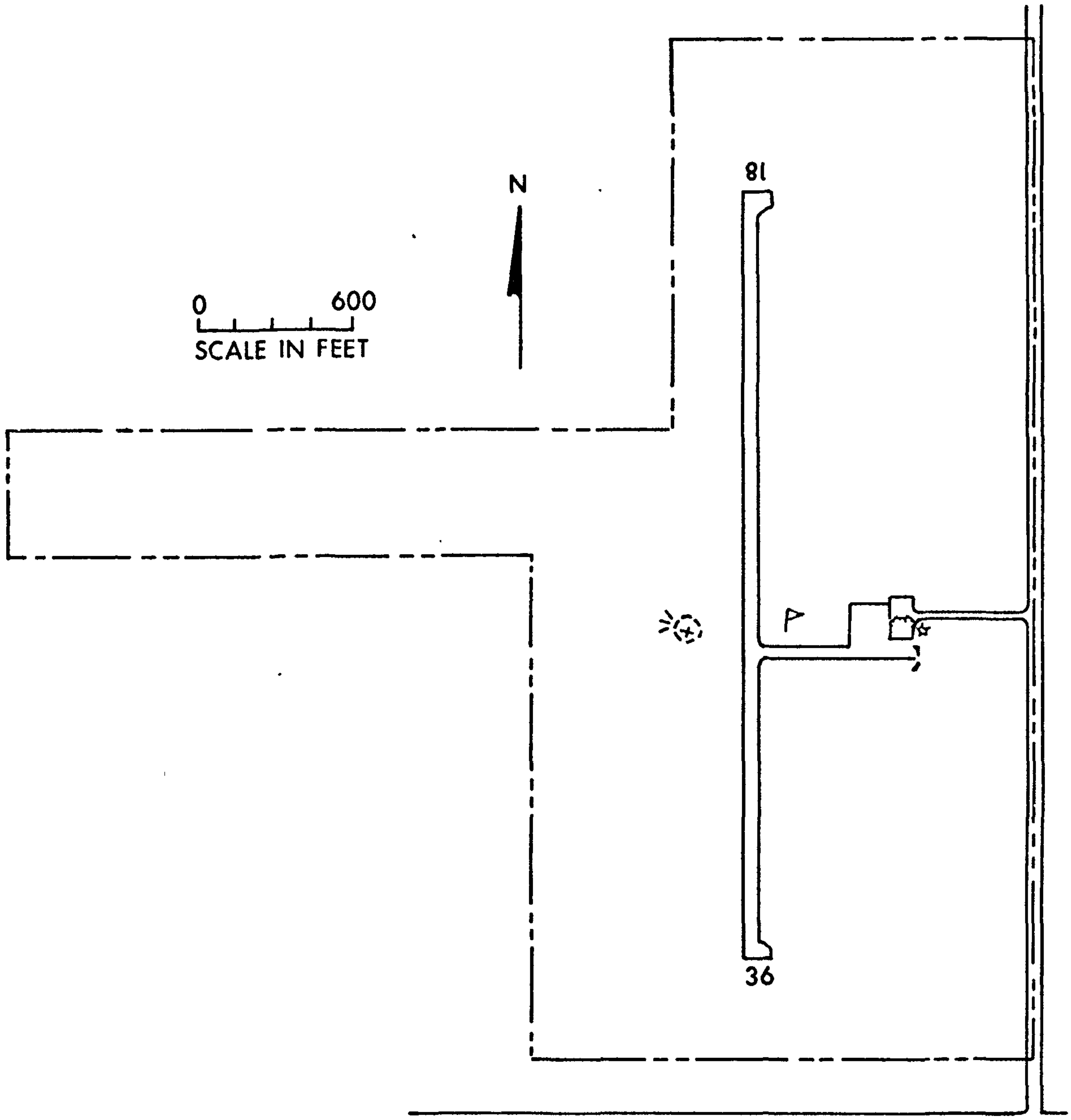

Figure 20. Diagram of Greenville Airport - grid element 1815

Table 47. TIMES IN MODE FOR GENERAL AVIATION AIRCRAFT AT CIVILIAN AIRPORTS

Mode	Time (minutes)
Idle	8.0
Taxi	8.0
Takeoff	0.3
Landing	0.3
Climbout	4.98
Approach	6.00

Table 48. ANNUAL VOLUMES OF FUEL SALES AT THE GENERAL AVIATION AIRPORTS

Airport	Annual fuel sales (1000 gallons)
Sparta	36
Greenville	15
Gebhardt	15
Highland	26
Bi-State Parks	350
Civic Memorial	350
Festus	42
Weiss	48
Creve Coeur	26
St. Charles	48
St. Charles Smartt	20
St. Clair	48
Arrowhead	48
Wentzville	15
Spirit of St. Louis	200

The emissions from one or two fueling trucks are negligible compared to emissions from automobile traffic, and hence ground service vehicle emissions (where they exist) will be excluded from the methodology for civilian airports.

FUEL STORAGE AND HANDLING

Fuel storage and handling losses are calculated as at Lambert and Scott. The working loss factor is 5 kg/1000 gallons. The general aviation airports were surveyed to determine their fuel sales. Table 48 shows the annual gallons of fuel pumped at each airport. These annual figures are converted to hourly volumes by applying the aircraft volume distributions of Tables 37, 38, and 39 as described previously for Lambert Field.

ENGINE TESTING AND MAINTENANCE

Engine testing and maintenance at the small airports is limited and sometimes non-existent. Predicting the occurrence or frequency of this emission source with any accuracy is unreasonable on an hourly basis. Because of this, and because this source is such a small contributor to emissions at these airports, emissions from engine testing and maintenance will not be considered.

SECTION VIII

METHODOLOGY SUMMARY

This section presents a "step-by-step" methodology for computing emissions at the airports in the St. Louis AQCR. It is based on the results of data collection from the individual airports. It is also based on an assessment of the amount of detail which can be extracted from available data and on the extent to which additional data can be reasonably and reliably collected in the field. The basic method by which emissions are estimated is to construct matrices and vectors of the applicable data and then to add and multiply these matrices and vectors so that the result is hourly emissions for each of the grid elements involved.

LAMBERT FIELD

Emissions From Aircraft Flight Operations

Step 1. Identify the month, day of the week, and hour of the day for which emissions are to be estimated.

Step 2. Determine the active runway from the wind direction and/or aircraft category.

Step 3. For the time identified (Step 1), determine the activity factors for the different aircraft types:

M_i = percent of annual volume occurring during the month (aircraft category i),

D_i = percent of monthly volume occurring on the given day of the week (aircraft category i),

H_i = percent of daily volume occurring during the hour of interest (aircraft category i).

Step 4. For the active runway determined in Step 2, locate the k grid elements through which aircraft pass.

Step 5. Determine the percent of activity due to takeoffs and the percent due to landings for the different aircraft types for the hour:

to_i = percent taking off (aircraft category i),

l_i = percent landing (aircraft category i).

Step 6. Compute the takeoff and landing volumes for the hour for each category as follows:

$$VTO_i = \frac{A \cdot M_i \cdot D_i \cdot H_i \cdot to_i}{(OD_M)(10^8)},$$

where:

VTO_i = number of takeoffs for aircraft category i

A = annual air traffic volume

OD_M = average occurrence of the day of the week during the month

= 4.43 for 31-day months

= 4.29 for 30-day months

= 4.00 for February (4.14 in a leap year)

10^8 = factor to convert percentages to decimals.

Likewise,

$$VL_i = \frac{A \cdot M_i \cdot D_i \cdot H_i \cdot l_i}{(OD_M)(10^8)}$$

Step 7. For the different aircraft categories, activity volumes, and grid elements identified above, determine the j engine operating modes for each grid element.

Step 8. Determine the time-in-mode for each aircraft category for each mode in each grid.

T_{jik} = time-in-mode j for aircraft category i in grid k.

Step 9. Identify the emission rates of the 1 pollutants, EF_{ilj}, of the different aircraft categories for the various engine operating modes.

Step 10. Estimate hourly emissions for aircraft category i for each pollutant and grid element as follows:

$$EAFO_{ikl} = (VTO_i \cdot EF_{ilj} \cdot T_{jik}) + (VL_i \cdot EF_{ilj} \cdot T_{jik})$$

Step 11. Compute hourly emissions from all aircraft in each grid element by repeating Step 10 for all categories:

$$EAFO_{kl} = \sum_i E_{ikl}$$

Emissions From Ground Service Vehicles

Step 12. Identify ground service vehicle requirements for each aircraft type in each grid.

GSV_{imk} = ground service vehicle of type m which is required by aircraft type i in grid k.

Step 13. Determine service times for each vehicle for each aircraft.

ST_{im} = service time of ground support vehicle type m for aircraft type i.

Step 14. Determine fuel consumption rates for the different ground service vehicles.

FC_m = fuel consumption rate for ground service vehicle type m.

Step 15. For each type of ground service vehicle, identify the emission rate as a function of fuel consumption.

ER_{ml} = emission rate of ground service vehicle type m of pollutant 1.

Step 16. Locate the k grid elements in which ground service vehicles operate.

Step 17. Compute hourly emissions in each grid from activity of ground service vehicle type m servicing aircraft type i.

$$EGSV_{imkl} = \frac{1}{2} V_i \cdot GSV_{imk} \cdot ST_{im} \cdot FC_m \cdot ER_{ml} ,$$

where:

$EGSV_{ik}$ = emissions of pollutant 1 from ground service vehicle type m in grid k, and

V_i = hourly volume of aircraft type i

= $VTO_i + VL_i$.

Step 18. Compute the total ground service vehicle emissions by grid by pollutant summing over all types of aircraft and ground service vehicles:

$$EGSV_{kl} = \sum_i \sum_m EGSV_{imkl} .$$

Emissions From Fuel Storage and Handling

Step 19. Locate grid elements in which fuel is stored or handled.

Step 20. Identify types of fuel and volumes stored.

Step 21. Determine the mean daily high, low, and medium temperature for the month of interest.

Step 22. Determine the working loss factors for each of the three temperatures.

Step 23. Determine the daily volume of fuel pumped.

Step 24. Distribute the daily volume over 24 hours according to the diurnal flight activity pattern.

Step 25. Compute working losses for the hour of interest according to the volume of fuel pumped and the temperature applicable to the time of day as:

$EFSH_{kl}$ = emissions of pollutant l in grid k due to fuel storage and handling.

Emissions From Engine Testing and Maintenance

The data required to compute these emissions are classified. However, they are judged to be negligible and are neglected.

SCOTT AIR FORCE BASE

Emissions From Aircraft Flight Operations

Step 26. Identify the day of the week and the hour of the day for which emissions are to be estimated.

Step 27. Determine the active runway from the wind direction and/or aircraft category.

Step 28. For the time identified (Step 26), determine the activity factors for the different aircraft categories (jet and piston):

D_i = percent of monthly volume occurring on the given day of the week (aircraft i),

H_i = percent of daily volume occurring during the hour of interest (aircraft category i).

Step 29. For the active runway determined in Step 27, locate the k grid elements through which aircraft pass.

Step 30. Compute the total takeoff and landing volumes during the hour as follows (assume 1/2 landing and 1/2 take-off):

$$V_i = \frac{M \cdot D_i \cdot H_i}{(OD_M)\ (10^4)} ,$$

where:

M = mean monthly air traffic volume.

Step 31. For the different aircraft categories, activity volumes, and grid elements identified above, determine the j engine operating modes for each grid element.

Step 32. Determine the time-in-mode for each aircraft category for each mode in each grid.

T_{jik} = time-in-mode j for aircraft category i in grid k.

Step 33. Identify the emission rates of the l pollutants, EF_{ilj}, of the different aircraft categories for the various engine operating modes.

Step 34. Estimate hourly emissions for aircraft type i for each grid element as:

$$EAFO_{ikl} = V_i \, EF_{ilj} \, T_{jik}$$

Step 35. Compute hourly emissions from all aircraft in each grid element by repeating Step 34 for all categories:

$$EAFO_{kl} = \sum_i EAFO_{ikl}$$

Emissions From Ground Service Vehicles

Step 36. Identify ground service vehicle requirements for each aircraft type in each grid.

GSV_{imk} = ground service vehicle of type m which is required by aircraft type i in grid k.

Step 37. Determine service times for each vehicle for each aircraft.

ST_{im} = service time of ground support vehicle type m for aircraft type i.

Step 38. Determine fuel consumption rates for the different ground service vehicles.

FC_m = fuel consumption rate for ground service vehicle type m.

Step 39. For each type of ground service vehicle, identify the emission rate as a function of fuel consumption.

ER_{ml} = emission rate of ground service vehicle type m of pollutant l.

Step 40. Locate the k grid elements in which ground service vehicles operates.

Step 41. Compute hourly emissions in each grid from activity of ground service vehicle type m servicing aircraft type i.

$$EGSV_{imkl} = 1/2\ V_i \cdot GSV_{imk} \cdot ST_{im} \cdot FC_m \cdot ER_{ml} ,$$

where:

$EGSV_{ik}$ = emissions of pollutant l from ground service vehicle type m in grid k, and

V_i = hourly volume of aircraft type i

= $VTO_i + VL_i$.

Step 42. Compute the total ground service vehicle emissions by grid by pollutant summing over all types of aircraft and ground service vehicles:

$$EGSV_{kl} = \sum_i \sum_m EGSV_{imkl} .$$

Emissions From Fuel Handling and Storage

Step 43. Locate grid elements in which fuel is stored or handled.

Step 44. Identify types of fuel and volumes stored. (Actual volume stored is classified. Assumed storage volume equals one month's supply at current usage rates.)

Step 45. Determine the mean daily high, low, and medium temperature for the month of interest.

Step 46. Determine the working loss factors for each of the three temperatures.

Step 47. Determine the daily volume of fuel pumped.

Step 48. Distribute the daily volume over 24 hours according to the diurnal flight activity pattern.

Step 49. Compute working losses for the hour of interest according to the volume of fuel pumped and the temperature applicable to the time of day as:

$EFSH_{kl}$ = emissions of pollutant l in grid k due to fuel storage and handling.

Emissions from Engine Testing and Maintenance

Step 50. Locate the grid elements in which engine testing occurs.

Step 51. Determine the testing schedule (frequency and times of occurrence) for the different types of engines tested.

Step 52. Determine testing cycle for each engine type.

TT_{jn} = time-in-mode j for engine type n.

Step 53. Apply the emission factors for the engine and modes to determine the emissions from engine testing:

$$EET_n = TT_{jn} EF_{jn} ,$$

where:

EET_n = emissions from testing engine type n.

Step 54. Determine the total emission factors from engine testing by summing over all engine types tested.

$$EET = \sum_n EET_n .$$

If engine testing occurs during specific hours, apply the emissions to these hours.

If it occurs randomly over a longer time period (e.g., an 8-hour working day, 24 hours, or a week), distribute the emissions equally over the time period.

CIVILIAN AIRPORTS

Emissions from Flight Operations at Controlled Airports

Step 55. Identify the month, day of the week, and hour of the day for which emissions are to be estimated.

Step 56. Determine the prevailing wind direction for the month.

Step 57. Determine the active runway from the wind direction and/or aircraft category.

Step 58. For the time identified (Step 1), determine the activity factors for the different aircraft types:

M_i = percent of annual volume occurring during the month (aircraft category i),

D_i = percent of monthly volume occurring on the given day of the week (aircraft category i),

H_i = percent of daily volume occurring during the hour of interest (aircraft category i).

Step 59. For the active runway determined in Step 2, locate the k grid elements through which aircraft pass.

Step 60. Compute the air traffic volume for the hour from:

$$V_i = \frac{A \cdot M_i \cdot D_i \cdot H_i}{(OD_M)\ (10^6)},$$

where the factors are defined in Steps 3 and 6 and the subscript i refers only to general aviation aircraft.

Step 61. For the different aircraft categories, activity volumes, and grid elements identified above, determine the j engine operating modes for each grid element.

Step 62. Determine the time-in-mode for each aircraft category for each mode in each grid.

T_{jik} = time-in-mode j for aircraft category i in grid k.

Step 63. Identify the emission rates of the 1 pollutants, EF_{ilj}, of the different aircraft categories for the various engine operating modes.

Step 64. Estimate hourly emissions for aircraft type i for each grid element:

$$EAFO_{ikl} = V_i \, EF_{ilj} \, T_{jik}$$

<u>Emissions from Flight Operations at Uncontrolled Airports</u>

Step 65. Determine the annual volume of air traffic from FAA Form 5010 and discussions with airport personnel.

Step 66. Determine the prevailing wind direction for the month.

Step 67. Determine the active runway from the wind direction and/or aircraft category.

Step 68. For the time identified for estimating emissions, determine the activity factors for the different aircraft types:

M_i = percent of annual volume occurring during the the month (aircraft category i),

D_i = percent of monthly volume occurring on the given day of the week (aircraft category i),

H_i = percent of daily volume occurring during the hour of interest (aircraft category i).

Step 69. For the active runway determined in Step 67, locate the k grid elements through which aircraft pass.

Step 70. Compute the air traffic volume for the hour from:

$$V_i = \frac{A \cdot M_i \cdot D_i \cdot H_i}{(OD_M)\ (10^6)} ,$$

Step 71. For the different aircraft categories, activity volumes, and grid elements identified above, determine the j engine operating modes for each grid element.

Step 72. Determine the time-in-mode for each aircraft category for each mode in each grid.

T_{jik} = time-in-mode j for aircraft category i in grid k.

Step 73. Identify the emission rates of the l pollutants, EF_{ilj}, of the different aircraft categories for the various engine operating modes.

Step 74. Estimate hourly emissions for aircraft type i for each grid element as:

$$EAFO_{ikl} = V_i\ EF_{ilj}\ T_{jik}$$

Step 75. Compute hourly emissions from all aircraft in each grid element by repeating Step 74 for all categories:

$$EAFO_{kl} = \sum_i EAFO_{ikl}$$

Step 76. Locate grid elements in which fuel is stored or handled.

Step 77. Identify types of fuel and volumes stored.

Step 78. Determine the mean daily high, low, and medium temperature for the month of interest.

Step 79. Determine the working loss factors for each of the three temperatures.

Step 80. Determine the daily volume of fuel pumped.

Step 81. Distribute the daily volume over 24 hours according to the diurnal flight activity pattern.

Step 82. Compute working losses for the hour of interest according to the volume of fuel pumped and the temperature applicable to the time of day as:

$EFSH_{kl}$ = emissions of pollutant l in grid k due to fuel storage and handling.

SECTION IX

IMPROVING ESTIMATES

Table 4 (page 2) displays the percent of emissions contribution by source at O'Hare Airport. Except for CO, aircraft are the predominate source of emissions, and even for CO they account for greater than two thirds. It is immediately evident then that an improved knowledge of aircraft operations will offer the most improvement in emissions estimation. There is the added benefit that a better knowledge of aircraft operations will improve the estimates for ground service vehicles and fuel handling and storage, since these depend ultimately on aircraft for their employment.

The first step would be to find precisely the volume and makeup of air traffic for a given hour. However, it is essentially impossible to predict accurately what will occur in a given hour. Since this probably accounts for the greatest uncertainty in the hourly emissions estimate, the greatest improvement would come about from actually gathering data during the period of interest.

After volume and makeup are known, the next important factor is time in mode, since this is the multiplying factor for a relatively constant emission rate for a given mode. There is not likely to be much variation in takeoff, climbout, approach, or landing times for a given type of aircraft, more variation will arise from idle and taxi time differences although even these were found to be fairly standard upon observation.

On this level of detail the actual pollutant for which emissions are being estimated becomes important. Idle and taxi modes have a relatively high emission rate for CO and hydrocarbons; NO_x emissions are higher during takeoff, climbout, and approach; and CO and NO_x emissions are high during landing.

Airport emissions cannot be precisely estimated due to all the influencing factors described in Section III. It is felt that the methodology given in this report strikes a good balance between maximum potential accuracy and the rapidly increasing level of effort required as estimates become incrementally more precise.

SECTION X

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