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Air Pollution Mitigation Measures for Airports and Associated Activity

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

AIR RESOURCES BOARD
Research Division

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Final Report

Contract No. A132-168

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ABSTRACT

The growth of air travel in California is becoming a concern for air quality planners. Air travel throughout the U. S. has grown more than 5% per year for the past decade and that growth is expected to continue. California has become one of the fastest growing air transportation links to the Pacific Rim, pushing its average growth even higher. This has resulted in airport-related activity becoming an increasing component of the state's emission inventory.

This report is a reference guide to emission mitigation techniques that can be applied to aircraft and their operations, the ground support equipment that service aircraft at airports, and other airport on-road and off-road emission sources such as maintenance, passenger, and employee vehicles. Each measure is described along with guidelines for its use and constraints that may limit its effectiveness. The information in the report can be used to quantify emission reductions that result from operational, procedural, or technological changes to these sources. Projects and plans to reduce air pollution at U. S. and European airports are described. A detailed description of procedures used to calculate aircraft emissions is provided in an appendix.

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maintenance operations, air freight/cargo companies, parking facilities, federal, state, and local aviation agencies, and construction projects, which support the airport. The last category also includes stationary emission sources like boilers for power and heat. Since stationary sources generally are covered by existing environmental regulations, which require permits and controls for some sources, this report focuses on mobile sources at airports. Because of the different operations and emissions sources associated with aircraft, GSE, and landside vehicle activity it is useful to analyze them independently.

The report discusses the three categories of airport activity and possible emission mitigation methods for each. In general, this report is organized as a reference document for evaluating mitigation methods that can be applied to the various emissions sources. Section 2 of the report discusses approaches for mitigating air emissions in general and describes some sources of information on these measures. Section 3 focuses on aircraft emissions, Section 4 on ground support equipment, and Section 5 on the airport landside operations. Section 6 describes actions some airports already have taken. Figure 1-1 summarizes the mitigation measures covered by Sections 3, 4, and 5 of the report.

FIGURE 1-1
Mitigation Measures For Airport Sources

Mitigation Measure	Benefit Desired	Primary Pollutants Affected	Responsible Party
Single/reduced engine taxing	Reduce engine idle time	HC, CO	Airlines
Reduce reverse thrust use	Reduce high power engine operation	NO_x	Airlines
Tow aircraft to runway	Reduce engine idle time	HC, CO	Airports/ Airlines
Take passengers to aircraft parked near runway	Reduce engine idle time	HC, CO	Airports
Reduce airport airside congestion	Reduce engine idle time	HC, CO	Airports/ FAA
Modernize fleet	Decrease fleet engine emissions	HC, CO	Airlines
Establish new engine emission standards	Reduce aircraft engine emissions	NO_x	EPA/FAA
Derate takeoff power	Decrease engine emissions at high power	NO_x	Airlines
Use larger aircraft	Reduce LTOs	HC, CO, NO_x	Airlines
Increase load factor	Reduce LTOs	HC, CO, NO_x	Airlines
Limit number of operations	Reduce LTOs	HC, CO, NO_x	FAA/EPA
Manage fleet	Increase seats per LTO	HC, CO, NO_x	Airlines
Provide central ground power and air	Reduce aircraft engine idle time	HC, CO	Airports/ Airlines
Alternative fuels for GSE	Reduce GSE emissions	HC, CO, NO_x	Airports/ Airlines
Employee VMT reduction TCM	Reduce VMT	HC, CO, NO_x	Airports
Passenger VMT reduction TCM	Reduce VMT	HC, CO, NO_x	Airports
Idle and circulation management TCM	Reduce vehicle emissions	HC, CO, NO_x	Airports
Alternative fuels for rental cars	Reduce vehicle emissions	HC, CO, NO_x	EPA/ARB
Alternative fuels for heavy duty commercial vehicles	Reduce vehicle emissions	HC, CO, NO_x	EPA/ARB

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When evaluating mitigation methods, there are various approaches for reducing emissions. They could include capturing or controlling emissions directly, reducing the emissions rate, reducing activity of the source, or improving the system efficiency. Each of these approaches are considered and included in the measures discussed in this report.

This section discusses aircraft, GSE, and vehicles as emission sources generally. Specific measures that apply to each source type are discussed in more detail in subsequent sections. The last part of this section discusses some other sources of information on mitigation methods.

2.1

Aircraft Emission Sources And Pollutants

To decide the types of mitigation measures to consider, it is important to understand the source or cause of emissions of different pollutants. This section briefly describes the various emission sources associated with aircraft and related activity.

Air emission inventories for aircraft use a landing and take off (LTO) cycle as their basis. An LTO includes the aircraft operation from the time the aircraft starts its engines, taxis to the runway, takes off, and climbs out toward cruise altitude as well as the approach, landing, and taxi in to the gate where the engines are shut down. HC and co emission indexes are very high during the taxi/idle operations when aircraft engines are at low power and operate at less than optimum efficiency. These emissions fall, on a per pound of fuel basis, as the aircraft moves into the higher power operating modes of the LTO cycle. Thus, operation in the taxi/idle mode, when aircraft are on the ground at low power, is a significant factor for HC and CO emissions. When considering mitigation methods for HC and CO, the objective is to minimize the aircraft operation at idle and low power taxi.

When calculating hydrocarbon emissions it is preferable to quantify individual compounds rather than total organics, however, little data on organic speciation is available for aircraft engines. Two potential sources for speciation profiles are EPA's *Air Emissions Species Manual, Volume 1, Volatile Organic Compound Species Profiles* and ARB's *Identification of Volatile Organic Compound Species Profiles*, 2nd Edition, August 1991. The speciation profiles for aircraft engine exhaust in current versions of these reports, however, are not well developed. Additional research and testing under realistic conditions will be required to refine these profiles.

NO_X emissions are low when engine power and combustion temperature are low but increase as the power level is increased and combustion temperature rises. Therefore, the takeoff and climbout modes have the highest NO_X emission rates.

Particulates form as a result of incomplete combustion. Particulate emission rates are somewhat higher at low power rates than at high power rates since combustion efficiency improves at higher engine power. Particulate emissions are highest during takeoff and climbout, however, because the fuel flow rate also is high. Very little is known quantitatively about particulate emissions from aircraft engines. As a result, particulate emissions from aircraft engines are not covered by this report.

In addition to knowing how pollutants are emitted from aircraft, it is important to antici-

— SECTION 1 —

Air Pollution Mitigation Measures For Airports And Associated Activity

1.1

Introduction

Growth in air travel in the U.S. has averaged more than 5% per year for the past decade. The growth in California has even been higher since it is the U.S. gateway for travel to Asia, the fastest growing segment of international air travel. And the growth rate is not expected to diminish much during the 1990s. To accommodate this growth several California airports have plans to expand their runways, their facilities, or both. San Francisco, Oakland, San Jose, LAX, Ontario, and Palmdale all have major construction projects either underway or in design. Robust growth of this sort can lead to congestion on both the airport airside and landside. Aircraft may wait in line to take off and, upon arrival, wait for an empty gate. During peak periods, passenger traffic to the airport can overload access roads and parking facilities as well. Construction, congestion, and increased activity all result from growth and the net effect of this growth on air quality is that emissions of hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_X), and particulates from activities on and adjacent to California airports are a growing part of the state's emission inventory.

While airport activities and emissions are increasing, California is limited in its ability to mitigate the emissions. Particularly on the airside of the airport, the state has limited jurisdiction to require technology standards or to set limits on emission rates. As current programs to control emissions from stationary and mobile sources advance, airports may be left as one of the few targets for further emissions reductions. This report identifies air pollution mitigation measures that may apply to airports and describes their use and the possible benefits derived from them.

1.2

Report Organization

There are three areas of activity at an airport that are important from an emissions standpoint: the aircraft operations, the ground support equipment (GSE) that service the aircraft while it is at the gate, and other activities that relate directly or indirectly to the operation of an airport. The first two categories of sources are considered part of the airport airside operations. The last category is the airport landside operations including airport-related activities. Included in this last category are the activities of the airport tenants such as food service providers and caterers, rental car agencies, airline have tailpipe, evaporative, and crankcase hydrocarbon emissions. NO_X and particulates also are emitted from the tailpipe although the particulate emissions are minimal.

Aircraft ground support equipment include the following types of vehicles:

- baggage tractors
- aircraft tractors
- ground power units
- air-conditioning units
- air start units
- baggage conveyors
- other secondary GSE

Of these, the engine air start units utilize the largest engines (350 to 460 HP), while all others generally use engines ranging from 50 to 250 HP. A significant percentage of the smaller engines are gasoline powered; only the larger engines tend to be diesel, and even these engines are sometimes run on Jet A (kerosene jet fuel). At some California airports, notably LAX, the airlines have begun to phase out the gasoline powered equipment for LPG-fueled units.

The set of equipment that are certified to on-highway standards are buses, cars, pickup trucks, and vans. These vehicles may see operation both inside and outside airports. Firefighting equipment usually is kept ready for service and generally use on-highway certified engines.

Another set of equipment are not related to aircraft operations but to airport operations. Most airports maintain some construction equipment for emergency repairs or normal runway maintenance. In addition, runway and apron sweepers and airfield inspection carts often are used. Cargo operations in major airports use cranes and forklifts to manage and store cargo in airport warehouses. In a few airports in California, special snow clearance equipment (blowers, front-end loaders) may be used.

Among the mitigation measures appropriate for ground support equipment, ARB is already acting on imposing emission standards on off-highway engines. Other mitigation measures include:

- Installation of centralized air and electrical ground power at each gate area
- Electrification of ramp service (food, cargo, water/sewage) vehicles
- Use of alternative fuel engines on airport service vehicles such as sweepers, baggage, and tractors.

2.3

Emissions From Airport Related Activity

Emissions from vehicular traffic through the airport and nearby areas are a very large contributor to airport HC and NO_X emissions. Vehicle activity includes:

- Private vehicles dropping off and picking up passengers
- Public transit vehicles (buses and vans) offering connections to downtown and suburban locations
- Shuttle buses for car rental, off-airport parking and hotel pickup
- Cargo vehicles for delivery of luggage, express mail and bulk air cargo
- Construction vehicles for supporting off-airport building, commercial and industrial development

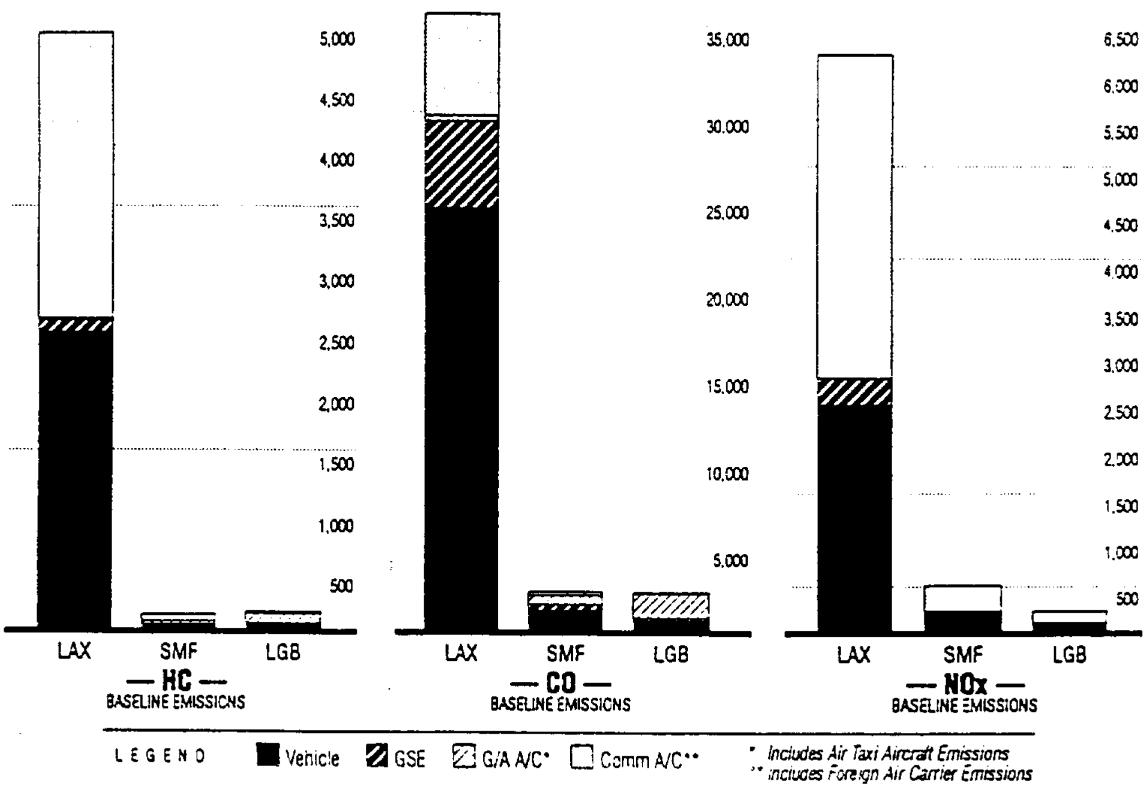
Except for the last category, all of the vehicles involved are certified to on-highway standards. A large number of mitigation actions can be taken to address vehicular activity in each category. The reduction of vehicle trips falls under the cat-

SECTION 2:

Approach To Mitigating Air Emissions

When considering approaches to mitigate emissions at airports it is important to understand the relative sizes of the sources. Figure 2-1 summarizes the 1990 emissions of commercial and general aviation aircraft, GSE, and light duty vehicles for a large, medium, and small commercial airport in California: Los Angeles International (LAX), Sacramento Metro (SMF), and Long Beach (LGB) respectively. These emission summaries were computed as reference values to evaluate the potential benefits of various mitigation measures. They portray a range of airport sizes and are used illustratively. They are not intended to be considered baseline emissions for these airports.

FIGURE 2-1
Airport Reference Emissions – 1990
— EMISSIONS IN TONS PER YEAR —



Individual Airports

Airports themselves are a valuable source of information. Airport managers and airport master plans can provide information about expansion plans, scope of construction projects, and anticipated changes within the airport and airport vicinity. They typically are more familiar with emission mitigation measures that affect the airport as a whole, such as ground transportation measures.

Open Literature

Open literature is a limited source of information. General discussions of airside measures can be found in several magazines, such as *Aviation Week & Space Technology* and *AIRPORT Magazine*. Literature also is available that addresses transportation control measures like carpooling and vanpooling, transit, parking, and user fees.

2.5

Report Scope

This report includes a review of the mitigation measures that may apply to airport airside and landside emission sources. It is organized as a reference manual for mitigation measures. Section 3 describes measures that apply to aircraft, Section 4 describes measures that apply to ground support equipment, and Section 5 describes measures that apply to the airport landside and related activities. Information provided for each measure includes a definition, guidelines on how it should be applied, data that is required to evaluate its use, and when it can be most effective. Sample calculations showing its use are provided where helpful, and references for further information are listed.

This is an overview report. As described in the individual sections, data used for sample calculations come from various sources, which are believed to be reasonable but may not be representative of actual operations at all California airports. Also some calculations use EPA-defined default values, which are not ARB-approved default values. The reader is cautioned to use actual data, specific to local conditions and individual airports, when evaluating mitigation measures for a specific location. Each section discusses sources of information to guide the reader in locating the appropriate data. Appendix F also references several data sources.

pate changes to the overall fleet since newer aircraft generally have lower HC and CO emissions and higher NO_X emissions. There are two primary factors driving the changes to the fleet: noise regulations and growth. National noise regulations call for the phase out of older aircraft, which typically have old, loud engines, by the end of this decade. These are known as Stage II aircraft. The newer, Stage III aircraft have newer, high-bypass engines, which are not only quieter, but emit less HC and CO. As Stage III aircraft replace Stage II, the average emissions of these pollutants for the fleet declines. The one exception to this is when airlines buy "hushkits" which muffle the noise from the low-bypass engines but do nothing to affect emissions directly. These kits enable the older, dirtier engines to remain in service longer. While the growth curve for air travel has flattened during the present recession most analysts expect continued robust growth throughout the 1990s. This will stimulate continued modernization of the U.S. fleet, which must be considered when evaluating alternative emission mitigation methods.

Mitigation measures that are targeted to HC and CO emissions usually focus on relieving congestion on the airside of the airports since congestion causes aircraft to sit on taxi-ways with engines running. Congestion relief measures discussed in the next section of the report include:

- improvements to the layout of taxi-ways on the airport
- upgraded instrumentation and air traffic control procedures to minimize spacing between incoming aircraft and to better coordinate landings and takeoffs
- controlling aircraft departures through gatehold procedures
- transporting passengers to aircraft parked close to runways.

HC and CO mitigation measures that do not relate to airport airside congestion include:

- single-engine or reduced engine taxiing
- provision of ground-based electricity and preconditioned air so APU (Auxiliary Power Unit) operation is unnecessary.

Mitigation measures that address NO_X are much more limited because takeoff and climbout times are relatively short and must take place at very narrow engine power ranges. Probably the best mitigation methods relate to engine design changes, however, states do not have the authority to dictate such changes. Other alternatives include:

- derated takeoff
- limiting the number of operations allowed
- encouraging the use of larger aircraft, which move more people into and out of the airport with each LTO.

These and other mitigation measures are discussed in Section 3.

2.2

Aircraft Service Equipment Emission Sources And Pollutants

A wide variety of equipment are used in ground support to aircraft operations and they are needed to move, service, load, fuel and power the aircraft. Three distinct categories of equipment for emissions purposes include: mobile equipment with engines certified to on-road emissions standards, mobile equipment that currently are unregulated, and transportable equipment that currently are unregulated. These equipment

3.1.1

Sources of Information on Emission Mitigation Measures

Various information sources are available on aircraft mitigation measures. General information on mitigation measures in use or proposed for use at U.S. airports is available from government documents (EAs, EISs, and EIRs), airport management, airlines, and open literature. Airport and airline staff are responsible for implementing most aircraft mitigation measures. Airport activity and operational data is available from airport management, airlines, and government documents, and publications. Airport management generally can provide airport specific information including the total number of LTOs, aircraft landing weights and fees, and apron and airfield procedures. Airline specific data such as number of LTOs, time-in-modes, load factors, GSE population and use, aircraft/engine combinations, and airline policies are tracked by individual airlines. FAA publications, including *Airport Activity Statistics of Certificated Route Air Carriers*, *FAA Air Traffic Activity*, and *FAA Statistical Handbook of Aviation*, contain data on aircraft models and number of LTOs for airports with FAA control towers, which includes most U.S. airports with commercial air traffic. Valuable sources of current and planned airport projects include EAs, EISs, EIRs, airport management, airlines, and magazines. Specific information sources for evaluating some mitigation measures are discussed later.

TABLE 3-1
Potential Measures for Use with Aircraft

Objective	Measure	Primary Pollutants Affected
Decrease Engine Operation	• Single/reduced engine taxing	• HC, CO
	• Reduce use of reverse thrust	• NO_x
Decrease Times in Mode	• Tow aircraft to runway	• HC, CO
	• Take passengers to aircraft parked near runway	• HC, CO
	• Reduce airport congestion	• HC, CO
Decrease Fleet Average Engine Emission Factors	• Modernize fleet	• HC, CO
	• Establish new engine emission standards	• HC, CO, NO_x
	• Derate takeoff power	• NO_x
Decrease LTOs	• Use larger aircraft	• HC, CO, NO_x
	• Increase load factor	• HC, CO, NO_x
	• Limit number of operations directly	• HC, CO, NO_x
Increase Number of Seats	• Manage fleet	• HC, CO, NO_x

TABLE 3-2
Basic Calculation Procedures For Aircraft Emissions

$$E_{ij} = \Sigma (TIM_{jk}) * (FF_{jk}/1000) * (EI_{ijk}) * (NE_j)$$
$$ET_i = \Sigma (E_{ij}) * (LTO_j)$$

Where:

- E_{ij} = total emissions of pollutant i, in pounds, produced by aircraft type j for one LTO cycle
- TIM_{jk} = time in mode for mode k, in minutes, for aircraft type j
- FF_{jk} = fuel flow for mode k, in pounds per minute, for each engine used on aircraft type j
- EI_{ijk} = emission index for pollutant i, in pounds of pollutant per one thousand pounds of fuel, in mode k for aircraft type j
- NE_j = number of engines used on aircraft type j
- ET_i = total emissions of pollutant i, in pounds, produced by all aircraft operating in the region or airport of interest
- LTO_j = number of landing and takeoff cycles by aircraft j for the time period of interest.
- i = hydrocarbon, nitrogen oxides, or carbon monoxide
- j = A320, B757, MD11 for example
- k = taxi/idle out, takeoff, climbout, approach, taxi/idle in

(For more information on this procedure, see Appendix A)

egory of Transportation Control Measures (TCM). Reduction of vehicle emissions can involve switching to alternative fuels or entirely replacing vehicles with electrified light rail. TCM's reduce vehicle trip activity and the net reduction in number of vehicles results in decreased congestion, and this in turn reduces emissions of the vehicles operating in the airport. Private (non-commercial) automobile traffic is a primary target for TCM's, since other strategies such as conversion to alternative fuel use is far more difficult to implement. Candidate strategies for vehicles include:

- ridesharing (car and vanpooling)
- transit encouragements
- remote and close in park and ride
- telecommuting
- variable work hours
- parking management and pricing.

2.4

Sources Of Information On Mitigation Measures

This section summarizes some of the sources of information that are available on the use of emissions mitigation measures and the data needed to assess their benefits. Sources of information include: government agencies and documents, individual airports, and open literature. Additional information on some of these sources is discussed under the specific measures in later sections of the report. Appendix F lists references used in developing this report. A table cross-referencing the sources and applicable mitigation measures appears on page F-1.

Government Agencies and Documents

The Federal Aviation Administration (FAA) publishes numerous documents on airport and aircraft activity. One document that is required by the FAA for construction of new airports as well as major airport expansions is an Environmental Assessment (EA). An EA is prepared by the organization advocating the construction project and considers the potential environmental impacts. The completed document is reviewed by local, state, and federal government agencies. An Environmental Impact Statement (EIS) is developed from an EA by adding sections that cover specific steps in the planning process. Many EAs and EISs address air quality and emissions, listing background data, air pollution mitigation measures, and the effect of measures on air quality. Generally, an EA and EIS will contain both airside and landside air pollution mitigation measures. EISs recently have been prepared for new airports in Dallas (Alliance Airport, dedicated to cargo/ industrial activity) and Denver, and airport expansions at the Dallas/Ft. Worth, O'Hare, and Pittsburgh International Airports.

The U.S. Environmental Protection Agency (EPA) publishes guidance and data compilation documents such as *Procedures for Emission Inventory Preparation and Compilation of Air Pollutant Emission Factors*. These documents are an excellent source of emission factors and calculation methodology.

Many state and local government agencies publish documents and require reports similar to an EIS. Environmental Impact Reports (EIR) are prepared in accordance with California Environmental Quality Act Statutes and Guidelines. Several EIRs have been prepared for California airports with expansion plans or active projects such as those for Los Angeles, Ontario, Burbank, Palmdale, San Jose, San Francisco, and Oakland Airports.

3.2

Measures

This section discusses air emission mitigation measures that potentially can apply to aircraft. A description of each measure is followed by a discussion of constraints, applications, key inputs, and sample calculations. Where feasible and appropriate a calculation procedure for determining emission reduction benefits and direct and indirect implementation costs is described. The emissions reduction benefit is supplied where possible. Costs are highly site-specific and are not calculated here so as not to mislead the reader. Finally, references for further information and variations of the measure are provided. Under the discussion of implementation feasibility, a responsible party is identified. Generally, airlines are responsible for aircraft operational issues, airports are responsible for airport facilities, FAA is responsible for aircraft procedural issues, and EPA is responsible for environmental regulations, although responsibility is shared for some measures. This evaluation does not constitute a legal opinion on the authority of these parties to implement these measures. Reference and variation information is not comprehensive. Also, the measures, discussed in the report include those that are believed to have a significant impact on air quality. Emission benefits may be obtained by other methods or procedures as well. For example, where aircraft can roll onto a runway from the taxiway and takeoff without stopping, emissions will be lower than they would be if the aircraft came to a stop before initiating its takeoff roll. This and other measures generally will have smaller air quality benefits than those discussed in the report and consequently have not been analyzed in detail.

3.2.1

Single/Reduced Engine Taxiing

This measure reduces engine operating time at idle.

Large commercial aircraft have two, three, or four engines. Since low thrust is needed to taxi an aircraft, one or more engines can be shutdown during taxi. Not only does shutting down an engine reduce the emissions from the engine(s) shutdown, the remaining engine(s) operates at higher RPM. This results in more efficient operation and lowers the HC and CO emissions per pound of fuel consumed. It also results in higher engine exhaust velocity. Single/reduced engine taxiing, which also is referred to as engine-out taxiing, only affects the taxi mode emissions. In addition to emission reduction benefits, this measure also may conserve fuel.

Constraints

Some constraints such as the number and placement of engines on an aircraft type, narrow or contaminated ramps and taxiways, and bad weather limit the use of single/reduced engine taxiing. Also, immediately prior to takeoff, all engines must run for at least two minutes to achieve thermal stability. Two minutes operation at idle also is necessary for engine cool down.

Large commercial aircraft have two, three, or four engines that can be mounted in various combinations on the wing of an aircraft or rear-fuselage. The engine(s) that remains running during single/reduced engine taxiing must enable the pilot to operate the aircraft safely and with adequate control. For some aircraft, reduced engine taxiing results in power being supplied from only one side of the aircraft. When the power is unbalanced, the pilot uses the brakes to control and

SECTION 3:

Measures For Mitigating Emissions From Aircraft Operations

3.1

Introduction

Aircraft operating at commercial airports include large commercial jets, smaller commuter aircraft powered by turboprop engines, piston-engined general aviation aircraft, and other miscellaneous aircraft. A variety of military aircraft also operate at some commercial airports in addition to their operations at military airbases. This section primarily focuses on measures that may apply to commercial jets since their emissions represent the largest portion of the total aircraft emissions inventory. Obtaining data to assess the effect of these measures on smaller aircraft, particularly general aviation aircraft, is more difficult. Where measures are appropriate for mitigating emissions of other classes of aircraft, their relevance is discussed.

Large aircraft have two sources of air emissions: the engines and the auxiliary power unit (APU). The engines are a much larger emissions source than the APU. The traditional way to consider aircraft emissions is pounds of pollutant emitted per LTO (landing and take off cycle). An emissions inventory (pounds emitted) then is a function of:

- number of engines in operation during each mode of the LTO (taxi out, take-off, climbout, approach, taxi in),
- time the aircraft operates in each mode,
- emission factors for the aircraft engines during each mode,
- number of LTO cycles,
- emission factors for the APU, and
- APU operating time during each LTO cycle.

Since a commercial airline's purpose is to transport passengers (and freight, to a lesser extent), however, another way to evaluate the emissions generated at an airport is to consider pounds of pollutant emitted per passenger. In addition to the factors listed above, emissions per passenger is a function of:

- number of seats on individual aircraft and
- number of actual passengers per aircraft (passenger load factor).

On this basis, there are several possible approaches to mitigating emissions from aircraft. Table 3-1 summarizes mitigation measures that address these specific factors. Table 3-2 shows the equations used to calculate aircraft emissions. Additional details on quantifying emissions can be found in a document called *Procedures for Emission Inventory Preparation, Chapter 5 - Aircraft*, which is published by EPA and is included in Appendix A: Data Required to Evaluate Aircraft Measures. Calculations of aircraft emissions referenced in this section were based on the procedure outlined in the EPA document.

Calculation Procedure

$$E_{ij} = \sum (TIM_{jk}) * (FF_{jk}/1000) * (EI_{ijk}) * (NE_j)$$

Emission Reduction Benefit

Assume for TIM:

All engines operate for 5 minutes prior to takeoff or shut-down (2 minutes minimum for thermal stability/cool down)

No change to average taxi time

Assume for NE:

A300 - 1 engine	B747 - 3 engines	DC9/MD80 - 1 engine
A310 - 1 engine	B757 - 1 engine	DC10 - 2 engines
A320 - 1 engine	B767 - 1 engine	MD11 - 2 engines
B727 - 1 engine	L1011 - 2 engines	
B737 - 1 engine	DC8 - 2 engines	

Frequency of Use:

70% of all taxi periods > 5 minutes

Emission Benefit:

Difference between emissions calculated using base-line assumptions and those calculated after applying above assumptions

Implementation Costs

Direct:

Fuel cost/savings =
(engine-out taxi time) * (FF_{idle}/1000) * (jet fuel cost)

Indirect and Noneconomic:

Pilot training costs

Assumptions

The following assumptions were made in estimating emissions for aircraft with single/reduced engine taxiing for the sample calculations. These assumptions allow for possible constraints limiting the use of the measure. They are:

- this measure can be used 70% of the the time,
- all engines must run for at least two minutes before takeoff,
- all engines are run for five minutes during taxi-in and taxi-out,
- only one (or two) engine(s) is run for the remaining taxi time, and
- at least one engine, but not more than two, are shut down during taxi for aircraft not listed under the calculation procedure above.

Running all engines for five minutes (instead of two minutes) of the taxi time and using the measure only 70% of the time allows for limits due to narrow taxiways, bad weather, and other limiting conditions. Airport specific data should be used if available.

Sample Calculations

This sample calculation illustrates the procedure for determining the benefit of single engine taxiing on HC emissions for B737-300 aircraft. A similar procedure is followed to determine CO and NO_X emissions. Fleet emissions without single engine taxiing are compared to those while using the procedure for commercial aircraft at LAX in 1990.

To calculate an emissions estimate, average taxi-in and taxi-out times for the airport were determined from FAA data. Climbout and approach times in mode were adjusted to reflect the average summer morning mixing height for LAX (1800 feet). As discussed more fully in Appendix A, airport-specific mixing height should be used to adjust climbout and approach times for calculating emissions at any airport.

References

There is no universal policy on single/ reduced engine taxiing. Some domestic airlines have a policy of practicing single/reduced engine taxiing, yet leave it to the discretion of the pilot. Contact airlines for individual practices. Some airports, such as Heathrow in the U.K., encourage aircraft to taxi with reduced engines for fuel economy reasons. Generally, however, reduced engine taxiing is left up to the pilot's discretion.

Measure Variations

No other variations to this measure were considered.

3.1.2

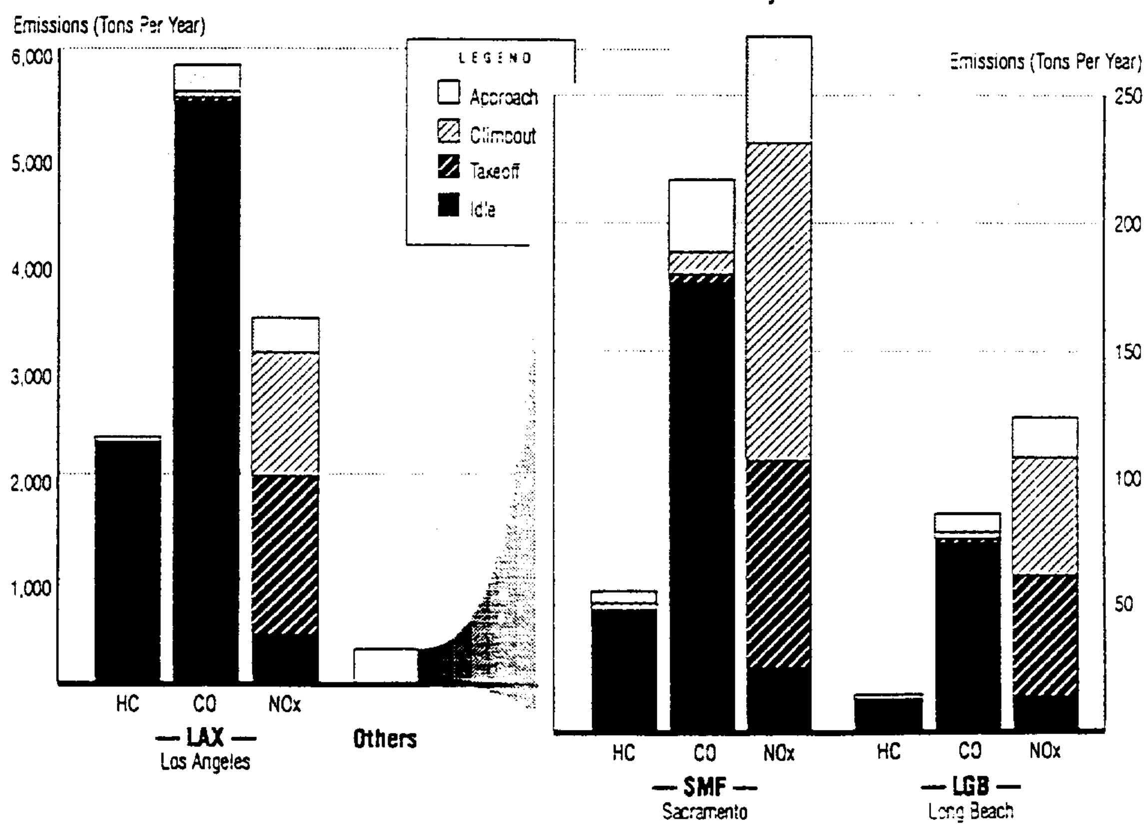
Reference Emissions

To evaluate the mitigation measures discussed in this report, reference emissions estimates were calculated for commercial aircraft operations. These estimates were based on aircraft activity during 1990 as reported in city of Los Angeles Department of Airports' (LADOA) LAX revenue landing statistics report for periods 1/90 through 12/90 and FAA's *Airport Activity Statistics of Certified Route Air Carriers.* The estimates are used as a basis for comparison with emission estimates of select aircraft mitigation measures to provide the measures' emissions reduction benefits. A quantitative comparison is made for those measures for which data is available to calculate resulting emissions. The commercial aircraft emissions references are based on operations at three California airports: Los Angeles International Airport (LAX), Sacramento Metro Airport (SMF), or Long Beach Airport (LGB). The 1990 reference estimates are:

	Emissions (lb/yr)		
Pollutant	LAX	SMF	LGB
HC	4,697,755	111,671	28,313
CO	11,672,618	434,428	172,216
NOx	6,939,500	546,952	248,515

The resulting emissions also are displayed in Figure 3-1 by pollutant and operational mode. The following discussion identifies the key inputs for calculating the emissions reduction benefit for each measure.

FIGURE 3-1
Commercial Aircraft Reference Emissions By Mode – 1990



3.2.2

Reduce Use Of Reverse Thrust

This measure reduces engine operating time at full throttle.

Airport runways vary in length. If the runway is relatively short and engine power is needed to reduce the aircraft's speed quickly, thrust reversers are used. A longer runway allows room for an arriving aircraft to slow down after landing using wheel brakes and without the need for reverse thrust from the aircraft engines. While all runways should be long enough for approved aircraft to land using brakes only, heavy braking significantly reduces the life of the brakes and tires.

For reverse thrust, mechanical devices in the engines deflect the engine exhaust forward. For maximum breaking of the aircraft, the engines are run at near full power with the thrust reversers engaged. On a typical landing, the thrust is reversed for approximately 15 seconds although this varies depending on the aircraft and runway length. The pilot in control of the aircraft makes the decision on whether to use reverse thrust. Because the engines are run at full throttle, thrust reversal is a source of NO_X emissions.

Aircraft size and weight also is a factor in whether reverse thrust is needed. Larger, heavier aircraft need more room to slow down than do small aircraft. For a given runway length, some aircraft typically may use reverse thrust while others do not.

Constraints

Space availability and construction capital requirements are constraints to lengthening a runway. To lengthen an existing runway, land for the runway extension and space for changes to the approach and departure patterns must be available. This measure is not feasible for a space constrained airport. Runway improvements also are relatively high cost construction. Because an airport is a place of almost continuous activity there may be serious limits on when construction can take place.

Safety may be a factor in using reverse thrust. Certain weather conditions may dictate that the pilot rely on reverse thrust rather than wheel brakes. Airport design also is a factor. High-speed turnouts enable an aircraft to exit the runway without coming to a near stop. Ninety-degree, unbanked turns between the runway and taxiway require the aircraft to slow much more. Also, if one turnout is missed due to slower braking speed, taxi-in time may increase. As mentioned, heavy braking increases maintenance costs on brakes and tires.

Another constraint that is difficult to assess objectively is the pilot's desire to land the aircraft smoothly. Since the landing is the last phase of the flight, it is often the most memorable for passengers. As a consequence, many pilots will use as much of the runway as possible to insure a smooth landing rather than forcing the aircraft down early. The further down the runway the wheels touchdown, the more likely reverse thrust will be required.

Applications

Runway length is an important consideration in the design of new airports. Prospects for extending a runway or building a new runway at an existing airport may be more limited. Since reducing the use of reverse thrust is one of the

Sample Calculation For... **Single Engine Taxiing**

Emissions = Σ(TIM) • (FF/1000) • (EI) • (NE)

— HC Emissions —

B737-300 Aircraft
CFM 56-3B Engine

TAXIING NOT IN USE

Mode	Time In Mode	Fuel Flow	HC Emission Factor	No. Of Eng.	Emissions
	MIN	LB/MIN	LB/1,000LB		LBS
Taxi-out	15.00	17.20	1.25	2	0.6450
Takeoff	0.95	150.79	0.04	2	0.0115
Climbout	1.14	123.02	0.05	2	0.0140
Approach	2.40	47.62	0.08	2	0.0183
Taxi-in	8.80	17.20	1.25	2	0.3784

Note: Taxi on single engine only for part of taxi time.

TAXIING IN USE

Mode	Time In Mode	Fuel Flow	HC Emission Factor	No. Of Eng.	Emissions
	MIN	LB/MIN	LB/1,000LB		LBS
Taxi-out	5.00	17.20	1.25	2	0.2150
Taxi-out	10.00	17.20	1.25	1	0.2150
Takeoff	0.95	150.79	0.04	2	0.0115
Climbout	1.14	123.02	0.05	2	0.0140
Approach	2.40	47.62	0.08	2	0.0183
Taxi-in	5.00	17.20	1.25	2	0.2150
Taxi-in	3.80	17.20	1.25	1	0.0817

	Taxiing Not In Use	Taxiing In Use
B737-300 Emissions per LTO (lbs/LTO)	1.0672	0.7705
Annual B737-300 LTOs	39,184	39,184
Total Annual HC Emissions (lbs)	41,816	30,190

HC emissions are calculated for all aircraft in the fleet and summed to get total annual HC emissions.

	Taxiing Not In Use	Taxiing In Use
Fleet Total Annual HC Emissions (lbs)	4,697,755	3,664,634
Fleet Avg Emissions per LTO (lbs/LTO)	19.53	15.23

CO emissions are determined using similar calculations with appropriate emission factors.

	Taxiing Not In Use	Taxiing In Use
Fleet Total Annual CO Emissions (lbs)	11,672,618	9,276,108
Fleet Avg Emissions per LTO (lbs/LTO)	48.52	38.56

NOx emissions are determined using similar calculations with appropriate emission factors.

	Taxiing Not In Use	Taxiing In Use
Fleet Total Annual NOx Emissions (lbs)	6,939,500	6,744,466
Fleet Avg Emissions per LTO (lbs/LTO)	28.84	28.03

— Emissions Benefit —

Difference between emissions generated when the measure is not in use compared to when the measure is in use.

HC Emissions

w/o measure	4,697,755 lbs
with measure	3,664,634 lbs
HC Benefit =	1,033,120 lbs
Percent Reduction =	22 %

CO Emissions

w/o measure	11,672,618 lbs
with measure	9,276,108 lbs
CO Benefit =	2,396,510 lbs
Percent Reduction =	21 %

NOx Emissions

w/o measure	6,939,500 lbs
with measure	6,744,466 lbs
NOx Benefit =	195,034 lbs
Percent Reduction =	3 %

Implementation Feasibility

- This measure apparently can be implemented under few constraints since it already is policy at some airports and for some airlines.
- Airlines are responsible for implementing this measure. Airlines should work with airports to determine any site-specific limitations for this practice. FAA Advisory Circular No. 91-41 (Appendix B) addresses this measure and recommends that the practice not be made mandatory at any time.
- Data is available for taxi time from the FAA for some airports, although it may be difficult to obtain for all airports of interest. Emission factor data is not available for the higher RPM idle needed for single/reduced engine taxiing, but available idle emission factors can be used to provide a conservative result.
- Significant emissions reduction is achievable at little or no cost (maybe even a cost savings).

Sample Calculation For... **Reducing Reversed Thrust**

Emissions = Σ(TIM) • (FF/1000) • (EI) • (NE)

— HC Emissions —

B737-300 Aircraft
CFM56-3B Engine

REVERSED THRUST IN USE

Mode	Time In Mode (MIN)	Fuel Flow (LB/MIN)	HC Emission Factor (LBS/1,000LB)	No. Of Eng.	Emissions (LBS)
Taxi-out	9.90	17.20	1.25	2	0.4257
Takeoff	0.95	150.79	0.04	2	0.0115
Climbout	1.14	123.02	0.05	2	0.0173
Approach	2.80	47.62	0.08	2	0.0213
Taxi-in	4.60	17.20	1.25	2	0.1978

Note: Lower time in mode at takeoff power level

REVERSED THRUST USE REDUCED

Mode	Time In Mode (MIN)	Fuel Flow (LB/MIN)	HC Emission Factor (LBS/1,000LB)	No. Of Eng.	Emissions (LBS)
Taxi-out	9.90	17.20	1.25	2	0.4257
Takeoff	0.70	150.79	0.04	2	0.0084
Climbout	1.14	123.02	0.05	2	0.0173
Approach	2.80	47.62	0.08	2	0.0213
Taxi-in	4.60	17.20	1.25	2	0.1978

	Reversed Thrust In Use	Reversed Thrust Use Reduced
B737-300 Emissions per LTO (lbs/LTO)	0.6736	0.6706
Annual B737-300 LTOs	6,459	6,459
Total Annual HC Emissions (lbs)	4,351	4,332

HC emissions are calculated for all aircraft in the fleet and summed to get total annual HC emissions.

	Reversed Thrust In Use	Reversed Thrust Use Reduced
Fleet Total Annual HC Emissions (lbs)	28,313	28,150
Fleet Avg Emissions per LTO (lbs/LTO)	1.94	1.93

CO emissions are determined using similar calculations with appropriate emission factors.

	Reversed Thrust In Use	Reversed Thrust Use Reduced
Fleet Total Annual CO Emissions (lbs)	172,216	171,397
Fleet Avg Emissions per LTO (lbs/LTO)	11.81	11.75

NOx emissions are determined using similar calculations with appropriate emission factors.

	Reversed Thrust In Use	Reversed Thrust Use Reduced
Fleet Total Annual NOx Emissions (lbs)	248,515	225,676
Fleet Avg Emissions per LTO (lbs/LTO)	17.04	15.47

— Emissions Benefit —
Difference between emissions generated when the measure is not in use compared to when the measure is in use.

HC Emissions

w/o measure	28,313 lbs
with measure	28,150 lbs
HC Benefit =	163 lbs
Percent Reduction =	1 %

CO Emissions

w/o measure	172,216 lbs
with measure	171,397 lbs
CO Benefit =	820 lbs
Percent Reduction =	0 %

NOx Emissions

w/o measure	248,515 lbs
with measure	225,676 lbs
NOx Benefit =	22,839 lbs
Percent Reduction =	9 %

Sample Calculations

An emission estimate for lengthening runways was made for Long Beach Airport based on 1990 data. The change in emissions resulting from eliminating reverse thrust use on landing was estimated.

To estimate the emissions, average taxi-in and taxi-out times for Long Beach Airport were taken from FAA data. Climbout and approach times were adjusted to reflect the 2100 foot mixing height at Long Beach. The assumptions reflected in the sample calculations represent a best case for NO_X emissions reductions.

References

There is no universal policy on the use of reverse thrusters for landing. The decision to use reverse thrust is made by the pilots on each landing. Munich 2 Airport in Germany has two 4000m (13,080 feet) runways, which are among the longest found at commercial airports. The airport management indicates that these runways allow any aircraft to land safely without using revere thrust. *San Francisco Bay Area Airports: Task Force Capacity Study of SFO, SJC, and OAK International Airports* discusses reductions in aircraft delay from several measures such as extend-few measures for reducing NO_X emissions, it may be an important consideration for some airports.

KEY INPUTS

Reverse thrust is not included in EPA's standard LTO emission calculations, as described in Appendix A. For this report, the reverse thrust component of the LTO cycle has been added to the calculations. Engine operating conditions are similar to takeoff so additional time (15 seconds) has been added to the takeoff mode as a surrogate to evaluate the implications of reverse thrust. Because of the constraints discussed above, it is difficult to generalize about the need for using reverse thrust. Data should represent the site specific factors that are important at a given airport.

The key data needed to assess lengthening a runway is frequency and duration of the use of reverse thrust. To evaluate this measure, emissions should be calculated for aircraft using the standard LTO cycle to represent the use of no reverse thrust. To evaluate the use of reverse thrust, 15 seconds should be added to the takeoff time-in-mode (to represent time in reverse thrust). If reverse thrust is not used, the engine power is reduced to idle while the aircraft slows down. EEA is unaware of any sources of information on the frequency of reverse thrust use by aircraft at specific airports. Site specific data collection probably is necessary to refine this calculation. However, using standard data on time-in-mode and 15 seconds of reverse thrust time, a conservative emissions estimate can be calculated.

CALCULATION PROCEDURE

$$E_{ij} = \sum (TIM_{jk}) * (FF_{jk}/1000) * (EI_{ijk}) * (NE_j)$$

Emission Reduction Benefit

Assume for TIM:

Use of reverse thrust is eliminated reducing high power operation (at equivalent of takeoff thrust) by 15 seconds.

No effect on delay or airport capacity.

Frequency of Use:

90% of all landings; all airports

Emission Benefit:

Difference between emissions calculated assuming 15 seconds reverse thrust use on every landing and those calculated assuming 15 seconds reverse thrust use on 10% of landings.

Implementation Costs

Direct:

Fuel cost/savings =
$(0.90) * (15/60) * (FF_{co}/1000) * (\text{jet fuel cost})$

Capital cost =
site specific factors may be important and need to be considered

Indirect and Noneconomic:

Reduced maintenance cost on engines

Added maintenance cost on wheel brakes

ASSUMPTIONS

The following assumptions were made in the sample calculations for a lengthened runway that eliminates the need for reverse thrust during landing. The assumptions are for an extreme situation to evaluate the maximum benefit. They are:

- every aircraft needs to use reverse thrusters during all landings,
- the thrust is reversed during landing for 15 seconds, and
- 90% of the use of reverse thrust use will be eliminated by a lengthened runway.

parts replacement on the nosegear. Some new tugs actually lift the nosegear to tow the aircraft and completely avoid towbars. These tugs may not reduce the nosegear life appreciably.

The emissions from the tug and APU offset some of the savings from towing an aircraft. Section 4 describes, in some detail, the procedure for calculating the tug's emissions.

Safety also is an important consideration for extensive aircraft towing. Crosswinds, standing water, and ice can be hazards to towing and may limit the amount of time this can be practiced.

Conventional towing is quite slow and more tugs would be required to implement this measure than are currently used. There would be increased ground traffic with tugs shuttling between the gate and runway, which most likely would increase on-ground congestion. The slower ground movement of aircraft could be a problem particularly when weather conditions require deicing. At some airports even towing aircraft to maintenance using conventional tugs may cause a net increase in emissions because of the time required to cross active runways and the possibility of delaying arriving aircraft. New high-speed tugs are available that can tow significantly faster than conventional tugs or aircraft taxi speed. However, these high-speed tugs are quite expensive (approximately $1 million per unit). The initial investment of a high-speed tug is offset in part by savings in ground support labor and fuel costs and aircraft engine hours. Some airlines have found high-speed tugs to be economical, with a three year payback in specific applications such as towing to maintenance areas. An offsetting cost consideration is cabin and cockpit labor costs. These employees typically are paid for all time the aircraft is away from the gate. If towing takes longer than taxiing, labor costs will increase.

Applications

The longer the taxi time, the greater the potential emission and time benefits from towing aircraft. Taxi-out time tends to be longer than taxi-in time due to queuing for takeoff and on-ground congestion. Therefore, a high-speed tug would be most effective if used for towing departing aircraft to the runway.

Key Inputs

The key input to towing aircraft to the runway is the tug's engine emission factor and the APU's emission factor. To evaluate the measure, emissions from the tug and APU must be calculated. These emissions then would be compared to the aircraft's emissions to estimate possible emission reductions. Engine data needed includes exhaust emission factors of HC, CO, and NO_X, for the tug and APU, and crankcase HC, evaporative HC, HP rating, and in-use load factor for the tug. Engine data may be available only for certain aircraft tugs. See discussion of ground support equipment in Section 4.

Calculation Procedure

$$E_{ij} = \sum (TIM_{jk}) * (FF_{jk}/1000) * (EI_{ijk}) * (NE_j)$$

Emission Reduction Benefit

Assume for TIM:

All engines operate in taxi/idle mode for 2 minutes prior to takeoff or shutdown for thermal stability/cool down

Other Assumptions:

APU operates while aircraft is being towed.

Using conventional tow vehicles: tow speed is 5 mph average and will cover X miles (site specific - distance from terminal to departure runway or from taxiway near exit of end of arrival runway); tug engine is conventional diesel ed runways. Information on runway lengths for individual airports is available from Airport Master Plans, FAA Form 5010, and the airports themselves.

Measure Variations

A variation to lengthening a runway is to build a new longer runway. *San Francisco Bay Area Airports: Task Force Capacity Study of SFO, SJC, and OAK International Airports* estimates aircraft delay reductions from construction of an independent parallel runway. For SFO, a new parallel runway would reduce delay by 26%, or almost 37,000 hours per year out of 142,000 hours of delay experienced. A variation on constructing a new runway would be to convert a taxiway to a runway.

Implementation Feasibility

- Data on default takeoff times and FAA airport average taxi times are available. Actual reverse thrust time and use frequency are not available, but they can be estimated and used to provide a conservative result.
- Airports are responsible for lengthening runways.
- Runways can be lengthened at airports if additional land is available.
- Reductions of NO_X may be possible if a runway is lengthened.

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3.2.3

Tow Aircraft to Runway

This measure reduces engine operating time at idle.

Instead of taxiing, a departing aircraft can be towed from the terminal gate to the runway. This is known as dispatch towing. Towing aircraft could substantially decrease the time the engines idle. Aircraft taxi at inefficient power settings and have relatively high HC and CO emissions. The tradeoff is between aircraft engine exhaust emissions and emissions from the tow tug and the aircraft's auxiliary power unit (APU). The APU must be run while the aircraft is being towed to provide electricity and interior ventilation, as well as compressed air to start the main engines away from the gate.

Tow tugs with varying maximum towing speeds are available. High-speed tugs tow aircraft quickly through runway and taxiway intersections, alleviating the need for intermittent stopping and cutting down the time to reach the runway. As a result, HC and CO emissions are reduced further. In addition to emission reduction benefits, the measure also conserves fuel.

Constraints

Possible constraints to aircraft towing include hook-up, emissions, safety, and speed. Traditional tugs hook-up to and tow an aircraft by means of a connecting bar or towbar. The towbar places a horizontal stress on the nosegear as opposed to the vertical stress the nosegear experiences during landing. The nosegear is designed for infrequent towing for pushback from the gate or towing to a maintenance hangar rather than frequent, long-distance towing for each LTO. The additional towing means more frequent maintenance and

Measure Variations

The United Airlines' tug at San Francisco International Airport is used to transport aircraft to and from the maintenance facility. They have not announced plans for dispatch towing of departing aircraft.

It may be possible to tow arriving aircraft from the runway to the gate. Since arriving taxi times generally are shorter than departing taxi times, this variation may not have as significant an affect on taxi time and emissions.

Implementation Feasibility

- Towing aircraft to the runway with high-speed, towbarless tugs is technically feasible. However it may not be very practical due to safety constraints, increased congestion, and added maintenance requirements.
- Airlines, in cooperation with airports, are responsible for implementing this measure.
- Significant emissions reduction apparently is possible, although the estimated benefit could not be defined due to a lack of emissions data on the high-speed tugs. High costs related to the initial investment may be balanced by other savings.

3.2.4

Take Passengers to Aircraft

This measure reduces aircraft taxi time (or reduces engine operating time at idle).

Typically, passengers board an aircraft while it is parked at a terminal gate. The aircraft then taxis with the passengers for some distance to the runway for takeoff. Instead of boarding the aircraft at the gate, passengers could be transported to the aircraft parked close to the runway. Modifying procedures for aircraft servicing and/or baggage handling may or may not be necessary. This measure would decrease an aircraft's taxi time. Much like towing aircraft to the runway, limiting the taxi time decreases the aircraft's HC and CO emissions particularly. In addition to emission reduction benefits, the measure also may conserve fuel in most applications.

Constraints

Original airport design, airfield space, hubbing, and cost are significant factors to consider for transporting passengers to aircraft. For an airport to accommodate this measure, sufficient space must be available to park aircraft near the runway without increasing congestion. This measure generally is not feasible as a retrofit measure due to the space required near the runways. For airports that serve as hubs, it is particularly difficult to accommodate all the aircraft and required passenger transport vehicles. The emissions from the passenger transport vehicle partially offset the reductions achieved from the reduced taxi time. The initial investment in passenger transport vehicles must be considered in addition to the cost of the additional land use. The initial invest-

Using towbarless tug: tow speed is 15 mph average and will cover same distance; tug engine is either electric or high efficiency diesel

Frequency of Use:

100% of all LTOs

Emission Benefit:

Difference between taxi/idle emissions calculated using baseline assumptions and tug, plus APU, plus engine warmup/cool down emissions (2 minutes out + 2 minutes in at idle)

Implementation Costs

Direct:

Fuel cost/savings = [(baseline taxi time - 4 minutes) * (FF_{idle}/1000) * (jet fuel cost)] - [(tow time) * (FF_{tug}) * (diesel fuel/electricity cost] - [(tow time) * (FF_{APU}) * (jet fuel cost)]

Labor costs = (tow time - baseline taxi time) * [(aircraft crew labor costs) + (additional labor cost of towing crew made up of 3 crew per additional tug)]

Equipment costs = annualized cost of 2.5 times the number of tugs currently in use (1.7 tugs per gate needed vs. 0.7 tugs per gate needed under current operations, in the experience of one airline) + annual vehicle maintenance cost + replacement parts for key nose gear components (assume 25% reduction in component life)

Indirect and Noneconomic:

APU operating costs (excluding fuel costs)

Increased complexity of on-ground operations and communications

Value of passenger time due to increased on-ground operations

Assumptions

If emissions data for the new high-speed tugs and estimates of increased ground congestion were available, the following assumptions could be made in calculating an emissions estimate for towing aircraft to the runway:

- assume the use of a high-speed towbarless tug
- the tug will tow at the maximum towing speed
- all aircraft engines are off during towing and the APU is in operation at full power
- all aircraft engines must run for at least two minutes before takeoff to reach thermal stability
- engine operation under taxi conditions is reduced by the taxi-out time less two minutes.

Sample Calculations

Insufficient data is available currently on the potential high-speed tug emissions and increase in ground congestion to calculate the benefit meaningfully.

References

Two sizes of high-speed towbarless tugs are commercially available from Mercury GSE -Krauss Maffei in El Segundo, CA. The tugs have the capability of towing at speeds up to 20 mph. The tugs have been tested at various airports around the world including those in Munich, Frankfurt, Zurich, Copenhagen, Stockholm, New York, Chicago, San Francisco, and Toronto. A Mercury GSE tug currently is operated by United Airlines at San Francisco International Airport. Amsterdam's Schiphol Airport evaluated towing aircraft to mitigate emissions. Since they have relatively short taxi times they decided not to tow aircraft because it would be too expensive for the resulting benefit. At Switzerland's Zurich Airport, aircraft are towed by a high-speed towbarless tractor between the terminal and maintenance facility. They decided this alternative was not feasible for towing aircraft from the gate to the runway due to short taxiways and infrequent ground delays that result in average taxi times of 8.5-10 minutes. United Kingdom's Heathrow Airport investigated and rejected aircraft towing due to the numerous runways and taxiways to cross.

costs) + (additional labor cost of van operating crew made up of 2 crew per van)]

Equipment costs = annualized cost of additional vans equivalent to 5 times the number of tugs currently in use (2 • 1.7 tugs per gate needed vs. 0.7 tugs per gate needed under current operations per one airline's experience) + annual vehicle maintenance cost

Indirect and Noneconomic:

Increased complexity of on-ground operations and communications

Increased passenger time spent enplaning and deplaning

Assumptions

The following assumptions were made in calculating an emissions estimate for taking passengers to aircraft:

- passenger transport vehicle's primary engine is left to idle between transport operations
- the vehicle has 200 BHP primary and auxiliary engines and an average load factor of 51%
- it takes eight minutes to go between the main terminal and a plane
- the average time the vehicle waits to load or unload passengers is 10 minutes
- two vehicles must each make one trip for each LTO
- the average daily operation cycle is 5am to 11pm (eighteen hours) with twenty-eight trips per day
- APU operates for 30 minutes to accommodate passenger loading and main engine start.

Sample Calculations

To calculate emissions from the APU assume 30 minutes operating time:

HC= 30 minutes • 6.88 lbs fuel/minute • 0.16 lbs HC/1000 lbs fuel + 1000 = 0.03 lbs

CO= 30 minutes • 6.88 lbs fuel/minute • 5.89 lbs CO/1000 lbs fuel + 1000 = 1.22 lbs

NO_x= 30 minutes • 6.88 lbs fuel/minute • 5.95 lbs NO_x/1000 lbs fuel + 1000 = 1.23 lbs

To calculate emissions from the passenger transport vehicle the following emission factors are used:

Pollutant	Emission Factor (G/BHP-HR)
HC	1.57
CO	6.06
NO_x	14.00

The main engine emissions for each trip are:

$$\text{Emissions} = \frac{G}{\text{BHP-Hr}} \cdot \text{BHP} \cdot \text{load factor} \cdot \text{hours of use}$$

HC = 1.57 • 200 • 0.51 • (8/60) = 21.35g

CO = 6.06 • 200 • 0.51 • (8/60) = 82.42g

NO_x = 14.00 • 200 • 0.51 • (8/60)=190.40g

The auxiliary engine emissions for each trip are:

HC = 1.57 • 200 • 0.51 • (18/60) =48.04g

CO = 6.06 • 200 • 0.51 • (18/60)=185.44g

NO_x = 14.00 . 200 • 0.51 • (18/60)= 428.40g

Therefore the total exhaust emissions for two vehicles making a sight trip are:

HC = 2(21.35 + 48.04)/454 g/lb= 0.31 lbs

CO = 2(82.42 + 185.44)/454 g/lb= 1.18 lbs

NO_x = 2(190.40 + 428.40)/454g/lb= 2.73 lbs

This compares to average taxi-out emissions for commercial aircraft per LTO at LAX based on the FAA average taxi-out time of 15 minutes:

Pollutant	LB/LTO
HC	11.91
CO	28.80
NOX	2.49

ment is partially offset by savings in fuel costs and aircraft engine operating hours. Unless permanent parking facilities are established, power and air would have to be provided to the aircraft by ground power units and portable air compressors or the APU, which would offset the benefits somewhat.

Applications

The longer the aircraft taxi time, the greater the potential emissions benefit from taking passengers to aircraft. Dulles Airport near Washington, DC was originally designed to operate this way. This potentially could be a retrofit measure for an airport if taxi times are long and a sufficient amount of space is available near the runways for an aircraft staging area. The likely application for taking passengers to aircraft may be in the design of a new large airport. Space could be provided near the runways for parked aircraft and passenger boarding.

Key Inputs

The key data needed to assess the benefit from this measure is engine emission data for APUs and the vehicles that transport passengers to aircraft. To evaluate the measure, emissions from the APU and passenger transport vehicle must be calculated. The emissions from all the vehicle's trips and the APU would then be compared to the aircraft's emissions to estimate potential emission reductions. Vehicle engine data needed includes emission factors for exhaust (HC, CO, and NO_X), crankcase HC, evaporative HC, HP rating, and in-use load factor. APU data needed includes emission factors for exhaust (HC, CO, and NO_X).

Calculation Procedure

Aircraft and APU

$$E_{ij} = \Sigma (TIM_{jk}) * (FF_{jk}/1000) * (EI_{ijk}) * (NE_j)$$

Passenger Transport Vehicle

$$E_{ij} = \Sigma (EF_j) * (BHP_j) * (LF_j) * (\text{Use Hours}_j)$$

Emission Reduction Benefit

Assume for TIM:

All engines operate for 5 minutes prior to takeoff or shutdown (minimal taxi time plus 2 minutes minimum for thermal stability/cool down)

Other Assumptions:

Special vans (similar to those used at Dulles Airport) are used to transport passengers from terminal gates directly to the aircraft. Passenger transport vans will be fueled by natural gas or electric engines. Vans can accommodate 35 passengers.

On average, will need twice as many vans per LTO as tugs needed to tow aircraft to runway (2 vans/tug = 1.7 tugs per gate)

A concrete holding pad must be constructed adjacent to each runway to accommodate parked aircraft. Centrally supplied air and power, as well as other services, will be made available to the aircraft on the holding pad.

Frequency of Use:

100% of all LTOs

Emission Benefit:

Difference between taxi/idle emissions calculated using baseline assumptions and emissions from the transport vans and apu plus engine warmup/cool down emissions (10 minutes at idle total)

Implementation Costs

Direct:

Fuel cost/savings = [(baseline taxi in plus taxi out time - 10 minutes) * (FF_{idle}/1000) * (jet fuel cost)] - [(passenger transport time) * (FF_{van}) * (natural gas/electricity cost]

Labor costs = [passenger transport time - (baseline taxi time - 10 minutes taxi time)] * [(aircraft crew labor

NOx.... 2.49 2.73 1.23 0.83 -92%

have "open" gates, which are located some dising taxi times considerably compared to the former design where the terminal was located some distance from the runways. This design includes a central terminal with ticketing and baggage claim adjacent to public parking. This terminal can be accessed by ground traffic. An underground people-mover rail system then transports up to 13,200 passengers per hour to the mid-field terminal located between the runways. Aircraft park at gates at this terminal.

Some airports can use this design in modifying an existing facility. Dulles Airport added its mid-field terminal about ten years after the airport was built to accommodate airline hub operation. Operating as a hub typically increases the total number of flights, which arrive and depart on a coordinated schedule. The increased activity at Dulles would have caused severe congestion due to the number of lounges required to service the aircraft. The approach taken was to construct the new mid-field terminal. Mobile lounges now transport passengers from the main terminal to the mid-field terminal for approximately seventy-five to eighty percent of the flights.

Other airports have constructed terminals close to the runways for similar reasons. The United Kingdom's Heathrow Airport near London has four terminals, three of which are located in the area between the runways. An underground tunnel connects to the central terminal area. A third terminal is planned at Charles de Gaulle Airport, outside of Paris, France along with a shuttle between terminals.

Implementation Feasibility

- Space requirements for parking aircraft and operating passenger transport vehicles or constructing a terminal adjacent to existing runways limit the likelihood of this measure being adopted as a retrofit. New airports can easily include this approach into their original design. The most practical variation appears to be building a mid-field terminal near the runway connected underground to another terminal that provides access to the surface transportation network.
- Airport owners have the responsibility for implementing this measure.

3.2.5

Congestion — On-Ground and In-Air

This measure reduces aircraft taxi time.

Delays at airports are a major cause of excessive aircraft idling. Some of the causes of delay include weather, airports design limitations, aircraft operating procedures, gatehold procedures, and air traffic control procedures. The majority of delays are related to runway constraints. This section discusses various ways to reduce airside delays.

On-ground congestion extends taxi time and can be a significant cause of aircraft sitting with engines running. Taxiing and idling primarily are sources of HC and CO emissions. Examples of on-ground congestion include arriving aircraft waiting for a gate to become available or departing aircraft waiting to get to the runway for takeoff. Various techniques are available for relieving on-ground congestion such as:

- Gatehold Procedures
- Taxiway Improvements
- High-Speed Taxi Turnouts
- Intersection Departure

Gatehold Procedures

Different airports manage air traffic control (ATC) delays differently. In some cases, aircraft begin taxiing to the runway as soon as they are ready. If ATC delays prevent them from being cleared for takeoff, they idle on the taxiway until they receive clearance. Other airports hold the aircraft at the gate until they are ready to depart and have received clearance to takeoff. This minimizes the delay while taxiing to the runway.

Taxiway Improvements

Various approaches can make taxiways more efficient for moving aircraft quickly between the gate and runway. Depending on site-specific factors and original airport design, improvements may include widening, extending, or building new taxiways. A double-width taxiway allows aircraft to pass side-by-side, reducing intermittent stops and allowing aircraft cleared for takeoff to pass aircraft that may be experiencing ATC delays. Extending taxiways may allow access to other taxiways and runways. New taxiways may be necessary to allow aircraft to taxi more directly to runways or to decrease intermittent stopping to cross runways and taxiways or to pass other aircraft.

High-Speed Taxi Turnouts

Some turnouts from runways to taxiways are constructed at a 90° angle and aircraft must nearly stop to make the turn. A high-speed turnout is curved or angled and banked to allow an arriving aircraft to enter the taxiway from the runway much faster. This clears the runway much more quickly to allow for other landings or takeoffs, thereby reducing delays.

Intersection Departure

Under most conditions aircraft do not need the full length of the runway to takeoff. Some airports allow aircraft, particularly smaller aircraft, to access the runway at the intersection of a taxiway and the runway rather than taxiing all the way to the end of the runway. At some airports this can cut taxi time substantially. While intersection departures are possible most often by commuter and general aviation aircraft, they also are feasible for smaller narrow-body aircraft such as B-737s and MD-80s at some airports.

Aircraft holding areas and additional noise barriers also may contribute to reducing aircraft taxi delays.

In-air congestion also can cause delays on the ground because arriving aircraft have priority over departing aircraft. Reducing in-air congestion can reduce on-ground delays by allowing aircraft to be cleared for takeoff more quickly. Techniques to reduce in-air congestion include:

- Reduce Aircraft Spacing
- Separate Runways
- Peak-Period Pricing

Reduce Aircraft Spacing

Reducing the longitudinal separation between inbound or outbound aircraft while in the air can increase the capacity of some airports by getting more aircraft to or away from the airport. For many airports this can be accomplished by upgrading ATC instrumentation or revising approach or departure procedures.

Separate Runways

Many airports use the same runway for commercial and commuter/general aviation aircraft. Commercial aircraft operate at higher speeds on approach or climbout than the smaller aircraft. By using separate runways, air traffic can be managed more efficiently with reduced spacing and fewer delays required to prevent one aircraft from overrunning another.

Peak-Period Pricing

Peak-period pricing for landing fees may induce airlines to schedule more flights during off-peak periods. Cutting the number of flights scheduled for peak periods would reduce delays due to congestion.

These measures have the potential to reduce in-air and runway congestion resulting in reduced taxi delays.

Constraints

Various constraints must be considered when implementing and evaluating on-ground and in-air congestion reducing measures. Some of the constraints on the measures discussed include:

- Gatehold Procedures
- Taxiway Improvements
- Intersection Departure
- Separate Runways
- Peak-Period Pricing

Gatehold Procedures

Gatehold procedures can cause departing aircraft to be held at gates that arriving aircraft need causing congestion on the taxiways.

Taxiway Improvements

Taxiway improvements require additional space and considerable construction time. The airport design may not accommodate the additional space needed on the airfield to widen or build a taxiway. Also the level of activity at many airports limits the hours available for construction to take place without interfering with airfield operations.

Intersection Departure

An intersection departure may present a safety concern. LAX allowed intersection departure until a landing air carrier aircraft collided with a commuter aircraft that was moving into position to takeoff from an intersection on the same runway. ATC procedures no longer allow intersection departure at LAX.

Separate Runways

Airport layout and terminal design may make it infeasible for commercial and commuter/general aviation aircraft to operate from separate runways.

Peak-Period Pricing

Peak-period pricing for landing fees is intended to deter activity during peak-periods. Due to business factors, such as scheduling and marketing considerations, airlines may continue peak-period operations in spite of the higher landing fees. Landing fees are a small component of an airline's total airport costs, which typically are about 5% of the airline's total variable cost. Substantial increases in peak-period landing fees may be required to influence flight schedules.

Applications

Where airports experience long taxi times due to delay, there is a potential emissions benefit from reducing on-ground or in-air congestion. Most of the actions that can be taken to reduce delay are influenced largely by site-specific factors and should be considered individually.

Key Inputs

The key information needed to evaluate potential benefits due to delay reduction is average taxi time during periods of congestion as well as periods free of congestion. To evaluate this measure, emissions are calculated using an average taxi time-in-mode that includes periods of congestion and comparing the total emissions to those calculated using an average taxi time-in-mode without congestion.

Calculation Procedure

$$E_{ij} = \sum (TIM_{jk}) * (FF_{jk}/1000) * (EI_{ijk}) * (NE_j)$$

Emission Reduction Benefit

Assume for TIM:

Minimum taxi time is the average of the lowest 10 percentile of all taxi times. Taxi times that exceed the minimum are a result of congestion, local and remote weather, and mechanical failure/maintenance delay. Delay resulting from congestion assumed to be 75% of all delay.

Target of Measure:

Assume all congestion-induced delay is eliminated through a combination of measures, which will be site specific.

Emission Benefit:

Maximum benefit is the difference between emissions calculated using baseline assumptions and those assuming no congestion-induced delay.

Implementation Costs

Direct:

Fuel cost/savings = (average taxi time - average of lowest 10%ile taxi times) * ($FF_{c/e}$/1000) * (jet fuel cost)

Capital cost = cost of congestion relief measures and equipment needed to implement, which will be site specific

Labor cost = (average taxi time - average of lowest 10%ile taxi times) * (aircraft crew labor costs)

Probably minimal or no added labor cost for most congestion relief measures. Overall probably a labor cost savings due to aircraft crew savings.

Indirect and Noneconomic:

Possibly tower staff training costs

Assumptions

Congestion reduction opportunities are highly site specific. The potential emission reductions are based on the potential to reduce the average taxi time. A reasonable assumption for the minimum taxi time is the average of the lowest 10 percentile of all taxi times for the airport or for an individual carrier, depending on the level of disaggregation of the taxi time-in-mode data.

Sample Calculations

To evaluate the potential benefit of reducing congestion, the average of the lowest 10 percentile of all taxi-out times for three airlines was assumed to be the average taxi-out time. This resulted in an overall reduction in taxi time of 25.36%. This percentage reduction in taxi time was applied to FAA's data on airport average taxi time. This was applied to all LTOs to represent the maximum benefit.

Data for actual taxi times for three airlines was used to determine the reduced taxi-out times that may be feasible as a result of reduced congestion.

References

Many airports have tested or implemented congestion reduction measures. There is no universal set of measures appropriate for all airports. The United Kingdom's Manchester Airport is planning to revise gatehold procedures to reduce congestion. Switzerland's Zurich Airport is planning to construct double taxiways and holding bays that will enable aircraft to pass in case of changed departure sequences. At Sacramento

Sample Calculation For... **Congestion Relief**

Emissions = Σ(TIM) • (FF/1000) • (EI) • (NE)

— HC Emissions —

B737-300 Aircraft
CFM56-3B Engine

CONGESTED CONDITIONS

Mode	Time In Mode	Fuel Flow	HC Emission Factor	No. Of Eng.	Emissions
	MIN	LB/MIN	LB/1,000LB		LBS
Taxi-out	15.00	17.20	1.25	2	0.6450
Takeoff	0.95	150.79	0.04	2	0.0115
Climbout	1.14	123.02	0.05	2	0.0140
Approach	2.40	47.62	0.08	2	0.0183
Taxi-in	8.80	17.20	1.25	2	0.3784

Note: Lower Taxi-out time.

CONGESTION REDUCED

Mode	Time In Mode	Fuel Flow	HC Emission Factor	No. Of Eng.	Emissions
	MIN	LB/MIN	LB/1,000LB		LBS
Taxi-out	8.96	17.20	1.25	2	0.3853
Takeoff	0.95	150.79	0.04	2	0.0115
Climbout	1.14	123.02	0.05	2	0.0140
Approach	2.40	47.62	0.08	2	0.0183
Taxi-in	8.80	17.20	1.25	2	0.3784

	Congested Conditions	Congestion Reduced
B737-300 Emissions per LTO (lbs/LTO)	1.0672	0.8075
Annual B737-300 LTOs	39,184	39,184
Total Annual HC Emissions (lbs)	41,816	31,639

HC emissions are calculated for all aircraft in the fleet and summed to get total annual HC emissions.

	Congested Conditions	Congestion Reduced
Fleet Total Annual HC Emissions (lbs)	4,697,755	3,544,279
Fleet Avg Emissions per LTO (lbs/LTO)	19.53	14.73

CO emissions are determined using similar calculations with appropriate emission factors.

	Congested Conditions	Congestion Reduced
Fleet Total Annual CO Emissions (lbs)	11,672,618	8,882,368
Fleet Avg Emissions per LTO (lbs/LTO)	48.52	36.92

NOx emissions are determined using similar calculations with appropriate emission factors.

	Congested Conditions	Congestion Reduced
Fleet Total Annual NOx Emissions (lbs)	6,939,500	6,698,006
Fleet Avg Emissions per LTO (lbs/LTO)	28.84	27.84

— Emissions Benefit —

Difference between emissions generated when the measure is not in use compared to when the measure is in use.

HC Emissions

w/o measure	4,697,755 lbs
with measure	3,544,279 lbs
HC Benefit =	1,153,475 lbs
Percent Reduction =	25 %

CO Emissions

w/o measure	11,672,618 lbs
with measure	8,882,368 lbs
CO Benefit =	2,790,250 lbs
Percent Reduction =	24 %

NOx Emissions

w/o measure	6,939,500 lbs
with measure	6,698,006 lbs
NOx Benefit =	241,495 lbs
Percent Reduction =	3 %

Metropolitan Airport, high-speed turnouts and parallel runways have resulted in reduced taxi times. During peak periods, Sacramento tries to limit general aviation activity to the secondary runway. This separation of general aviation aircraft from jet aircraft helps to reduce peak congestion delays. LAX is planning to add to their existing high-speed taxiway exits.

The San Francisco Bay Area Airports: Task Force Capacity Study of SFO, SJC, and OAK International Airports proposes several measures for reducing delays at the area's three major airports. The report evaluates potential aircraft delay reductions from several measures such as high-speed taxi turnouts, extended taxiways, and new taxiways.

Measure Variations

There are several possible variations of the congestion reducing measures mentioned above. For example, Greater Pittsburgh International Airport installed a Norden Systems' Airport Surface Detection Radar. The radar aids controllers in directing traffic on taxiways, runways, and aprons during low-visibility weather and on obstructed areas of the airfield. Frankfurt Airport in Germany operates Sieman's Departure Coordination System (Depcos), which replaces paper flight strips with a computerized system. Controllers enter requests and clearances (e.g. start-up, push-back, and taxi) for departing aircraft into the system. The system reduces the time needed to coordinate aircraft for departures. Three systems are in place at Germany's Munich 2 Airport. Sieman's Computer-Controlled Runway System improves aircraft flow and safety for movements on the taxiway. The Apron Control System is directed by a special team of controllers in the tower who are responsible for aircraft as they enter the apron area from the taxiways. When a taxiing aircraft approaches a gate, a controller identifies the aircraft type and model for the Aircraft Docking Guidance System. At Switzerland's Zurich Airport, slot coordinated engine startup is planned in which the clearance to start an aircraft's engines will not be given before the assigned slot for the aircraft is actually approved.

Two measures have been implemented at Germany's Munich 2 airport to cope with cold weather. The water table was lowered at the airport to ensure frost-free runways, taxiways, and aprons, which delay taxiing aircraft. The airport also has purchased a deicing system that is about 4 times faster than standard deicers. Both measures reduce congestion during inclement weather.

Gatehold procedures keep departing aircraft at their gates until a takeoff space is available. If all gates are occupied with departing aircraft waiting for clearance, an arriving aircraft may have to wait in a taxiway or in the terminal area. Using holding areas as a variation of a gatehold helps alleviate this problem, however, it may increase engine idle time. A holding area would be built near the runway for aircraft that had departed the gate and were waiting for a takeoff space. By freeing up gates, the congestion created by arriving aircraft stopped in taxiways and the terminal area would be relieved. Arriving aircraft also could stop in the holding area if no terminal gates were available. Another gatehold variation is to have a staging pad near the departure end of a runway to allow aircraft to pass each other in case any problems arise.

To minimize on-ground congestion at the Denver International Airport, scheduled to open in March 1994, service tunnels will connect the terminals to transfer baggage. These tunnels will reduce ground support equipment traffic on the runways and taxiways, a common source of congestion at airports.

Separate runways for commercial and commuter/general aviation aircraft improves the flow of aircraft into and out of an airport. A variation on using separate runways is to divert smaller aircraft to other airports or ban them completely during peak-periods of activity. All runways then could be used for larger and faster commercial aircraft. Other approaches would be to distribute traffic more evenly at one airport to minimize peaks or among area airports to reduce operations at congested airports.

One way to encourage fewer operations during peak periods is to charge commuter/ general aviation aircraft higher landing fees (either during peak periods or all of the time) to deter activity. Higher fees are more likely to deter the activity of commuters and smaller aircraft used for personal trips.

Implementation Feasibility

- Data is available for taxi time from the FAA or from the airlines. Data on aircraft delays for select measures (calculated as total hours of delay) at particular airports is provided in the *San Francisco Bay Area Airports: Task Force Capacity Study of SFO, SJC, and OAK International Airports.* Many techniques are very difficult to evaluate, especially in-air techniques. Existing data can be used to estimate emissions reductions for a few measures.

- Congestion reducing measures that do not involve construction apparently can be implemented at existing and new airports under few constraints. Those measures that require construction may be limited because of a lack of space; at new airports they can be incorporated in the original design.

- Emissions reduction is achievable but highly site specific for most congestion reducing measures.

- Airports and the FAA would be responsible for implementing these measures.

3.2.6

Fleet Modernization

This measure reduces the fleet average HC and CO emission factors (fleet average NO_X emission factors increase as the fleet modernizes).

Large commercial airlines' fleets tend to change every year as new aircraft are purchased or leased and older aircraft are leased out, sold, or retired. The aircraft to be added to the fleets of major domestic commercial airlines within the next several years already are on order. Newer aircraft typically have cleaner engines than the aircraft they replace. Therefore, the acquisitions will lower the airline's average emissions of HC and CO per passenger.

CONSTRAINTS

Fleet modernization occurs continually although the rate of modernization varies according to numerous factors such as airline financial health, forecasts of demand for air travel, changes in marketing strategy, and cost of capital. Because of the high annual growth rate and forecasts of future growth experienced in the 1980s, many airlines aggressively modernized their fleets. While this aggressive modernization has diminished somewhat due to the recent financial problems experienced by the airlines, noise reduction legislation is acting to sustain or increase the rate. The noise legislation requires the phase out or conversion of older Stage II aircraft. When the Stage II aircraft are retired in favor of Stage III aircraft, the newer aircraft typically have engines with lower HC and CO emission factors. Converting Stage II aircraft to Stage III can be done by re-engining or by adding hushkits to muffle the noise. Re-engining usually replaces older engines with newer ones with lower HC and CO emission factors. Hushkitting has no direct effect on engine emissions. It does increase the total aircraft weight, however, which then causes a slight increase in engine emissions.

APPLICATIONS

Enforced aircraft fleet modernization is an extreme measure to take for mitigating air emissions. It is discussed in this report to illustrate the change to emissions that come about as a result of the turnover in the aircraft fleet.

KEY INPUTS

To determine the effect of fleet modernization on the total fleet emissions, it is necessary to know the current fleet make-up and have information on future aircraft purchases, retirements, sales, and leases. If detailed future aircraft information is not available, a forecast of the future fleet based on this information is sufficient. Given an airline's current fleet mix, the future mix is estimated by adding aircraft purchases and subtracting aircraft retirements, sales, and leases. To evaluate the benefit, emissions then must be calculated for both the current and future fleet mix. A specific airline's current fleet and some plans for future fleet changes are presented in its annual report. Generally, the report lists aircraft firm orders by aircraft model and year of delivery. Aircraft firm order data by airline, aircraft model, and delivery year also is available from aircraft manufacturers. Specific information is not readily available on an airline's aircraft retirements, sales, and leases. Some informed judgement will have to be applied in estimating these factors.

A similar approach can be taken for estimating historic emissions. For example, this approach could be used to adjust a baseline estimate. U.S. airline jet airplane inventories for past years is available from aircraft manufacturers, such as Boeing and McDonnell Douglas. Aircraft model and populations are contained in the *Boeing Jet Airplane Inventory*, a yearly publication. Fleet and LTO data by airport and airline for past years are contained in that year's publication of FAA's *Airport Activity Statistics of Certificated Route Air Carriers*.

ASSUMPTIONS

The following assumptions were made in calculating an emissions estimate for future fleet modernization as it would affect LAX. They are:

- all current aircraft orders and options will be exercised by 2010
- aircraft are retired when they reach 30 years old
- Stage II aircraft still in service will have been "hush-kitted" rather than re-engined.

SAMPLE CALCULATIONS

Based on the procedure and assumptions described above, the change in fleet makeup for LAX was forecast. Table 3-3 summarizes the LTOs by aircraft type for 1990 and 2010 (including the

TABLE 3-3
Forecast Of Aircraft Fleet Changes At LAX
— LTO BY AIRCRAFT TYPE —

	1990	2010
Airbus		
A-300-600	484	8,313
A-300B	4,615	1,960
A-310-200	410	133
A-310-300	265	645
A-320-100	59	8,421
A-320-200	0	8,503
A-321	0	2,150
A-330	0	9,712
A-340	0	5,041
Boeing		
B-707-300	208	0
B-727-100	4,820	0
B-727-200	33,070	6,414
B-737-100	28,490	0
B-737-200	1,095	3,963
B-737-300	39,523	83,295
B-737-400	2,504	5,333
B-737-500	480	10,882
B-747-100	2,707	123
B-747-200	10,454	1,493
B-747-300	1,520	500
B-747-400	1,763	21,431
B-747-SP	192	0
B-757-200	8,284	56,664
B-767-200	11,243	6,153
B-767-200ER	56	178
B-767-300	2,484	29,679
B-777-200	0	8,360
McDonnell Douglas		
DC10-10	14,041	866
DC10-30	3,301	6,685
DC10-40	2,159	2,459
DC8-50F	485	0
DC8-60	0	143
DC8-62	542	0
DC8-63F	762	0
DC8-70	0	3,870
DC8-71	2,058	0
DC8-73	520	0
DC9-15F	1,113	0
DC9-30	1,208	17,655
DC9-40	36	432
DC9-50	0	721
DC9-80	16,731	48,321
MD11-11	0	14,630
Other		
ATR-42	0	2,118
BAC 111-400	1	0
BAE 146-200	15,035	577
Beech 18	25	0
C-208	384	13,430
DASH 7	0	381
DHC-6/300	0	169
DHC-8	0	593
EMB-110	5,312	0
EMB-120	2,358	4,406
EMB-145	0	2,542
F-27 SERIES	0	1,313
F-28	0	793
F100-100	0	16,575
Jetstream 31	10,275	1,440
L-100	267	0
L-1011-100	9,057	2,005
L-1011-50	0	4,057
L-1011-500	184	1,981
SA227	0	466
SF 340A	0	5,338
SHT 360	0	42
Super Jetstream 31	0	890
Total	**240,580**	**434,246**

expected growth in air travel). The resulting change in emissions per LTO are:

Pollutant	1990 Fleet (LB/LTO)	2010 Fleet (LB/LTO)	Emission Reduction
HC	19.53	7.40	62%
CO	48.52	30.30	38%
NO_x..........	28.85	31.25	-8%

References

Airlines change their fleets annually as they make decisions on purchases, leases, sales, and retirements. Contact airlines and aircraft manufacturers for information on individual fleet plans.

Measure Variations

Some airports use a fee-based mechanism, such as charging higher landing fees for aircraft with higher emissions, as a way to encourage airlines to operate a more modern fleet mix at that specific airport. As discussed under the congestion reduction measure, landing fees are a small component of an airline's total airport costs, which typically are about 5% of the airline's total variable cost. Substantial fee increases may be required to influence airline behavior. At Munich 2 Airport, the basic fee is paid by ICAO licensed aircraft in accordance with Annex 16, Chapter 3 (known as Stage III in the U.S.). The modern Chapter 3 aircraft tend to be lower emitting aircraft. Higher fees must be paid by older, polluting aircraft. At Stockholm's Arlanda Airport in Sweden, higher landing fees may be charged for aircraft with higher emitting engines. At United Kingdom's Manchester Airport, increased emission taxes and certificates (permits) for high emitting aircraft are measures under consideration.

Implementation Feasibility

- Current fleet data and aircraft firm order data by delivery year is available from airlines and aircraft manufacturers. Aircraft lease, sale, and retirement data for future years is not available and must be estimated. Simply adding the firm order data to the existing fleet mix will give a conservative result when calculating average fleet emissions for specific airlines. (Historic inventory data is available for U.S. airline jet airplanes. Past years inventory data and LTOs are available for airports and the individual airlines that operated there from FAA reports.)
- Fleet turnover occurs as airlines make their yearly purchases, leases, sales, and retirements. Future fleet modifications depend on many factors including travel demand forecasts and the financial situation of individual airlines.
- The emission reduction benefit of fleet turnover is expected to be significant over time.

3.2.7

New Engine Standards

This measure reduces the aircraft engine emission factors.

The U.S. EPA has the authority to establish emission standards for aircraft and aircraft engines in consultation with the FAA. HC emission standards for new aircraft gas turbine engines (greater than 6,000 lbs-thrust) were set in 1984. No CO and NO_X emission standards for new jet engines have been set. It may be feasible to establish tighter HC standards and new standards for CO and NO_X, although NO_X likely would be the target of new standards since the 1984 standards had the effect of significantly lowering HC and CO emissions. If new standards are set, future engines will be lower emitting than they would be otherwise. As new aircraft are added to the fleet, the average fleet emissions per passenger will decrease. New standards could reduce future emissions substantially.

Constraints

Manufacturing a lower emitting engine must be demonstrated as technically feasible before new standards can be established. While EPA has the authority to establish new standards they apparently do not have any immediate plans for doing so. The time required to establish the technical feasibility and set standards can be quite lengthy. As a result, new standards can not be applied as a short term measure. Also, since new standards would only apply to new jet engines, significant fleet turnover is required before the effect of the new standards is appreciable.

Applications

New engine emission standards likely would apply to all new engines above a certain size, which would depend on the technology required to achieve the lower emission levels. The HC standard applied to all engines greater than 6,000 lbs-thrust, which covers most jet engines used by commercial airlines. Compliance with the new standards would have to be demonstrated by the engine manufacturers to receive certification by the FAA.

Key Inputs

To evaluate the effect of new standards, emissions would be calculated for an aircraft fleet with its existing engines and compared to the same fleet using new standards. That would give the maximum benefit, which would be achieved over time as the fleet turns over and the new engines achieve full market penetration.

Assumptions

No quantitative information was available on the emissions levels technically achievable by jet engines. As such, no credible assumptions for calculating an emissions estimate were made.

Sample Calculations

The calculation procedure to evaluate the effect of new standards is straight forward, as described above. However, since there was no basis to assume a specific value for new standards, no sample calculations are provided.

References

The HC emission standards for jet engines set by EPA in 1984 are codified at 40 CFR Part 87 - Control of Air Pollution from Aircraft and Aircraft Engines. A copy is provided in Appendix C. They also cover the limitations on fuel venting and smoke standards. The International Civil

Aviation Organization (ICAO) is reviewing aircraft engine NO_X emissions and considering establishing a standard. While ICAO standards do not have force of law in the U.S., they would have the same effect since the major engine manufacturers need a single standard for all major markets and likely would comply with all engines manufactured. However, one source said the level being considered by ICAO is the level now achieved by the major manufacturers, which is below the current certified level, so no future benefit would be realized (nor would the emission levels get worse).

MEASURE VARIATIONS

Since no assumptions were made about specific standards, a discussion of variations is not applicable.

Implementation Feasibility

- No data is available on likely new standards, therefore, potential emission reduction benefits are uncertain.
- EPA has the authority, established by the Clean Air Act, to set new standards.
- Significant emissions reduction may be possible in the future if new standards bring new lower-emitting engines into a significant share of the market.

3.2.8

Derated Takeoff

This measure reduces engine power at takeoff.

Aircraft are designed to takeoff fully loaded on a hot day with enough of a safety factor to ensure safe operation. Full engine thrust is needed only under extreme conditions. The maximum thrust is not needed under more typical operations when the aircraft is not fully loaded and weather conditions are normal. With a derated takeoff, the engine thrust can be reduced from maximum thrust to the minimum safe level necessary given the aircraft weight and atmospheric conditions. As an aircraft's thrust is reduced, the NO_X emissions are reduced. Therefore, derated takeoff can reduce the total NO_X emissions during takeoff. As an added benefit, derated takeoff can reduce fuel consumption. For this reason, many airlines routinely practice derated takeoff.

CONSTRAINTS

Some aircraft models have been supplied with two or more engine models. For example B737-200s are certified for the JT8D-7, JT8D-9/9A, JT8D-15/15A, and JT8D-17/17A/17R. The thrust of these engines range from a low of 13,900 lbs-thrust for the -7 to a high of 17,400 lbs-thrust for the -17R. The excess thrust therefore can vary greatly over all of the B737s in the U.S. fleet. This measure is much more practical for the higher thrust engines than for the lower thrust engines.

The higher an aircraft's thrust, the faster it clears the runway and local air space. During a period of high activity use of derated takeoff may be undesirable because it would increase congestion around the airport. Also, noise reduction requirements may not permit low power takeoff because the flight path may take the aircraft over residences at a lower altitude.

Applications

The lower the thrust can be reduced, the greater the emission benefit from derated takeoff. There is a minimum safe level to which the thrust can be reduced. However, to a greater or lesser degree, derated takeoff can be practiced on most operations and even a slight reduction in takeoff thrust can reduce NO_X emissions.

Key Inputs

The key data needed to evaluate the emissions reduction benefit of derated takeoff are emission factors for normal takeoff and derated thrust power. To evaluate this measure, emissions first should be calculated for normal takeoff. The derated thrust emission factors then should be used to calculate the alternative emissions. The difference between the total emissions for normal takeoff and the alternative is equivalent to the benefit. However, emission factors are available for only one high power thrust level. If the takeoff thrust is reduced only slightly, the emission benefit can not be quantified.

In some circumstances, takeoff thrust reductions may be as low as the normal climbout thrust, for which emission factors are available. In such a case, the normal takeoff and climbout emission factors, available from sources including EPA's *Compilation of Air Pollutant Emission Factors* (AP-42), can be used to evaluate derated takeoff.

Calculation Procedure

$$E_{ij} = \Sigma (TIM_{jk}) * (FF_{jk}/1000) * (EI_{ijk}) * (NE_j)$$

Emission Reduction Benefit

Assume for TIM:

Takeoff time-in-mode is reduced to 0 and climbout time-in-mode is increased by 10% as a way to calculate the effect of derated takeoff.

No effect on delay or airport capacity.

Frequency of Use:

25% of all flights can apply derated takeoff 90% of the time

Emission Benefit:

Difference between emissions calculated using baseline assumptions and those calculated after applying above assumptions

Implementation Costs

Direct:

Fuel cost/savings = (frequency of use) $*$ [(TIM_{to}) $*$ $(FF_{to}/1000)$ - (ΔTIM_{co}) $*$ $(FF_{co}/1000)$] $*$ (jet fuel cost)

Indirect and Noneconomic:

Possibly pilot training costs

Assumptions

The following assumptions were made in calculating an emissions estimate for derated takeoff. The assumptions are for a situation in which derated takeoff thrust is as low as normal climbout thrust.

They are:

- derated takeoff will not affect airport congestion
- a pilot will apply derated takeoff only 90% of the time due to aircraft weight limits
- 25% of the airport's flights are able to takeoff using normal climbout thrust
- the time-in-mode for takeoff reduced to 0 and the climbout time-in-mode is increased by 20% as a calculational short cut.

Sample Calculations

An emissions estimate for derated takeoff was calculated for commercial aircraft at LAX in 1990. The estimate is valid only if takeoff thrust reductions are as low as the normal climbout thrust.

Sample Calculation For...

Derated Takeoff

Emissions = Σ(TIM) • (FF/1000) • (EI) • (NE)

— HC Emissions —

B737-300 Aircraft
CFM 56-3B Engine

DERATED TAKEOFF NOT IN USE

Mode	Time In Mode	Fuel Flow	HC Emission Factor	No. Of Eng.	Emissions
	MIN	LB/MIN	LB/1,000LB		LBS
Taxi-out	15.00	17.20	1.25	2	0.6450
Takeoff	0.95	150.79	0.04	2	0.0115
Climbout	1.14	123.02	0.05	2	0.0140
Approach	2.40	47.62	0.08	2	0.0183
Taxi-in	8.80	17.20	1.25	2	0.3784
B737-300 Emissions per LTO (lbs/LTO)					1.0672
Annual B737-300 LTOs					39,184
Total Annual HC Emissions (lbs)					41,816

Note: Takeoff time reduced to reverse thrust time only. Climbout increased by normal takeoff time.

DERATED TAKEOFF IN USE

Mode	Time In Mode	Fuel Flow	HC Emission Factor	No. Of Eng.	Emissions
	MIN	LB/MIN	LB/1,000LB		LBS
Taxi-out	15.00	17.20	1.25	2	0.6450
Takeoff	0.25	150.79	0.04	2	0.0030
Climbout	1.84	123.02	0.05	2	0.0226
Approach	2.40	47.62	0.08	2	0.0183
Taxi-in	8.80	17.20	1.25	2	0.37840
					1.0673
					39,184
					41,823

HC emissions are calculated for all aircraft in the fleet and summed to get total annual HC emissions.

	Not in use	In use
Fleet Total Annual HC Emissions (lbs)	4,697,755	4,697,437
Fleet Avg Emissions per LTO (lbs/LTO)	19.53	19.53

CO emissions are determined using similar calculations with appropriate emission factors.

	Not in use	In use
Fleet Total Annual CO Emissions (lbs)	11,672,618	11,673,194
Fleet Avg Emissions per LTO (lbs/LTO)	48.52	48.52

NOx emissions are determined using similar calculations with appropriate emission factors.

	Not in use	In use
Fleet Total Annual NOx Emissions (lbs)	6,939,500	6,757,017
Fleet Avg Emissions per LTO (lbs/LTO)	28.84	28.09

— Emissions Benefit —

Difference between emissions generated when the measure is not in use compared to when the measure is in use.

HC Emissions

w/o measure 4,697,755 lbs
with measure 4,697,437 lbs
HC Benefit = 318 lbs
Percent Reduction = 0 %

CO Emissions

w/o measure 11,672,618 lbs
with measure 11,673,194 lbs
CO Benefit = -576 lbs
Percent Reduction = 0 %

NOx Emissions

w/o measure 6,939,500 lbs
with measure 6,757,017 lbs
NOx Benefit = 182,483 lbs
Percent Reduction = 3 %

References

Some airlines encourage derated takeoff as a policy to save fuel, but leave it to the pilots' discretion to implement. Contact airlines for individual practices.

Measure Variations

A variation of this measure is to takeoff at full thrust but to cut back power at a lower altitude than otherwise. After takeoff, the pilot reduces from takeoff thrust to climbout thrust. As thrust decreases, the NO_X emissions are reduced. If thrust is reduced at a lower altitude, less time is spent operating at takeoff thrust. The less time the engines operate at full power, the lower the NO_X emissions. Some noise reduction takeoff profiles call for low altitude thrust reduction, particularly when residential areas are quite close to the end of the runway.

Implementation Feasibility

- Emission factor data is not available at two high-power thrust levels. Data only is available for normal takeoff and climbout thrusts. Available data can be used to calculate an emissions estimate if derated takeoff thrust is as low as normal climbout thrust.

- Implementing this measure is the responsibility of the airlines, working with the airports and FAA to insure the resulting flight path is safe and consistent with noise reduction plans.
- The measure apparently can be implemented under few constraints.
- The NO_X emission reductions are expected to be small, however, they are realized at no cost or even a cost savings.

3.2.9

Use Larger Aircraft

This measure increases the number of passengers per LTO, thus reducing total LTOs for a given number of passengers.

The U.S. aircraft fleet includes aircraft of various sizes. The same number of passengers can be serviced with fewer LTOs if larger aircraft are substituted where smaller aircraft currently are in use. For example, a Boeing 737-200 has approximately 110 seats and a Boeing 767-300 has approximately 220 seats. One 767 LTO can replace two 737 LTOs. Depending on the engines used, the pollutants emitted per seat may be lower for one 767 LTO than for two 737 LTOs. The measure has the potential of lowering both the number of LTOs and total emissions.

Constraints

Fleet mix and flight schedules are the primary constraints in using larger aircraft as replacements for smaller aircraft. Matching available aircraft to the service the airlines want to provide can be very complex. Projected demand for a particular route, availability of specific aircraft, opportunities for alternative uses for an aircraft, and potential load factor all must be considered. To make a larger aircraft available to replace the service being provided by smaller aircraft, the service provided by the larger aircraft must be replaced. This change in turn may affect connecting flight schedules and aircraft requirements. Business factors, such as scheduling and marketing considerations, also may be serious impediments for airlines trying to substitute aircraft on an existing route. These considerations drive airlines' decisions on where specific aircraft should operate and what type of aircraft to operate on a given route. For example, an airline that operates a B737-200 between two cities each hour may loose market share if it changes to a B767-300 operating every other hour because potential passengers may feel a loss in schedule convenience. This schedule also may be an inefficient way to deploy the B767-300 because its daily utilization (block hours per day) may decrease.

In some cases, emissions from one large aircraft may be higher than from two small aircraft. Therefore, substituting the larger aircraft may have reduced the number of operations, but not the total emissions.

Finally, while it may be a modest factor, it may cost an airline more to land one large aircraft than two small aircraft. Aircraft landing fees are established and administered by individual airports. Various factors, such as airport maintenance and operating expenses, are considered in calculating a fee. Landing fees are administered based on the aircraft's Maximum Gross Approved Landing Weight, a universally applied weight for an airline's aircraft model. For example, LAX's landing fee for a signatory airline's aircraft weighing more than 25,000 pounds is $0.51/1000lbs. The fee charged at LAX for landing two Boeing 737-200 Advanced, each with a landing weight of approximately 107,000 pounds would be $109. Conversely, the fee for landing one Boeing 767-300ER with a landing weight of approximately 320,000 pounds would be $163. Therefore, it would be slightly less expensive for the airline to land two 737s than one 767. This difference is more pronounced where landing fees are higher.

Applications

The most likely application for using larger aircraft is substituting two small aircraft with one large aircraft that has lower emissions. Individual airlines would be responsible for implementing this measure where feasible considering fleet, scheduling, and marketing issues.

An airport could possibly implement this measure by using a fee-based mechanism such as charging higher landing fees according to the number of aircraft seats or amount of emissions. Fees per landing could increase as the number of aircraft seats decreased or as aircraft emissions increased. Both approaches would encourage airlines to use larger aircraft and reduce LTOs, but the seat-related fee would not necessarily reduce emissions. Landing fees also would have to be substantially higher than they are at present to induce a change that may have significant costs in other areas.

Key Inputs

The key data needed for comparing emissions of large aircraft versus small aircraft is the number of seats by aircraft type. The number of seats on an aircraft varies by aircraft model, as well as within a particular model. Airlines choose the desired model configuration, which affects the number of seats. Seat data is available in the North American Edition of Official Airline Guides (OAG) *Desktop Flight Guide*, which displays most airlines' aircraft configurations by model. More detailed information is available from individual airlines, sometimes in their annual reports.

To the extent it is needed, aircraft landing weight is the key input for comparing fees paid for large aircraft versus small aircraft. Airlines and aircraft manufacturers calculate Maximum Gross Approved Landing Weights for all aircraft models according to FAA approved procedures. Aircraft weights are recorded by airports for every landing, usually for accounting purposes. Data is available from all three sources, depending on whether airline specific data is needed. Since an aircraft model's weight generally does not vary ular airport. The results of these changes are very difficult to anticipate. Emissions reductions can be calculated, but will not take into consideration possible changes to the makeup of the fleet servicing the airport.

Applications

The higher an aircraft's load factor, the lower the pollutants emitted per person. Load factors may vary among airports depending on the type of airport, such as hub versus primarily origination/destination. An incentive to raise load factor may be feasible at both types, however, the particular incentive may be different.

Key Inputs

The key inputs for evaluating increased load factor are current load factor and future fleet mix for a specific airport. To evaluate the measure, emissions must be calculated for an airport's expected fleet mix and load factor. Given an airport's current fleet mix and load factor, the emissions benefit is calculated as the difference between the baseline or current level and the future level. Sources for airport total and peak-period load factor data were not identified. *Air Transport World* magazine publishes national load factor data by airline for all major airlines based on Department of Transportation statistics. Current annual fleet mix data by airline and airport is available from FAA's *Airport Activity Statistics of Certificated Route Air Carriers.* The changes in the fleet servicing a particular airport due to the load factor limit must be forecast.

Assumptions

The following assumptions would have to be made in calculating a very rough emissions estimate for increasing load factor. The assumptions allow for the unknown load factor and fleet mix data.

They are:

- there will be no change in makeup of the fleet using the airport
- the average of all airlines' biannual system traffic load factor on a national level that operate at the airport is an adequate estimate of the load factor at a particular airport.

(Calculating an emissions estimate using these assumptions is not recommended as the results may be misleading. It should only be considered as a rough guide to the potential effect of changes in load factor.)

Sample Calculations

A meaningful emission estimate cannot be calculated due to the lack of information for a single airport. Generally, however, emissions will be reduced to the same extent average load factor improves, all else being equal.

References

Currently, no airport has applied a load factor limit as a way to control emissions. Contact airlines for individual load factor data. Some airports may collect this same data. Amsterdam's Schiphol Airport currently is involved in a large environmental impact study looking at air pollution measures related to airport activity. One phase of the study focuses on increasing load factors.

Measure Variations

No variations to simply increasing the load factor were determined.

Implementation Feasibility

- Current fleet mix data by airport is available. Airport total and peak-period load factor data is unavailable. National airline load factors can be obtained and used to provide a rough estimate. The future fleet mix that results from a load factor limit is a key factor in calculating emission reductions from the measure. Although current fleet mix data is available, future fleet mix must be forecast. Therefore, there is not enough data readily available by airport to credibly evaluate airport specific emission reductions.
- This measure would be the responsibility of the airlines working in conjunction with the airports.
- It appears difficult to implement the measure. Airlines may be limited in their ability to increase load factors during peak-periods because they already may be high.
- An emissions reduction would occur from increasing average load factor, but it is difficult to quantify the benefit.

3.2.11

Limit Aircraft Operations

This measure
limits the total number of LTOs,
which limits the total emissions.

Currently, four U.S. airports have federal limits on the number of aircraft operations allowed (O'Hare, Washington National, Kennedy, and La Guardia). For these airports, the number of landing slots is established by FAA to limit airspace congestion. The slot limit is determined by the airport's capacity. Limits on the number of operations per hour are set for three operator types: air carrier, commuter, and other (general aviation). In general, an airport's aircraft emissions increase with every additional LTO. Therefore, setting a limit on the number of aircraft operations allowed at a particular airport can limit the total aircraft emissions.

Constraints

Constraints in applying an operations limit include methods for establishing a limit and estimating emissions reductions and fleet changes. The FAA procedure for setting slot limits is a long process. Limits have only been established for four airports, with no other airports being considered at this time. As of now, the FAA is the only federal agency authorized to impose operation limits and only for reasons of aviation safety. If a limit on operations is set, it is difficult to estimate the emission reduction because the emissions change as the fleet changes and the fleet will change to make the most economic use of available slots. An airline's fleet and emissions also change as aircraft are bought, sold, leased or retired. Modifications in the fleet may include substituting larger aircraft for smaller aircraft in order to move more passengers with less operations. Depending on the aircraft that fill the slots, emissions per LTO could increase.

APPLICATIONS

A likely target for this measure would be limiting the number of aircraft operations at an airport where the number of LTOs is increasing past the airport's design capacity, since FAA's authority only covers situations of aviation safety. This measure may be most appropriate for reducing emissions at general aviation airports.

KEY INPUTS

The key inputs are LTOs and fleet mix for calculating emissions reductions from the limitation of aircraft operations. To evaluate the measure, emissions must be calculated for a future fleet mix and a given LTO limit. Future fleet mix must be forecast. The emissions estimate is compared to emissions from current LTO and fleet mix data, which is available. This data can be used to estimate emission reductions, but would assume no change in makeup of the fleet using the airport.

ASSUMPTIONS

Several assumptions were made in calculating an emissions estimate for limiting aircraft operations at an airport. The first assumption addresses the primary constraint of future fleet changes. They are:

- there will be no change in makeup of the fleet using the airport
- the limit on aircraft operations reduces the total number of LTOs by 5%
- total pollutant emissions will reduce the same percent as the LTO reduction.

SAMPLE CALCULATIONS

An emissions estimate for limiting aircraft operations was calculated for commercial aircraft at LAX in 1990. The emissions estimate does not consider future fleet changes, which affect emissions. The calculated emission reduction benefit is:

Pollutant	Reference Emissions 240,580 LTOs (lb/yr)	Emissions[1] 228,551 LTOs (lb/yr)	Limited LTOs Emission Reductions (lb/yr)
HC	4,697,755	4,462,867	234,888 (5%)
CO	11,672,618	11,088,986	583,631 (5%)
NOX	6,939,500	6,592,525	346,975 (5%)

1. The annual LTOs are reduced 5%.

REFERENCES

The four airports with FAA established slot limits are Kennedy, La Guardia, National, and O'Hare (see Appendix D - 14CFR 93.121 High Density Traffic Airports). At this time, no other airports are being considered for slot limits.

MEASURE VARIATIONS

One measure variation is to limit another variable that is a surrogate for operations, such as total emissions, total passengers, or the type of aircraft allowed to use a specific airport.

IMPLEMENTATION FEASIBILITY

- ▶ While emission reductions can be calculated assuming no change in makeup of the fleet using the airport, fleet changes are likely and the nature of those changes must be carefully forecast.
- ▶ Limiting operations is the responsibility of the FAA.

- ▶ It may be difficult to implement this measure in the near future or at all. FAA currently is not considering any additional airports for slot limits. Even if slot limits were established, an accurate emission reductions estimate would be difficult to calculate due to the lack of future fleet mix data based on the operations limitations.

✣ ✣ ✣ ✣ ✣ ✣ ✣

3.2.12

Manage Fleet To Minimize Emissions

This measure is intended to increase the number of seats per LTO and minimize the emissions per seat.

Most airlines' fleets are comprised of a variety of aircraft and engines. Some aircraft have much lower emissions than others due to the engine model and vintage. Airlines also have different designs for the aircraft interiors that accommodate more or fewer seats. Airlines manage their fleets according to related business factors, such as scheduling and marketing considerations. It may be possible for an airline to manage its fleet so only the cleanest aircraft operate into particular airports or, more likely, geographic regions. If the fleet is managed so that only the cleanest aircraft operate with the highest feasible load factor at a given airport (or all airports in a given region), the airport's emissions would be reduced.

CONSTRAINTS

Constraints to implementing this measure include current fleet mix, competitive business factors, and the possible illegality of imposing fleet mix requirements. An airline's existing fleet may not accommodate the efficient substitution of aircraft due to varying sizes and populations of aircraft models. Fleet management also depends on many business factors, such as scheduling and marketing considerations. These factors drive airlines' decisions on where specific aircraft should operate and what type of aircraft to operate on a given route. Finally, it may be illegal to impose this type of constraint on airlines.

Applications

The older, larger, and more diverse an airline's fleet, the greater the potential emissions reduction benefit from airline fleet management. It may be illegal to impose this measure on airlines.

Key Inputs

The key data needed to evaluate management of the fleet are current fleet mix and engine model by aircraft type. The measure is evaluated by calculating emissions for a potential airport fleet that is made up of the cleanest aircraft in the total fleet. Given an airport's current and possible fleet, emissions would be calculated for the cleanest potential fleet. An airport's current fleet by airline is available in FAA's *Airport Activity Statistics of Certificated Route Air Carriers.* An airline's current total domestic aircraft fleet is available from its annual report. Information on the engines operating on the aircraft is not readily available.

Assumptions

This measure was not assessed because the feasibility of an airline placing its cleanest aircraft into a single market is unknown. No data is available to formulate the necessary assumptions for calculating an emissions estimate.

Sample Calculations

No data is available to provide sample calculations for managing fleet to minimize emissions.

References

No attempt by airlines to manage their fleet to place their cleanest (or newest) aircraft into a single market has been identified. Contact airlines for individual policies and capability.

Measure Variations

No variations to this measure were considered.

Implementation Feasibility

- An airport's current fleet by airline and an airline's current total fleet are available. Data on the engines operating on the aircraft are not readily available.
- Implementing this measure would be the responsibility of the airlines.
- It may be illegal to impose this measure on airlines.

3.3

Conclusions

Several operational, procedural, and technological measures that can reduce emissions from aircraft operations are possible. Table 3-4 summarizes those measures and shows the relative emission reduction potential. Many of these can be implemented at little or no cost and may even result in cost savings while for many others the costs are indeterminate without much more information than is available generally. Particularly for those measures that rely on changes to the make up of an airlines' fleet or the mix of aircraft that operate at a given airport, it is extremely difficult to quantify the costs. In all likelihood, the costs would vary widely between individual airlines and airports. For practically all of the listed measures, additional data would be very helpful, if not essential, for quantifying emission reductions and implementation costs precisely.

TABLE 3-4
Aircraft Emission Mitigation Measures

Mitigation Measure	Benefit Desired	Pollutants Affected	Responsible Party	Emission Reduction Potential	Relative Cost
Single/Reduced Engine Taxiing	Reduce Engine Idle Time	HC, CO	Airlines	Moderate	Low
Reduce Reverse Thrust Use	Reduce High Power Engine Operation	NO_x	Airlines	Small	High
Tow Aircraft to Runway	Reduce Engine Idle Time	HC, CO	Airlines, Airports	Large	Moderate
Take Passengers to Aircraft	Reduce Engine Idle Time	HC, CO	Airports	Indeterminate	Indeterminate
Congestion Reduction	Reduce Engine Idle Time	HC, CO	Airports, FAA	Large	Low to Moderate
Fleet Modernization	Decrease Fleet Engine Emissions	HC, CO	Airlines	Large	High
New Engine Standards	Reduce Engine Emissions	HC, CO, NO_x	EPA	Large	Moderate
Derated Takeoff	Decrease Engine High Power Operation	NO_x	Airlines	Small	Low
Use Larger Aircraft	Reduce LTOs	HC, CO, NO_x	Airlines	Large	Indeterminate
Increase Load Factor	Reduce LTOs	HC, CO, NO_x	Airlines	Indeterminate	Indeterminate
Limit Aircraft Operations	Reduce LTOs	HC, CO, NO_x	FAA, EPA	Large	Indeterminate
Manage Fleet to Minimize Emissions	Increase Seats per LTO	HC, CO, NO_x	Airlines	Indeterminate	Indeterminate

— SECTION 4 —

Ground Support Equipment

4.1

Introduction

Emissions from ground support equipment (GSE) range from 2-6% of total emissions at commercial airports. This section describes measures to reduce these emissions in ways that would have little impact on the services they provide.

A variety of equipment is used at airports to service aircraft. Several types of equipment are common at most commercial airports.

- **Baggage Tractors** haul baggage trailers between the terminal and the aircraft.
- **Aircraft Tractors** tow aircraft from the taxiway to the terminal and push back the aircraft from the terminal to the taxiway. They also are used to tow aircraft to hangers for maintenance.
- **Ground Power Units** (GPU) are ground based mobile generator sets. They supply electricity to aircraft while they are parked at the airport.
- **Air-conditioning Units** provide conditioned air to ventilate, cool, and heat parked aircraft.
- **Air Start Units** provide large volumes of compressed air that is used by the aircraft to start the main engines (jet turbine).
- **Baggage Conveyors** are mobile conveyor belts used to lift baggage from the tarmac to the aircraft's hold.
- **Other Secondary GSE** includes items such as forklifts, deicing trucks, lavatory trucks, fuel trucks, miscellaneous load handling equipment, carts, lifts, maintenance trucks, and other miscellaneous equipment.
- **Auxiliary Power Units** (APUs) are small turbine engines on-board the aircraft designed to supply the electrical, ventilation, and air starting needs of the aircraft without using GSE. Although this equipment is on the plane, APU use will be analyzed with the GSE because they are used in the absence of GSE.

The majority of GSE have engines that burn gasoline, diesel, or LPG, while APUs burn jet fuel (Jet A), although there are electric versions of most types of GSE on the market.

In order to analyze the benefits of eliminating or altering any specific type of GSE, it is first necessary to estimate the emissions generated by the current fleet of GSE; i.e., determine the "reference" emissions generated in ground support. The emissions reductions from a given measure is determined by comparing the new emissions generated to the "reference" emissions. The emissions generated by GSE and APU operations can be determined by first estimating the population of each type of equipment. Combined with the engine and usage characteristics (BHP and load factor), usage time, and the emission factors, an estimate of operational emissions can be calculated. Total emissions from GSE are calculated with the following formula:

$$E_i = \Sigma(P_j \cdot BHP_j \cdot LF_j \cdot \text{Use Hours}_j \cdot EF_{ij})$$

Where:

- E_i = total mass of emissions of pollutant i (CO, HC, NO_x, PM)
- P_j = population of ground support equipment of type $_j$
- BHP_j = the rated horse power of equipment type $_j$
- LF_j = the load factor of equipment type $_j$
- Use Hours_j = the operating time of equipment type $_j$ in hours per day.
- EF_{ij} = the emission rate of pollutant i in gm/BHP-hr from ground support equipment of type $_j$

4.2

Population Estimation

The population of GSE at an airport can be determined by obtaining detailed counts or by estimation. Detailed population data was difficult or impossible to obtain for all airports in california. Thus populations were estimated by calculating the relationship between the known population of GSE at a subset of California airports to the commercial aircraft activity at the airports. GSE inventories were provided in confidence by several air carriers for their GSE operations in California. The operational activity of air carriers is documented in the annual FAA publication, *Airport Activity Statistics of Certificated Route Air Carriers*. The relationship between GSE inventories and several measures of aircraft activity was analyzed. Aircraft activity is represented by the total number of departures, the number of departures by body type (narrow v. wide), and by the number of seats. Given the limited available data, the best statistical correlation was found between the total GSE populations and the total departures. The regression was applied to each California airport's total departures yielding estimates of the total population of GSE in California (See Table 4-1). The total GSE populations were broken down to equipment type using the average percent of equipment by type to total population. The averages were calculated from data provided by some air carriers for California airports. The equipment ratios are contained in Table 4-2.

The other inputs to the emissions calculation are engine usage characteristics, brake horsepower (BHP), equipment usage time, operation load factors, and emissions factors. This information was provided by two air carriers and was supplemented with information from a variety of equipment manufacturers and from Jane's *Airport & ATC Equipment, 1992-93.*[1] This data is shown in Table 4-3. The final input to the emissions equation, emissions factors, are drawn from two CARB

1. Rider, David F. ed, "Jane's Airport & ATC Equipment 1992-93." Jane's Data Division, 1992.

TABLE 4-1

California GSE Population Estimates

Airport	Total Departures	Estimated Population*
Hollywood - Burbank	30,444	75
Indio/Palm Springs	9,270	25
Long Beach	14,443	37
Los Angeles International	240,579	1,235
Oakland Metropolitan	45,986	112
Ontario International	40,925	96
Orange County/John Wayne	37,275	89
Sacramento Metropolitan	39,723	94
Salinas/Monterey	5,276	16
San Diego - Lindbergh	70,156	166
San Francisco International	172,007	395
San Jose Municipal	49,173	119
Santa Barbara	9,999	27
TOTAL	**765,256**	**2,486**

** Populations are rounded to nearest whole number.*

TABLE 4-2

Breakdown Of GSEs

— BY EQUIPMENT TYPE —

Equipment Type	Ratio	Equipment Type	Ratio
Baggage Tug	23.57%	Service Truck	3.45%
Buses, Cars, Pickups, and Vans	11.20%	Lift	2.99%
Belt Loader	10.09%	Fuel Truck	2.54%
Forklift	9.24%	Bobtail	2.21%
Maintenance Truck	5.99%	Air Start Unit	1.82%
Aircraft Tug	5.60%	Lav Truck	1.63%
Other	4.69%	Air-conditioning Unit	0.98%
GPU	4.43%	Deicer	0.72%
Cargo Loader	4.23%	Lav Cart	0.52%
Cart	3.84%	Water Truck	0.26%
		Total	**100.00%**

TABLE 4-3

Ground Support Equipment Use Characteristics

Equipment Type	Engine Type	Coolant Type	BHP	Load Factor	Use Per Day	Equipment Ratio
Aircraft Tug (Narrow Body Aircraft)	Diesel	Water	175	80%	1.51	0.02965
	Electric	Water	0	0%	1.51	0.00260
	Gasoline (4 Stroke)	Water	130	80%	1.51	0.01042
	LPG	Water	130	80%	1.51	0.00260
Aircraft Tug (Wide Body Aircraft)	Diesel	Water	500	80%	1.41	0.01042
	Gasoline 4 Stroke	Water	500	80%	1.41	0.00130
Air-conditioning Unit	Diesel	Water	300	75%	0.06	0.00521
	Gasoline (4 Stroke)	Water	130	75%	0.06	0.00456
Air Start Unit	Diesel	Water	600	90%	0.37	0.01432
	Electric	Air	0	90%	0.37	0.00065
	Gasoline (4 Stroke)	Water	130	90%	0.37	0.00195
	Jet Turbine	Air	140	90%	0.37	0.00130
Baggage Tug	Diesel	Water	78	55%	2.40	0.08724
	Electric	Air	0	55%	2.40	0.01107
	Gasoline (4 Stroke)	Water	100	55%	2.40	0.11393
	LPG	Water	100	55%	2.40	0.02344
Belt Loader	Diesel	Water	45	50%	2.22	0.03971
	Gasoline (4 Stroke)	Water	60	50%	2.22	0.05404
	LPG	Water	60	50%	2.22	0.00716
Bobtail	Gasoline (4 Stroke)	Water	100	55%	2.40	0.02214
Cargo Loader	Diesel	Water	76	50%	1.97	0.03320
	Gasoline (4 Stroke)	Water	70	50%	1.97	0.00456
	LPG	Water	70	50%	1.97	0.00456

TABLE 4-3 (CONTINUED)

Ground Support Equipment Use Characteristics

Equipment Type	Engine Type	Coolant Type	BHP	Load Factor	Use Per Day	Equipment Ratio
Cart	Electric	Air	0	50%	0.41	0.02930
	Gasoline (4 Stroke)	Air	12	50%	0.41	0.00846
	LPG	Air	12	50%	0.41	0.00065
Deicer	Diesel	Water	93	95%	0.06	0.00065
	Gasoline (4 Stroke)	Water	93	95%	0.06	0.00651
Forklift	Diesel	Water	52	30%	1.99	0.00521
	Electric	Water	0	30%	1.99	0.01497
	Gasoline (4 Stroke)	Water	50	30%	1.99	0.03320
	LPG	Water	52	30%	1.99	0.03906
Fuel Truck	Diesel	Water	180	25%	0.06	0.00130
	Gasoline (4 Stroke)	Water	130	25%	2.96	0.02344
	LPG	Water	130	25%	2.96	0.00065
GPU	Diesel	Water	145	75%	2.18	0.03906
	Electric	Air	0	75%	2.18	0.00065
	Gasoline (4 Stroke)	Water	150	75%	2.18	0.00456
Lav Cart	Gasoline (4 Stroke)	Air	12	50%	0.50	0.00521
Lav Truck	Gasoline (4 Stroke)	Water	130	25%	3.32	0.01628
Lift	Electric	Air	0	50%	1.03	0.00586
	Gasoline (4 Stroke)	Water	100	50%	1.03	0.01497
	LPG	Water	100	50%	1.03	0.00911
Maintenance Truck	Diesel	Water	130	50%	1.23	0.00260
	Gasoline (4 Stroke)	Water	130	50%	1.23	0.05599
	LPG	Water	130	50%	1.23	0.00130
Other	Diesel	Water	50	50%	0.50	0.00260
	Gasoline (4 Stroke)	Water	50	50%	0.50	0.04232
	LPG	Water	50	50%	0.50	0.00195
Service Truck	Diesel	Water	170	20%	3.56	0.01107
	Gasoline (4 Stroke)	Water	180	20%	3.56	0.02148
	LPG	Water	180	20%	3.56	0.00195
Water Truck	Gasoline (4 Stroke)	Water	150	20%	0.85	0.00260
Bus	Diesel Truck	Water	180	25%	5.33	0.00651
	Gasoline Truck	Water	130	25%	5.33	0.00260
Car	Gasoline Car	Water	130	25%	0.51	0.01172
	LPG Car	Water	130	25%	0.51	0.00065
Pickup	Gasoline Truck	Water	130	25%	1.45	0.05404
	LPG Truck	Water	130	25%	1.45	0.00326
Van	Gasoline Truck	Water	130	25%	0.85	0.03320
Total						**1.0000**

reports: *"Regulatory Strategies For Off-Highway Equipment"* (draft) and *"Feasibility of Controlling Emissions From Off-Road, Heavy-Duty Construction Equipment,"* and are shown in Table 4-4.[2]

Road licensed vehicles such as cars, buses, pick up trucks, and vans were included in the GSE population provided by the airlines and are listed in Table 4-3. Because they are licensed for on-highway operations they are subject to current state and federal emissions and operational regulations (for example, the California LEV program and the federal clean-fuel vehicle requirements for centrally fueled fleets). Little additional benefit beyond that achieved from these programs can be realized by implementing the measures discussed in this section. Also, including emissions from these vehicles could lead to double counting emissions reductions or overlap with other programs. For these reasons, these vehicles have not been included in the emissions mitigation calculations in this report.

4.3

Measures

When parked at a terminal gate, large commercial aircraft require an electrical power source and, in warmer climates such as California's, air-conditioning. The electricity operates the avionics, on-board lighting, and other electrical equipment (i.e., cooling fans, coffee pots, cleaning equipment, etc.). Air-conditioning maintains the passenger compartment at a comfortable temperature and sensitive electrical equipment within its design operating temperature range. There are essentially three ways to provide for

2. "Regulatory Strategies For Off-Highway Equipment", draft report prepared for California Air Resources Board, El Monte, California, prepared by Energy and Environmental Analysis, January 1992. and "Feasibility Of Controlling Emissions From Off-Road, Heavy-Duty Construction Equipment", prepared for California Air Resources Board, El Monte, California, prepared by Energy and Environmental Analysis, December 1988.

TABLE 4-4

Emission Factors for GSE Engines

— IN GRAMS/BHP-HOUR —

Engine Type	Coolant Type	Horsepower Range	HC	NOx	CO	PM
Gasoline (4 Stroke)	Air Cooled	1 to 24	10.0	2.0	360.0	0.2
	Air Cooled	25 to 50	7.0	3.0	400.0	0.0
Gasoline (4 Stroke)	Water Cooled	25 to 50	4.0	4.0	240.0	0.0
	Water Cooled	51 to 9,999	4.0	4.0	240.0	0.0
Diesel	Water Cooled	1 to 50	1.0	11.0	4.0	0.7
	Water Cooled	51 to 9,999	1.2	11.0	4.0	0.5
OEM Optimized CNG	Water Cooled	1 to 24	5.0	4.0	180.0	0.0
	Water Cooled	25 to 50	2.0	6.0	120.0	0.0
	Water Cooled	51 to 9,999	1.0	3.5	2.1	0.0
Existing CNG or LPG	Air Cooled	1 to 24	5.0	4.0	180.0	0.0
	Air Cooled	25 to 50	4.0	6.0	200.0	0.0
Existing CNG or LPG	Water Cooled	1 to 24	5.0	4.0	180.0	0.0
	Water Cooled	25 to 50	2.0	6.0	120.0	0.0
	Water Cooled	51 to 9,999	2.0	6.0	120.0	0.0

these electric and cooling needs. First, in the absence of other support, the on-board Auxiliary Power Unit (APU) provides the electricity and air-conditioning by mechanically powering a generator and pneumatically powering the on-board air-conditioning system (it uses the compressed air from the turbine "bleed off"). Second, ground support equipment can provide electricity from a mobile ground power unit (GPU) and air-conditioning from a mobile air-conditioning cart. Both types of GSE burn either gasoline or diesel fuel. Finally, fixed power systems can draw electricity from the main power grid and convert it to the electrical current used by the aircraft. Fixed air-conditioning systems can supply air-conditioning to parked aircraft utilizing electric air-conditioning units or by providing compressed air to the on board air-conditioning system (pneumatic system). Both fixed electrical and air-conditioning systems are electric powered and power is supplied by the local utility power grid.

One mitigation measure considered in this analysis is to replace the use of APUs and GSEs with fixed electrical power and air-conditioning systems. Fixed systems provide all of the services needed by an aircraft parked at a terminal gate with none of the on-site emissions that come from the GSE and APUs.

4.3.1

Fixed Electrical Systems

This measure reduces the need for GSE and APU use.

Fixed electrical systems supply electricity from the local electric power grid to aircraft, eliminating the need for GPUs and APUs to meet the aircraft's power needs. However, the utility power must first be converted from the type the utility supplies (480 volt, 60 hertz) to the type large commercial aircraft use (120/208 volt, 400 hertz power). There are two different types of power conversion equipment, motor generators and solid state static inverters. Motor generators use the 60 hertz AC to power a motor that mechanically drives a generator that produces electricity at 400 hertz AC. Solid state static inverters electronically convert the 60 hertz AC to DC and then convert the DC to 400 hertz AC. There are three different systems used to distribute the 400 hertz power to the aircraft: centralized fixed power systems, mini-centralized fixed power systems, and point-of-use power systems. The three systems differ in the way power is distributed to the terminal gates and the location of the power converters.

Centralized fixed power systems convert the utility power from 60 hertz to 400 hertz at one central location with several converters working together to convert the power used by the entire system. A wiring network then distributes power from the central source to the gates. The network distributes 400 hertz power at 575 volts and transformers at each gate drop the voltage down to 120/208. The higher voltage is used in the distribution network to minimize the power losses in transmission. Centralized power systems normally require a redundant power converter to ensure system reliability.

Mini-central fixed power systems allocate the airport's gates into several sections. A power converter supplies 400 hertz power to each section independently. Otherwise, this type of system operates like a version of a centralized system. This system services the same number of aircraft as a centralized system only with more, albeit smaller, power conversion units. Redundancy is built into the system by using oversized or extra power converters.

Point-of-Use systems distribute the conventional utility power (60 hertz) to each gate where it is converted to the required 400 hertz power. This type of system generally converts the power with static inverters because of their compact size. They are also light enough to be mounted on the end of the passenger bridge. One drawback with in point-of-use systems is in the requirement to have a separate power converter for each gate, which leaves each gate vulnerable to interruption. However, anecdotal operational experience suggests that static inverters are reliable under all normal operational conditions.

CONSTRAINTS

In evaluating the functional differences between the three systems, the main issues are the ease of installation and the ability of each system to handle varied electrical loads. Fully centralized power systems are difficult to install because all of the gates must be wired to one central location. Often the terminal's architecture does not facilitate this type of installation retrofit. In these cases the terminal must be modified to ensure that the wiring takes the most direct path to reduce transmission losses. Mini-centralized systems are easier to install because the electric converter units are smaller and the wiring requirements are less intrusive. Point-of-use fixed power systems are easiest to install because the power converters are small enough to be mounted at the end of the passenger bridge servicing each gate independently. Also, utility level power lines are easier to install (often they are already installed) at the terminal gates.

On the other hand, centralized power systems are most capable of handling varying loads at airport terminals because of their built-in extra capacity and redundant power converters. Mini-centralized systems compromise on their ability to handle widely varying loads because of the reduced capacity power transformers. It is unclear whether point-of-use systems are capable of handling the largest power loads. For instance, the new B747-400 requires 211 kva to operate all of the on-board equipment necessary to complete a pre-flight take off and operate all of the kitchen equipment (coffee pots and ovens).[3] Until this new and largest class of aircraft entered service, all three systems were capable of handling loads of 60 and 90 kva. Now, the 90 kva point-of-use units can service this aircraft only if they can sustain up to 115% capacity for several minutes while the pre-flight check is conducted and no kitchen equipment is on. The 90 kva point of use power converters will have to be replaced with 225 kva units to service B747-400s.[4] With the centralized and minicentralized systems the excessive power requirements of a limited number of B747-400 could be absorbed by the additional capacity built into these systems. However, the B747-400 currently is serviced only at San Francisco and Los Angeles International Airports.

As part of a proposal to the Metropolitan Washington Airports Authority, a centralized power equipment contractor analyzed the costs and benefits of servicing 44 terminal gates. They summarized the pros and cons of each system and the information is shown in Table 4-5. The alternatives presented in Table 4-5 are compared to APU usage.

3. "Boeing 747-400 Ground Power Requirements Test", Stephen LeFevre, April 20, 1990.

4. The 747-400 requires 99 kva with a power factor of .80 to complete the pre-flight checklist with out turning on any of the kitchen equipment. The 16 on-board ovens alone require an additional 112 kva at a power factor of 1.0.

4.3.2

Fixed Air-conditioning Systems

This measure reduces the need for GSE and APU use.

In warmer climates (i.e., California) aircraft parked at terminal gates require air-conditioning to keep the cabin cool for the passengers and crew. All large commercial aircraft have on-board air-conditioning units that are powered by compressed air from the APU. The onboard air-conditioning unit uses an expansion turbine that converts the pressurized air to a lower pressure, cooling the air that is circulated throughout the aircraft cabin. As an alternative to APU powered cooling there are three different types of fixed air-conditioning systems that supply aircraft with cooled air: a centralized preconditioning system, a point-of-use preconditioning system, and a pneumatic system.

Centralized preconditioning systems utilize a central chiller plant and remote air handling units (AHU). The central chiller plant cools a liquid coolant (normally an ethylene glycol - water mixture) to 20°F. The coolant circulates to each gate in a piped loop or series of piped loops. At each terminal gate the AHU blows air across a radiator filled with the coolant, through a flexible hose (16" wide and 65' to 80' long), and into the aircraft via ventilation inlets in bottom of the aircraft. See Figure 4-1. An additional heating unit added to the AHU enables this system to

TABLE 4-5
Pros And Cons Of Centralized Power Systems

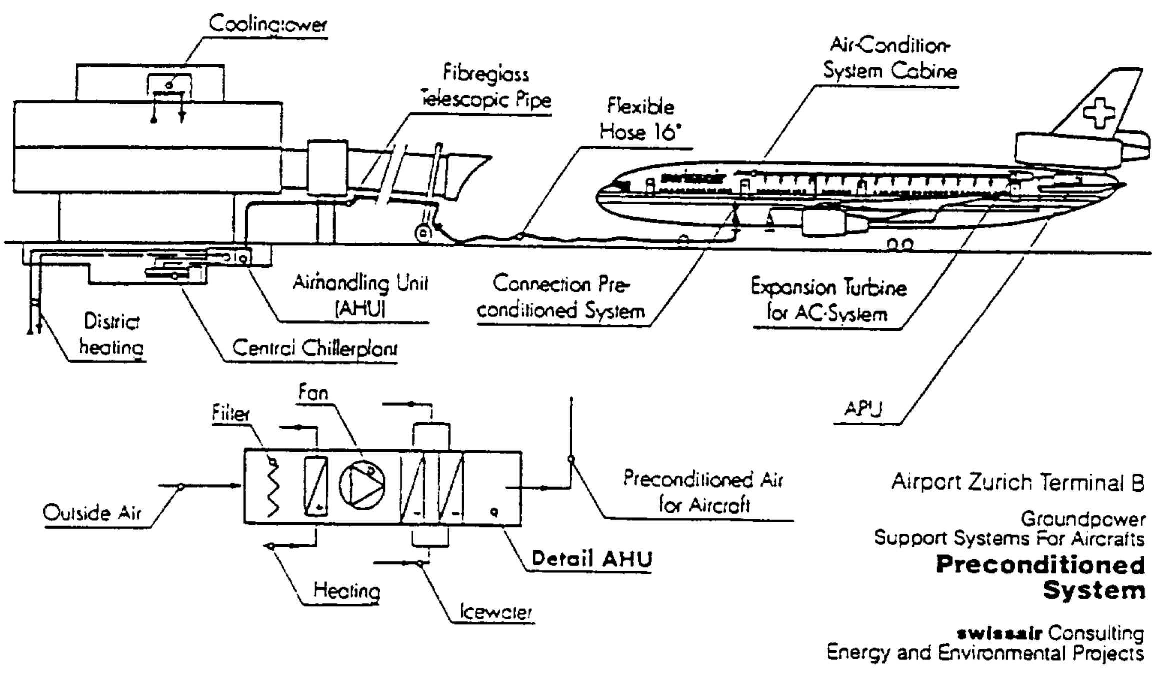
	APUs	Mobile Diesel	Mobile Elect.	Point-Of-Use	Mini-Central	Centralized
Initial Investment	None	Low	Low	Medium	Medium	High
Fuel Consumption	Very High	High	None	None	None	None
Air Pollution	Very High	High	None	None	None	None
Noise Pollution	Very High	High	None	None	None	None
Congestion	None	Yes	Yes	No	No	No
Flexibility	None	Yes	Yes	None	Yes	Yes
Electric Use	NA	NA	Low	Low	Low-Medium	Low-Medium
Electric Cost	NA	NA	Low	Low	Low-Medium	Low-Medium
Distribution	None	None	Low-Medium	Low-Medium	Medium	High
Electric Room	None	None	None	No	Yes	Yes
Substation Room	NA	NA	No	No	No	Yes
Ceiling Space	NA	NA	No	No	Yes	Yes
Maintenance	High	High	Medium	Medium-Low	Medium-Low	Medium-Low
Operating Efficiency	Very Low	Medium	High	High	High	Medium
Payback (Yrs)	Base	1.49	1.69	1.52	1.51 - 1.70	2.60 - 2.75

provide heat to the aircraft in the winter as well. The heat can be supplied by a centralized heating plant, by electric heating units, or both in colder climates.

Centralized preconditioning systems are available in a variety sizes, with the number of gates serviced dependent upon the size of the chiller plant. All centralized preconditioning systems utilize standard industrial chillers. The larger systems use traditional condensing methods for cooling, involving cooling towers or evaporative condensers. These systems utilize their economies of scale to efficiently service the varied levels of demand for cooling. Small chiller plants generally utilize two or more air cooled chillers (eliminating the need for cooling towers or evaporative condensers). Small chiller plants are more suitable to airports where the 480 volt, 60 hertz power is limited.

Point-of-use preconditioned air systems supply cool air to a single aircraft. These systems are small enough to be mounted under the gate bridge and they utilize an individual air conditioning and heating unit. They are powered with standard 480 volt, 60 hertz electricity and are available in sizes capable of supplying preconditioned air to both narrow and wide body aircraft. Because point-of-use systems are discrete systems, the airport's entire system is not vulnerable to failure. Conversely the entire network is vulnerable to interruption due to equipment failure in centralized systems. Point-of-

FIGURE 4–1
Centralized Air Conditioning System



use systems also require little disruption to the terminal during installation. This system is installed by attaching the air conditioning/heating unit to the bottom of the gate structure, wiring the unit into the terminal's electrical system, and attaching the hose storage basket and the operator station.

Pneumatic power distributed to each gate is another way to cool an aircraft with a fixed centralized system. This type of system uses a central electric screw type compressor and air storage tank(s) to compress and store air. High pressure hoses carry pressurized air from the compressor station to the gate through a dedicated line. At the gate, a reinforced flexible hose connects the compressed air outlet to the plane. The compressed air powers the aircraft's on-board air-conditioning unit.

Installing this type of system requires essentially the same type of additions as the centralized preconditioning systems. A central compressor must be connected to the gates with a series of reinforced pipes capable of handling the compressed air.

Disruptions due to installation and the necessary terminal modifications make central chiller plant and central compressor systems more difficult and costly to install than the point-of-use systems. However, centralized systems benefit over the long term from the economies of scale offered in servicing a number of gates with a single or several plants. Determining which system best suits a particular airport depends on a number of factors that must be analyzed airport by airport. The existing structure of the airport, cooling (and heating) needs, electric capacity, and budgetary considerations all play a role in determining which system works best at a given airport.

CONSTRAINTS

Installing and utilizing fixed electrical and air conditioning systems will not immediately eliminate the need for APU and/or GSE usage. Current fixed systems are not able to provide all the support needs of the aircraft parked at the gate. Also, installation of fixed support systems is difficult and costly, especially in existing terminals. These issues can inhibit the usage of central and air-conditioning support systems.

Fixed electrical and air-conditioning systems are not always utilized, even when they are available. To start the main engines, the APU must be started to provide the volume of pressurized air needed to start the main engines. The engines in typical narrow body aircraft require 90 pounds per minute (ppm) of air pressurized to 42 psi and wide body aircraft require approximately 120 ppm at 42 psi. APUs require about 10 minutes to warm up and start one or more jet engines. Sometimes when an aircraft is scheduled to be parked at the gate for a short stay (less than 30 minutes) pilots consider it advantageous to leave the APU running. At airports with only fixed electrical supply, the APU is operated to provide air-conditioning to the cabin as well as to start the main engines. Thus, without both fixed electric and air-conditioning the APU will be operated. Without ground support to start the main engines, the APU must be operated for a minimum of 10 minutes before each departure. At least one major air carrier currently has a policy instructing the captain to hook up to fixed power and air-conditioning systems whenever they are available to minimize APU usage. However, the final control of the aircraft's engines and APU remains with the captain and the flight crew and depend on local conditions and operational considerations.

A ground air start unit can be used to start the main engines. Typically this type of unit uses a large diesel engine and a screw compressor to provide the volume of compressed air needed. They often are used when the aircraft's APU is not working rather than being the preferred alternative to APU use.

Finally, there are additional zoning and building regulations at airports which make major modifications to the airport difficult. These regulations vary from airport to airport; they generally do not prevent the installation of fixed power and air-conditioning systems, but slow it down. This delay and administrative burden adds to the installation costs. Also, there are legal concerns about ownership and maintenance related to leased gates at terminals. These issues must be resolved before any fixed aircraft support equipment can be installed.

While these constraints to using fixed power and air-conditioning systems are serious, none of them is enough to prevent their installation and usage if the decision is made to install them and to significantly reduce the emissions from GPUs and APUs.

APPLICATIONS

There are few operational differences between fixed electrical and air systems and mobile GSE. Both systems are connected to the aircraft with standard plugs once the aircraft parks at the terminal gate. Both systems provide the electric power and air-conditioning in the levels needed by the aircraft at the gate. However, fixed systems offer some advantages over mobile GSE usage. In fixed systems operations, the power or air comes from outlets at the gate. This makes fixed systems less obtrusive than GSE at the gate. Also, mobile GSE use engines for power, which necessitates refueling and regular maintenance, whereas electric powered fixed systems require no refueling and less maintenance.

Airports can fall under the jurisdiction of the city, county, state and federal governments, or the Federal Aviation Agency (FAA), all of whom have their own set of construction codes. The airport authorities have a regulatory review process which coordinates the implementation of the regulations imposed by all concerned governments and agencies.

Thus, the specific building codes and operation regulations that apply to each airport changes from airport to airport. This process has become even more complicated in relation to air pollution regulations that cut across traditional political boundaries.

SAMPLE CALCULATIONS

To calculate the emissions savings offered by utilizing fixed electrical and air-conditioning systems at an entire terminal, or even a portion of the terminal, the level of emissions generated with the current operations are calculated and then the emissions generated by APUs, GPUs, and mobile air-conditioning units being replaced with the fixed ground support systems are subtracted from the baseline. This calculation is represented by the following formulas:

APU Emission Level	=	Population of A/C Using APUs • Fuel Flow Rate • Emissions /lb. fuel
GSE Emissions Level	=	Pop. of GSE by Type • HP • LF • Usage • Emissions/BHP-hr.
Total Emissions Level	=	APU Emissions + GSE Emissions
Displaced Emissions (On-Site)	=	[(Number of Aircraft Using Central System/Total Aircraft serviced) • APU Emissions Level)] + [Number of Aircraft Using Central System/Total Aircraft Serviced) • GSE Emissions Level]

As seen in Table 4-6, this analysis suggests that the economics of supporting aircraft parked at airport gates favor fixed power and air conditioning systems over a period of time. By eliminating the usage of APUs, fuel and maintenance costs are saved. The exact cost trade off depends on the construction and usage level associated with a specific airport. Table 4-6 itemizes the construction and energy costs of installing fixed electrical systems. Noticeably, this comparison suggests that using mobile GSE (GPUs) is the most cost effective alternative to APU usage, although, the difference is a payback of 1.49 compared to 1.52 for point-of-use (bridge mounted). Fixed air conditioning systems also offer cost advantages over APU usage. The higher capital and energy costs push up the payback period to approximately 3 years. As before, the cost analysis depends on the system selected, the cooling requirements, and the climate. Thus, both fixed electrical and air conditioning support systems have high construction costs, but can pay for themselves in energy savings alone, without considering the emission benefits.

KEY INPUTS

Airports service a wide variety of aircraft with an equally wide variety of operating practices and times. To date, very little reliable information is available regarding airport and airline specific aircraft servicing times and equipment operation times. The calculation of existing emissions should include the average time aircraft spend at the terminal gate by aircraft type. Additionally, the emissions calculations depend on the number of gates that are already equipped with centralized electric and/or air-conditioning service. Also, emission factors for the different types of APUs would increase the accuracy of the emissions estimates. The APU emissions factors used in this report are based on a limited number of APU models currently in use. The emissions estimates in this report are based on default times. Actual operating times should be used when calculating an emissions inventory for a specific airport.

REFERENCES

There is very little published information about installing fixed electrical and air-conditioning supply systems, because the systems are individually tailored to fit the needs of a specific project. Equipment manufacturers are a valuable

TABLE 4-6
Costs Of Central Power Systems

System	Costs Per GATE	Energy Costs (Annual)	Payback (Years)
Central			
Vertical M-Gs	3,963,039	232,081.20	2.70
Horizontal M-Gs	4,008,683	232,081.20	2.73
Inverters	4,020,768	180,960.36	2.64
Mini Central			
Vertical M-Gs	2,445,815	190,322.76	1.62
Horizontal M-Gs	2,547,245	190,322.76	1.69
Inverters	2,329,895	180,960.36	1.53
Localized			
Bridge Mounted	2,306,772	180,960.36	1.52
Mobile			
Electric (27)	2,447,402	180,960.36	1.63
Diesel (27)	2,057,623	325,807.20	1.49
Base			
APU	—	1,701,097.20	0.0

The payback period is estimated using the APU operating costs as a base cost.

$$\textit{Simple Payback Period} = \frac{\text{System Construction Cost}}{\text{APU (cost) - System (O\&M)}}$$

source of information on fixed electrical and air conditioning systems, but they are guarded about generalizing across the industry. Jane's *Information Group's Airport & ATC Equipment, 1992-93* provides a worldwide catalog of airport support equipment. Finally, the environmental impact statements for California airports sometimes contain estimates of emissions that could be eliminated with the installation of fixed electrical and air-conditioning systems, although many of these estimates lack documentation. Thus it is difficult to evaluate the accuracy of their estimates.

In general, the GSE industry does not deal with issues across applications, but with specific orders placed by airport authorities and/or specific airlines. This is reflected in the information available on fixed electrical and air conditioning systems.

Implementation Feasibility

- All of the systems discussed here are mature technologies, although improvements are always being introduced. This limits the concerns about the practical feasibility of fixed ground support to issues related to the intrusion and cost of installing fixed ground support systems at existing airport terminals. The limitations of each terminal and fixed support equipment must be addressed on a case by case basis because each airport has a different layout and services different aircraft.
- Replacing mobile air-conditioning units, GPU, and APU usage with fixed electrical and air-conditioning usage reduces the on-site emissions generated from servicing aircraft parked at terminal gates.

4.3.3

Conversion Of GSE To Alternative Fuels

This measure reduces the engine emission factors of large GSE

Airlines use a wide variety of equipment to service their aircraft at airports. The average GSE fleet includes aircraft tugs, baggage tractors, baggage and cargo handling equipment, and conveyor belts. Most types of GSE are powered by internal combustion engines.

Emissions from this equipment can be reduced or eliminated by providing the service through alternative means (such as fixed electrical and air-conditioning systems) or by converting the existing equipment to an alternative power source. The alternative fuels most often used in GSE are CNG/LPG and electricity.

In general, all non-road certified equipment (including GSE) are powered with "off-highway" engines built for agricultural, utility and industrial equipment manufacturers. As a group, GSE are powered predominately by industrial engines greater than 50 HP.

GSE manufacturing is a custom order business. Standard equipment designs are modified to the specifications of the airline. Equipment and the engine powering the equipment are sized according to the application and capacity specified by the airline. There are three main types of industrial engines/motors on the market: conventional fueled engines, CNG/LPG fueled engines, and electric motors. All three types can be used in GSE applications.

CONSTRAINTS

There are several obstacles to converting GSE to operate on alternative fuels. Engines using alternative fuels generally are more expensive, need to be refueled more often, and require different refueling stations.

CNG/LPG Fueled GSE

Until recently, the demand for industrial CNG/LPG fueled engines has been minimal. CNG/LPG equipment has not been practical for a wide variety of applications since the added costs involved prevented widespread acceptance of such equipment. Without sufficient market demand, engine manufacturers have not developed these engines at mass production levels, which keeps the incremental costs high. Only a few manufacturers currently produce engines that use alternative fuels. In the absence of OEM CNG/LPG engines, conversion kit companies have grown and remained the primary source of CNG/LPG engines. Emission factors shown in Table 4–4 for CNG are for converted engines. The emission factors for "future technology" are those expected for CNG engines from original equipment manufacturers (OEM). Conversions are available for most sizes of industrial engines, but are most often performed on medium (50 - 250 HP) and large (250 - 450 HP) gasoline engines. When these engines are available, either by conversion or from OEM suppliers they are generally more expensive than conventional engines.

Conventional engines are converted by replacing the existing carburetor or fuel injection systems with a new system capable of handling CNG/LPG. Existing fuel tanks are replaced with high pressure tanks for CNG, or low pressure tanks for LPG. Modifications are also made to the engine controls (the fuel to air mixture is typically leaner and the ignition timing advanced in gasoline engine conversions). However, the compression ratio cannot be modified in existing gasoline engines, because this is a function of the engine design and construction. Because of this, converted gasoline engines are less efficient than dedicated natural gas engines and many aftermarket CNG/LPG systems are sometimes calibrated rich. These factors lead to increased fuel costs and emissions (over dedicated CNG/LPG engines). Diesel engines are not converted to CNG/LPG given the extensive modifications that must be made. The greater reliability and increased efficiency of factory produced, dedicated CNG/LPG engines favor the use of dedicated CNG/LPG engines. OEM built, dedicated CNG engines can be utilized in applications that normally use diesel and gasoline engines. Some diesel manufacturers (Cummins, Detroit Diesel, and Hercules) have begun offering CNG engines.

There are only a few design obstacles to manufacturing GSE with engines that use CNG/LPG. Dedicated and dual fuel engines currently available from engine manufacturers and aftermarket converters (for gasoline engines) can be incorporated into GSE construction with relative ease. They have similar mounting, size, and weight specifications as conventionally fueled engines. Incorporating the new fuel tanks adds weight to the equipment, although weight is not a critical factor for aircraft and baggage tractors. Because of the reduced energy content by volume of CNG/LPG, alternative fueled equipment has traditionally experienced problems with limited operating times, which increases the non-operational refueling time associated with CNG/LPG equipment.

Another obstacle to using CNG powered equipment is the need for new refueling stations. CNG refueling stations compress natural gas to 3000 psi in the GSEs on-board fuel tanks. This can be achieved in one of two ways: slow fill and fast fill. The slow fill method is the easiest and least expensive way to refuel natural gas tanks. A small compressor slowly fills the on-board tanks with natural gas until the tanks reach 3000 psi (over a period of hours). This method works best with equipment that is not used for a long period of time each day (i.e., overnight). The fast fill method stores compressed natural gas in storage tanks and then fills the on-board tank from these storage tanks, switching from tank to tank as they equalize pressure with the on-board tanks. This tank switching (or cascading) continues until the on-board tank is full. The fast fill system is more expensive than the slow fill system because of the storage tanks and switching system increase the costs. Both systems can be sized to refill natural gas at any rate necessary to accommodate the refueling needs presented by the equipment population. A typical fast fill system capable of handling 12,000 SCF (Standard Cubic Feet) of CNG (the equivalent of 100 gallons of gasoline) per minute costs approximately $38,000 to $45,000 and the equivalent slow fill system costs approximately $30,000 to $40,000. The slow fill takes 10 times longer to fill the same amount of fuel. These systems generally receive natural gas from the natural gas supply network that is available in every major city. LPG refueling systems are less complicated than CNG systems. LPG is delivered to refueling stations in a liquid form and is kept in pressurized, insulated storage tanks. To refuel, the equipment's tank is connected to the storage tank, a valve is opened and the equipment's tank is filled.

CNG and LPG engines generally are less costly to maintain and tend to last longer than their conventionally fueled counterparts. Gasoline and diesel fuel contain contaminants that build up in the cylinders and exhaust system. Thus, alternatively fueled engines require some special maintenance, but on the whole they can require less maintenance and fewer overhauls.

None of the constraints to switching to CNG/LPG powered GSE prevents the usage of this equipment, they just add to the costs. Several manufacturers of GSE who were contacted about their experiences with CNG powered GSE stated that there should be no problems in delivering this type of equipment at an additional cost of 10% to 25%. The additional cost of the equipment would decline as production quantities increased over time and development costs are recovered. The cost of converting existing equipment varies with the size and complexity of the equipment to be converted; however, the average cost is between $2,000 and $3,000. Some airlines have begun using converted GSE at Denver's Stapleton Airport.[5] Additionally, programs are in place to test the ease of using GSE powered by CNG at Los Angeles International Airport and Boston's Logan Airport.

Electric Powered GSE

Electric GSE applications are limited by the battery's energy storage capacity. Electric GSE substitute conventional engines with an electric motor (or motors) and replace the fuel tanks with lead-acid batteries. This may add size and weight to the equipment, but because most GSE are not constrained by size and weight, these changes can be incorporated easily. Electric powered applications work well in tasks that experience short periods of activity throughout the day because electric motors use no energy while at

5. Bernhardt, Todd. "Ground Support: NGV use is really taking off at Denver's Stapleton Airport," American Gas, Sept. 1992, pp. 26-30.

rest. In fact, many different types of GSE, ranging from aircraft tugs to potable water carts and baggage conveyor belts, are currently available in electric versions. The main limitation to electric GSE is the lead acid batteries. They do not hold enough charge to work well in applications that have lengthy or sustained, heavy load operation (such as those experienced by GPUs and air conditioning units).

The time required to recharge the batteries is another limitation to using electric powered GSE. For example, Stewart and Stevenson manufactures an electric aircraft tractor, the EGT-50, which operates with much the same capabilities as their diesel powered GT-50. However, the EGT-50 must be recharged after 8 hours of constant operation and recharging takes approximately 8 hours. The GT-50 must be refueled after roughly 24 hours of operation and refueling takes approximately 5-10 minutes. The recharge requirement is generally handled with "opportunity charging" (i.e., plugging into battery chargers while the equipment is at rest).

The maintenance needs of electric equipment are very different than the conventional equivalent equipment. Electrical equipment requires very little routine service other than servicing the battery's water and acid levels. However, at every 3,000 to 6,000 hours of operation, the batteries must be replaced (the exact replacement schedule depends on battery quality, the equipment's duty cycle and load levels).

In general, electric versions of GSEs also cost more than their conventional counterparts. The cost difference varies from manufacturer to manufacturer and between equipment types, but averages 10% to 30% higher than similar conventionally powered equipment. Replacement cost of batteries also is quite high.

Applications

There are few operational differences between conventional GSE and GSE that use alternative fuels. GSE powered with CNG/LPG or electricity must be refueled more often. The additional refueling or recharging times also reduce the operational efficiency of the alternative powered equipment. Electric systems and slow fill natural gas systems take several hours to recharge or refill the systems. Fast fill natural gas refilling systems reduce the refueling time down to less than an hour. Other than these differences in refueling, there are no major operational difference between conventional GSE and GSE powered with CNG and electricity.

Key Inputs

The emissions factors measured to date for GSE and LPG powered engines apply to general usage as represented in test cycles. The estimates of emissions savings realized by switching to CNG/LPG could be verified with additional emissions factors obtained in new tests of CNG/LPG engines.

Sample Calculations

Switching from conventionally powered equipment to natural gas and electric powered equipment will reduce the emissions from GSE. The reductions realized from this conversion can be measured by changing the emissions factors to represent the change in fuel, calculating the emissions generated and comparing this emissions level to the emissions baseline. The emissions benefit realized by switching from using conventional GSE to electric GSE can be measured by eliminating the emissions of all equipment that is switched to electric power. This calculation is represented by the following formulas:

$$\text{Emission Reduction} = \Sigma(P_j * BHP_j * LF_j * \text{Use Hours}_j * (EF_{ic} - EF_{ij}))$$

Where

P_j = population of ground support equipment of type j

BHP_j = the rated horse power of equipment type j

LF_j = the load factor of equipment type j

Use Hours_j = the operating time of equipment type j in hours per day.

EF_i = the emission rate of pollutant i in gm/BHP-HR from ground support equipment of type c or j

c = conventionally fueled ground support equipment.

j = ground support equipment converted to alternative fuel use

Note, however, that the difference in emission factors may not hold true in the post - 1995 time frame when ARB's proposed standards for engines used in GSEs may lower the emissions from this equipment and result in gasoline and diesel powered engine emission factors being essentially equivalent to the emission factors for CNG or LPG vehicles. Of course, emission factors for electric GSEs are zero, so that the emission benefit is a given for this conversion.

References

Several of the major airlines and several airports have experimental alternative fueled equipment in operation. United Airlines and Alaska Airlines have alternative fueled GSE fleets in operation and they may be able to provide more specific details of performance and cost comparisons when their tests have been completed.

A more detailed discussion of regulatory issues surrounding light duty industrial engines in general is available in the reports prepared for the California Air Resources Board by EEA: "Regulatory Strategies for Off-Highway Equipment", January 1992 and the report "Feasibility of Controlling Emissions From Off-Road, Heavy-Duty Construction Equipment", December 1988. Jane's *Airport & ATC Equipment: 1992-93*, contains information about the equipment offered by the worlds GSE equipment manufacturers, including electric and CNG/LPG equipment availability.

Implementation Feasibility

- Properly tuned light duty spark ignition engines operating on CNG/LPG potentially reduce their HC and CO emissions by about 30 to 50 percent, although NO_X emissions increase by about 10 to 20 percent. However, HC + NO_X emissions are still expected to decline in most cases. By switching to electric GSE, the on-site emissions from the equipment are eliminated entirely.

4.4

Conclusions

Mitigation measures for GSE can significantly reduce total emissions from this source. While these options have a higher first cost than current technology, the fuel savings often result in a payback of less than three years. This is evident from the plans of many California commercial airports and airlines. Most airports expect to have fixed electrical systems installed at all gates by the end of the decade. Many airlines are experimenting with electric GSE and there also are demonstration tests being conducted with CNG GSE.

SECTION 5 —

TCMs And Vehicle Emissions

5.1

Introduction

Airports are destinations for thousands of vehicles daily, and these vehicles contribute to the local and regional air quality problems near airports. Consequently, reducing airport ground vehicle traffic through the implementation of transportation control measures (TCMs) has the potential for reducing the emissions associated with ground vehicle traffic. TCMs can reduce emissions from all modes of operation of passenger and employee vehicles, shuttle buses and vans, and commercial delivery and service vehicles.

There are several components of motor vehicle emissions, each of which corresponds to a particular mode of vehicle operation. These emissions components or operating (driving) modes comprise the *"reference trip emissions"*, which are the sum of exhaust and evaporative emissions for a complete trip to and from the airport for a vehicle on an average trip. Exhaust emissions occur during cold and hot starts, stabilized (or hot) cruises, and idle, while evaporative emissions include hot soak, diurnal, resting and running losses. Some TCMs are designed to eliminate entire vehicle trips, and thereby eliminate all emissions that would have been associated with a trip to and from an airport. Other TCMs target one or more aspects of vehicle travel to airports, and consequently reduce emissions from one or more specific driving modes.

This section examines several TCMs and discusses the effect those measures are expected to have on the ground vehicle reference trip emissions. First, several aspects of the reference trip are described, and then the individual TCMs are discussed. For each TCM, an example is given that can be used by planners to estimate the expected local and regional emissions reductions. The actual emissions reduction that will be realized by the use of the TCM will vary from airport to airport depending on a number of local factors. Those local factors are also discussed in this section. The last part of this section describes the use of alternative fuels to lower the emissions of some airport ground access vehicles.

5.2

Data Requirements For Calculating Emissions Reductions

The purpose of this analysis is to illustrate the emissions reductions that can be achieved through the use of various airport ground vehicle transportation control measures. The calculations of emissions reductions are made relative to the *reference trip emissions*, or the emissions from all ground vehicles before any control measures are implemented. Each transportation control measure affects one or more components of the reference trip, and as a result, the calculation of emissions reductions for a given transportation control measure may require data that are not needed for the other control measures. This section, therefore, describes the reference trip and its components, and identifies all the data items that are required to calculate the emissions reductions.

5.2.1

The Reference Trip Emissions

The airport ground vehicle reference trip emissions are the amount of hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_X), and particulate matter (PM) that are produced by all vehicle trips to and from an airport. The reference trip emissions are composed of HC, CO, NO_X, and PM exhaust emissions, which occur only when the engine is running, and HC evaporative emissions, which occur when the vehicle is operating and when it is parked. More specifically, exhaust emissions occur during cold and hot starts, stabilized or hot cruises, and idle, and evaporative emissions include hot soak, diurnal, resting, and running losses.

The reference trip emissions are calculated as the product of the *emission factors*, which are expressed in grams per mile of vehicle operation, and the *vehicle miles traveled*, or VMT. Each component of the reference trip has a separate emission factor, and those emission factors are dependent on the vehicle type (e.g., light duty cars and trucks versus heavy duty trucks), the vehicle or engine model year, and the odometer reading. Emission factors are adjusted by local conditions such as temperature, average driving speed, and fuel characteristics. Composite emission factors, which are calculated in an emissions factor model such as EMFAC or MOBILE, are used to describe the combined exhaust and evaporative emissions from the local fleet, based on the fleet's composition and local driving conditions. Separate emission factors exist for HC, CO, NO_X, and PM, but as the calculations for each pollutant are the same, only one generic calculation is shown in each sample calculation.

Since the reference trip emissions are expressed in grams per mile, it is apparent that reducing the VMT from airport related vehicle trips will have an effect on the total emissions. Eliminating complete vehicle trips eliminates all components of the reference trip emissions for that trip, but may result in increased emissions from other types of vehicles. Obviously, the intention is for the emissions reduction to outweigh the emissions increase. This is the case, for example, when implementing bus service to an airport reduces emissions from private automobiles, but increases emissions from transit buses. Eliminating portions of trips or driving modes also eliminates some emissions, or can swap emissions between modes (e.g., restricting vehicle idle times reduces idle emissions but adds to hot start emissions). Several types of ground access trips are associated with airports. Passengers and employees make trips to and from central terminals and outlying parking facilities by personal and rental car. Some of these people also travel in vans, limousines, shuttles, taxis, and buses. Cargo is transported by trucks to central terminals and more often to buildings away from the central terminal. Some employees also travel to these cargo areas outside the terminals. In this report the reference trip emissions typically include only passenger and employee trips to and from the central terminals and parking areas. Cargo-related traffic usually is not included in the reference trip emissions. These sources are noted when a TCM could be applied beneficially.

5.2.2

Data and Nomenclature for Example Calculations

The collection of reasonable and representative data that describes the reference trip emissions for each airport under consideration is the most important and most time consuming task incumbent upon local jurisdictions. To calculate emissions or the effects of mitigation measures it is essential that airport-specific information for vehicle mix, trip length, and other variables are used. The following bullets identify the data items that must be collected, and present them in a form that is used in the example calculations throughout Section 5.3. Upper case letters represent the data item, and lower case letters denote "drivers" as employees (e), passengers (p), taxis and shuttles (t), and commercial/cargo (c) vehicles, and other factors which affect the data item.

- The reference trip emissions (E), and its components:
  cold start (Ec), hot start (Eh), hot cruise (Ecr), and idle (Ei) exhaust emissions; diurnal (Ed), hot soak (Es), running loss (Er), and refueling (Ef) evaporative emissions. Each component is applicable to the three driver types e, p, and c.
- Total airport vehicle miles travelled (VMT) and % of VMT by driver type:
  VMTe, VMTp, VMTc, and VMTt.
- Total airport vehicle trips (N) and percent of trips by driver type:
  Ne, Np, Nc, Nt
- Employee and passenger access mode (A) percentages:
  Solo drivers (Aes, Aps);
  carpoolers (Aec, Apc);
  public transit riders (Aec, App)
- Emission factors (EF) by vehicle type:
  EFe, EFp, EFt, and EFc.
- Average trip length (L):
  Le, Lp, Lt, and Lc.
- Parking characteristics (P) for passengers:
  - percent that drops off and parks in short term lot (Ps)
  - percent that parks long term (duration of trip) (Pl)
  - percent of long term parkers on business trip (Plb)
- Average idle time (I) by driver type:
  Ie, Ip, It, and Ic
- Circuit VMT (C) by vehicle type:
  taxis (Ct), courtesy shuttle buses (Cb), and door-to-door vans (Cv).
- Rental car fleet (R):
  Number of vehicles that use alternative fuels (Na), average rental car daily VMT (VMTn), alternative fuel vehicle emission factor (EFa).

5.2.3

Calculating Vehicle Trips and Miles Traveled

The volume of ground access vehicle trips associated with California airports can be estimated. The best source of information comes from traffic and environmental studies conducted at individual airports. The *California Aviation*

System Plan, Ground Access Study prepared by the California Department of Transportation [Prepared for the Division of Aeronautics, Wilbur Smith Associates, August 31, 1991] summarizes trip information from these studies across several but not all California airports. Data in the report, as well as findings from national surveys, suggests there is a non-linear relationship between the volume of all ground access vehicle trips at airports and measures of airport use, whether use is defined by "enplanements" or million annual passengers ("MAPs"). Once the relationship is quantified, it can be used to estimate the volume of trips at all California airports where FAA records for enplanements or MAPS are used.

Generally, the rate of ground access vehicle trips decreases with increasing airport usage. One study of 20 airports across the nation found vehicle trips (passenger and employees) per enplanement (passengers only) decreased with increase in airport usage measured as enplanements per day[1]. For airports under 5,000 enplanements per day, the vehicle trips per enplanement (trip rate) ranged from about 2.0 to 4.0 trips per enplanement. For airports with over 15,000 enplanements per day, vehicle trips ranged from 1.0 to 2.0. The study found the best fit exponential curve relating vehicle trips to enplanements to be:

$$\text{Trip Rate} = \frac{4.5}{1+0.0117*\text{Enp}^{0.5521}}$$

An analysis of the data specific to California airports in the *California Aviation System Plan* shows a similar exponential relationship between the rate of ground access vehicle trips and passenger usage. Table 5-1 shows the airports and usage data. The vehicle trips in the table primarily include passenger and employee trips to central terminal areas, not cargo trips or employee trips to cargo areas. The best fit curve for the data is the exponential form:

$$Y = 2.72\,X^{-0.21}$$

Where

Y = Vehicle Trips Per Day (passengers and employees) Per Passenger (passengers only) - also defined as "Trip Generation"

And

X = Million Annual Passenger (MAP of the form x.xx million)

With information about the relationship between airport usage and vehicle trips, (cargo trips excluded) it is possible to estimate vehicle trips associated with all California airports, and the grand total vehicle trips. Table 5-2 displays this information. Column one shows a listing of California airports where the FAA collects information about passenger volumes. Column two shows MAP data for each airport. Where the airport is listed in the *Caltrans System Plan*, MAP data are taken from the plan. Where the Plan does not list the airport, MAP data are derived from 1990 FAA enplaned passengers multiplied by two. Column three is the trip generation rate (vehicle trips per passenger) listed in the *Caltrans System Plan* (as in Table 5-1) or derived from the above equation relating MAP and trip generation where no trip generation data was available. For very small airports (Arcata and smaller) outside the range of data supporting the equation, the trip generation rate is presumed to be 4.00 (based on the study for the Orlando International Airport referenced above). This rate is

1. Orlando International Airport, Application for Development Approval, Development of Regional Impact, Traffic Analysis, Fourth Runway Development, Appendix III.

slightly larger than the rates at Bakersfield and Monterey, the smallest airports where data are available or where the equation can reasonably apply. Finally, column four is the volume of daily trips by airport obtained by multiplying the trip rate by MAP divided by 365 days.

Overall, California airports generate about one half million vehicle trips per day, exclusive of trips associated with cargo facilities outside central terminals. Furthermore, about half of all the daily vehicle trips are generated by two airports, LAX and San Francisco. When cargo related trips are included for these two airports, daily vehicle volumes are even greater. According to the *California Aviation System Plan*, goods movement and employee trips to cargo areas add another 40 percent to central terminal trips for both LAX and SFO, again based on traffic studies within EIRs. Of course, these two airports are major cargo handling hubs. Cargo related trips

TABLE 5-1

CALIFORNIA AIRPORTS:

MAPS and Trips Per Passenger

Airport	MAP	Trips
Bakersfield	0.27	3.73
Burbank	3.49	2.1
Fresno	0.89	2.7
LAX	45.81	1.36
Oakland	5.51	1.81
Ontario	5.42	1.7
San Diego	11.1	2.11
Santa Barbara	0.62	3.2
San Francisco	30.39	1.1
San Jose	7.13	1.82
Sacramento	3.63	1.86
John Wayne	4.59	1.92

TABLE 5-2

CALIFORNIA AIRPORTS:

MAP, Vehicle Trip Rate and Total Vehicle Trips Per Day

Airport	Annual Passengers[1]	Trips Per Passenger[2]	Total Trips Per Day[3]
LAX	45,810,000	1.36	170,689
SFO	30,390,000	1.10	91,586
San Diego	11,100,000	2.11	64,167
San Jose	7,130,000	1.82	35,552
Oakland	5,510,000	1.81	27,324
Ontario	5,420,000	1.70	25,244
Orange County/ John Wayne	4,590,000	1.92	24,145
Sacramento	3,630,000	1.86	18,498
Hollywood-Burbank	3,490,000	2.10	20,079
Long Beach	1,420,000	*2.53*	9,831
Fresno	890,000	2.70	6,564
Palm Springs	*706,588*	*2.93*	5,664
Santa Barbara	620,000	3.20	5,436
Monterey	*336,352*	*3.42*	3,151
Bakersfield	270,000	3.73	2,759
Arcata	*107,030*	4.0	1,173
Buchanan Field (SF)	*99,046*	4.0	1,085
Sonoma County	*90,640*	4.0	993
Stockton	*88,252*	4.0	967
Lake Tahoe	*85,186*	4.0	934
Redding	*77,902*	4.0	854
Ventura	*47,678*	4.0	522
Palmdale	*38,450*	4.0	421
Modesto	*27,694*	4.0	303
Chico	*22,098*	4.0	242
San Luis Obispo	*17,796*	4.0	195
Santa Maria	*12,426*	4.0	136
Merced	*11,980*	4.0	131
McNamara (Crescent City)	*4,994*	4.0	55
Big Bear	*4,030*	4.0	44
Norton	*796*	4.0	9
TOTAL	**122,048,938**	—	**518,774**

1. Source: California Aviation System Plan, Caltrans, 1991 non-italicized; *FAA 1990 data italicized.*
2. Source: California Aviation System Plan, Caltrans, 1991 non-italicized; $Y = 2.72\ X^{-0.21}$ *italicized*; all others (Arcata and smaller) presumed to be 4.00 trip generation rate
3. The product of... $\frac{\text{column 2}}{365} \cdot \text{column 3}$

at other California airports probably add no more than a few percent to central terminal trips given in Table 5-2. Finally, Table 5-2 shows the same trend found in vehicle trip generation rates at other U.S. airports: the largest airports generate the fewest total vehicle trips per passenger, while the smallest generate the most total vehicle trips per passenger.

Once vehicle trips are established for an airport, emissions can be estimated, provided there is data on vehicle miles of travel and speeds. The *California Aviation System Plan, Table IV* provides average trip lengths for trips at selected airports. The trip lengths are given for each group of trips originating from surrounding counties. VMT can be calculated by multiplying the trips per day from the various counties by average distance from the center of the county to the airport, then summing the VMTs. Average travel times also are provided for trips by county, allowing calculation of an average speed for all trips. Table 5-3 displays daily VMT, VMT per trip and speeds for selected airports from the *System Plan.*

With this information on VMT and speeds, it is possible to make several important emissions calculations:

TABLE 5-3

VMT And Speed For Selected Airports

Airport	Daily VMT	VMT Per Trip	Speed (mph)
LAX	5,986,628	32	32
SFO	2,884,610	23	34
Oakland	602,011	22	39
Burbank	446,200	22	47
John Wayne	253,176	11	39

- Estimate total emissions generated by an airport due to passenger and employee ground access vehicles.
- Estimate emissions from airport expansion projects, provided additional vehicle trips associated with the projects are known.
- Estimate emission reductions associated with transportation control measures, provided reduction in vehicle trips can be estimated.

Taking Oakland airport as an example, Table 5-4 shows total emissions from the airport. The airport generates 602,011 daily VMT. The VMT are converted into emissions using emission factors developed specifically for a particular region. The emissions factors for total organic gases (hydrocarbons), carbon monoxide, and nitrogen oxides are from CALI5, which is a California-specific version of the MOBILE5a emissions factor model. The emission factor for total organic gases includes exhaust HC, evaporative HC, running loss HC, and resting loss HC. Exhaust emission factors include cold start, cruise, idle, and hot start emissions. The factors

TABLE 5-4

Oakland Airport
Ground Access Vehicle Emissions

Pollutant	VMT Per Day	Emission Factor (gm/mi @ 40mph)	Total Emissions (lbs/day)[3]
Carbon Monoxide	602,011	9.57[1]	12,703.5
Hydrocarbons	602,011	1.74[1]	2,309.7
Nitrogen Oxides	602,011	2.68[1]	3,557.5
Sulfur Oxides	602,011	0.21[2]	278.78
Particulates	602,011	0.31[2]	411.5
Total	**602,011**	**14.51**	**19,261**

1. Source: MOBILE5a: CA.specific version
2. Source: Air quality and Urban Development Guidelines for Assessing Impacts of Projects and Plans. Bay Area AQMD, November 1985. Table VI-B-2.
3. Column 2 • 3 • .002205 lbs. per gram.

for sulfur oxides and particulates can be found in *Air Quality and Urban Development, Guidelines for Assessing Impacts of Projects and Plans*, Bay Area AQMD, November, 1985. The emission factors vary by region and year depending on the mix of vehicles by age and type in a region, as well as average speed. In this case, factors represent the vehicle age and type mix for the Bay Area AQMD for 1990 at an average of 40 mph. Using these factors, the Oakland airport generates 19,261 pounds of pollution per day related to ground vehicles. Thus, for every one percent reduction in VMT brought about by transportation control measures at this airport, daily pollutants are reduced by 193 pounds.

One important point to note is the difference between airport related trips and airport related VMT. The two are similar in that each is composed of an airport employee component and a passenger component. However, since the average trip length varies between employee and passenger vehicles *at each airport*, the percent of trips attributed to a vehicle type is not equal to the percent of VMT for that vehicle type. For example, employees make 39 percent of the airport trips at LAX, but account for 12 percent of airport VMT because the average employee trip length is 10 miles, compared to an airport wide average trip length of 32 miles for all vehicles.

One area that cannot be addressed under the scope of this analysis is the effect that local road improvement projects will have on airport related trips and emissions. In general, projects which result in higher average vehicle trip speeds will result in lowered emissions, as gram per mile emission factors tend to decrease with increasing speed. Local planners who have knowledge of road conditions and planned roadway improvements are in the best positions to estimate the impact on vehicle emissions.

5.3

Airport Transportation Control Measures

The airport transportation control measures that are discussed below can be classified as either focusing on reducing airport related trips (hence, vehicle miles traveled, or VMT), or on reducing vehicle emissions without affecting the number of trips or VMT. Therefore, the TCMs are presented in sections pertaining to the target of that TCM. Each TCM is described in detail, including the goal or purpose of the measure, the components of the emissions reference trip that are affected by the measure, and the ranges of the TCM's expected impact on the reference trip components. The discussion also extends to information planners will need to evaluate the effectiveness of each TCM, references for information on the TCM, and finally, sample calculations.

5.3.1

Trip (VMT) Reduction TCMs

The goal of the transportation control measures discussed below is to eliminate all portions of some vehicle trips to the airports. Reducing the number of vehicle trips reduces VMT, and since vehicle emissions are ultimately expressed as functions of vehicle miles traveled, emissions are reduced. Further, since these TCMs reduce all components of the emissions baseline, these are potentially the most effective TCMs at reducing emissions.

Trip reduction TCMs are typically designed for controlling a specific type of vehicle trip, such as those associated with airport employees commuting to work, or trips by passengers to and from the proved slightly better at reducing solo driving. In the first, the City of Seattle reduced parking charges for carpools at two downtown Seattle parking facilities, from $25 to $5 per month at one facility and to no cost at another. The largest effect was to attract bus riders to carpooling: 45 percent of the participants in the discount program switched from transit, 29 percent previously carpooled, and 25 percent previously drove solo. A Portland, Oregon program which allowed carpool parking at street meters showed similar results: About half of the users were previous carpoolers, and half of the new carpoolers were former bus riders. The net effect of both programs, therefore, was to reduce VMT by 25 percent among those participating in the programs.

Applications

No evaluations of preferential parking for carpools at airports were found in the literature, although the Sacramento airport offers such an incentive program. At the Sacramento airport, 39 available carpool stalls have drawn between 10 percent and 13 percent employee participation. The prior mode of transportation for these airport carpoolers is not known, nor is the carpool rate before the designated carpool stalls were available. Given the results of other similar programs, however, the most optimistic assumption is that carpool incentive programs for airport employees reduce solo driving a few percent, and VMT a lesser amount since carpools still generate vehicle trips. At the low end, VMT reduction may be 0 percent if many new carpoolers are former public transit riders, while the high end may be 5 percent if solo drivers are attracted to carpools in significant numbers.

Key Inputs

In order to evaluate the effectiveness of this measure, it is necessary to know the rate of employee commuting by mode - solo drivers, carpoolers, and public transit riders - both before and after carpool incentives are put in place. These data can be used to calculate the reduction in employee trips, which when combined with the average trip length, produces the total VMT reduction. More precise estimates of VMT reduction can be made if the actual lengths of the trips that are eliminated through carpooling are known.

Emissions are also functions of the vehicle emission factors, and light duty trucks tend to have greater exhaust emission factors than light duty cars. If carpooling results in significant numbers of employees switching from passenger cars to vans, the fleet emission factors can increase. Therefore, knowledge of the vehicle mix for all employees who carpool, both before and after the carpool incentives are put in place, would improve the accuracy of the estimates of emissions reductions.

Sample Calculations

Emissions reductions are calculated as the product of the number of employees' vehicles that are replaced by carpool vehicles (Nec), the average employee trip length (Le), and the employee fleet emission factor (Efe). The product is the daily emissions reduction in grams.

TCM	*CALCULATION*
Rideshare/Carpool	Nec * Le * EFe

References

Early case studies of preferential parking by location are documented in *Traveler Response to Transportation System Changes - A Handbook for Transportation Planners*, R.H. Pratt Associates, for the Federal Highway Administration, February 1977. More recent evaluations are documented in *Transportation Control Measure Information Documents, Draft,* Cambridge Systematics, Inc. for the U.S. EPA, October 1991. *Parking Management and Traffic Mitigation in Six Cities: Implications for Local Policy,* K.T. Analytics, January 1989, and *Flexible Parking Requirements, An Urban Consortium Information Bulletin,* Public Technology, Inc., June 1982.

Reports which examine the effect that carpool preference programs have on public transit ridership include *Parking Discounts and Carpool Formation in Seattle,* Maria Olsson and Gerald Miller, the Urban Institute, 1979, and *Study of Parking Management Tactics, Volume 1: Overview,* Peat, Marwick and Mitchell, December 1979. The only reference to carpooling for airport employees is *Sacramento Metropolitan Transit Access Study,* J.D. Franz Research for Sacramento County Department of Airports, July 1992.

Parking Pricing and Subsidies

Airport employees often receive free or subsidized parking, which has the effect of promoting solo driving. It has been found that increasing parking prices or imposing them where they did not exist previously has had the greatest effect of any studied TCM at reducing employee VMT, as some employees find alternatives to driving solo, such as carpooling or using public transit. Where parking is subsidized by the employer, ending the subsidy or offering a travel allowance in place of the subsidized parking, can have a similar effect on solo driving rates.

CONSTRAINTS

This strategy is applicable only where airport employee parking is free or where employers subsidize paid parking. The effectiveness of this strategy may also be lessened if free or low-cost parking exists elsewhere around the airport, thus attracting airport employees who previously parked at the airport, and doing little to decrease overall employee VMT.

Constraints on implementing this measure at airports also extend to the fact that employees may not have as many public transit alternatives as workers in central business districts. Further, shift work schedules can make car and vanpooling less feasible than in other industries, which reduces the number of solo drivers that can make the switch to carpools.

APPLICATIONS

This control measure can be applied wherever employee parking is free or priced significantly below prevailing commercial rates. Many cases of significant declines in solo driving and trip making resulting from employers imposing paid parking or removing employee parking subsidies have been found in the literature. The most recent cases, some of which implemented paid parking alone, and some in combination with alternative mode programs, are summarized below:

- The Nuclear Regulatory Commission began charging market rates for parking in combination with guaranteed garage spaces for carpoolers, after which solo driving decreased 12 percentage points.
- After the City of Bellevue, WA began charging for employee parking, in combination with its long standing rideshare program, solo driving dropped 17 percentage points.
- A Seattle company, CH2M Hill, now gives all employees a $40 per month travel allowance, and charges $49 for parking for solo drivers, where pre-

viously no allowance was given and all parking was free (carpoolers still park free). Solo driving has decreased by 25 percentage points since the parking policies were implemented.

- Solo driving also decreased 25 percentage points at Twentieth Century Corporation after the company started charging $30 per month for parking, in addition to continuing its transit and vanpool subsidies, and its practice of providing preferential parking for carpoolers.

How these reductions in solo driving translate into vehicle trip reduction depends on how commuters shift to carpools, transit, walking, and other modes. The above cases and other data suggest that reductions in vehicle trips per 100 employees (i.e., employee VMT) will range up to 35 percent, especially when combined with incentives for carpooling and public transit.

Airport employees are probably unable to shift to carpools or public transit as easily as in other industries, for the reasons noted above. However, where non-employee parking rates are significant and where employees park for free or much reduced rates, a conservative estimate is a 10 percent reduction in employee trips and VMT where priced parking is adopted.

KEY INPUTS

The required inputs for calculating the effectiveness of this measure are similar to those required for the carpool incentive program: The rate of employee commuting by mode, actual lengths (i.e., total VMT) of eliminated trips, and the vehicle mix for all employees who carpool. The most important of these data is the rate of employee commuting by mode before and after the adjustments to parking pricing are made.

SAMPLE CALCULATIONS

The daily emissions reduction, in grams, is calculated as the product of the number of employees' vehicles replaced as a result of increased parking price or subsidies (Nep), the average employee trip length (Le), and the employee fleet emission factor (EFe).

TCM	*CALCULATION*
Parking Price/Subsidy	Nep • Le • EFe

REFERENCES

The Nuclear Regulatory Commission's experience with parking pricing is documented in *Evaluation of Travel Demand Management Measures to Relieve Congestion*, Comsis Corp. for the Federal Highway Administration, February 1990. The City of Bellevue's program is discussed in "The Difficulty of Easy Ride: Obstacles to Voluntary Ridesharing in the Suburbs," a paper presented before the Transportation Research Board by Stephenie Frederick and Kay Kenyon, January 1991. The results of CH2M Hill's new parking policies and travel allowance are documented in *Proceedings - Commuter Parking Symposium, sponsored by Metro and Association for Commuter Transportation*, Seattle, December 1990. Finally, the effect of Twentieth Century Corporation raising parking prices are documented in *Parking Subsidies and Commuter Mode Choice: Assessing the Evidence*, Richard Wilson, et al., UCLA, July 1989.

Public Transit and Alternative Mode Incentives for Employees

Incentives for airport employees to use public transit or any mode other than driving solo have the potential to attract solo drivers in situations where alternative modes are convenient and cost significantly less than driving solo. However, past evaluations of transit subsidies and other incentives have shown to be only modestly effective at attracting solo drivers, and may in fact attract carpoolers, previous transit users, and other non-solo drivers.

CONSTRAINTS

The usefulness of this measure for airport employees is limited by the fact that public transit is not always a viable option for airport workers because of factors such as variable work schedules. Other alternative commuting modes (principally biking and walking) are less attractive than in other industries because of the tendency for airports to be well removed from residential areas in which airport employees live.

Public transit and alternative mode incentive programs can be costly to employers who offer them, while incentive programs can be costly to transit agencies that honor them. The increased costs to employers in terms of new employee benefits is obvious, but costs can go beyond the costs of helping their employees commute to work. For instance, some programs distribute transit passes to employees, but no restrictions accompany those passes, and family and friends of employees almost certainly make use of the passes. As for costs to transit agencies, decreased fares may lead to decreased revenues, while increased ridership may lead to increased operating and capital costs if more frequent service is required for commuters.

APPLICATIONS

There is considerable experience with public transit subsidies among U.S. business in general, but very little experience with airport employees has been documented. There is also little well documented experience with alternative mode incentives in general, but what is known is promising. As shown below, the data suggest that transit incentives for employees decreases employee VMT by three percent at the most, while alternative mode incentives may offer as much as a five to seven percent VMT reduction.

Public transit subsidy programs have been successful in terms of getting employees to participate in them, but participation does not translate directly to VMT or trip reduction. This was shown in an Urban Mass Transportation Administration evaluation of several transit pass programs. Ridership increased in several cases evaluated by UMTA, but more from increased trip making among transit patrons than diversion from solo driving.

Transit incentive programs in California have been generally popular with employees, but the lack of information on employee commuting mode has made it difficult to differentiate the employees who have switched from driving solo to using public transit from those who have always used public transit. One company in the Bay Area offers free transit tickets to employees, and about ten percent of employees participates in the program each month. Usual transit shares in the area average about five percent, which suggests a doubling of transit use because of the program. Similar rates were found in another Bay Area company, which has offered a 25 percent transit subsidy since 1984. Transit pass sales at that company have doubled from three percent of all employees to six percent.

The documentation on alternative mode incentive programs is sparse but suggests promising results. Ventura County, for instance, offers an annual payment of $200 to $300 based on the number of days per week County employees consistently use any alternative commuting mode. The solo driving rate fell from 87 to 69 percent after introduction of the subsidy. ARCO in downtown Los Angeles subsidizes solo driver parking, but offers greater subsidies to users of alternative modes. Under the program, the company has maintained an alternative mode use rate between 55 and 65 percent of employees since 1983, which is five to 25 percentage points higher than for the downtown as a whole. The downside is that some carpooling has increased at the expense of public transit use.

KEY INPUTS

As with the other employee programs, in order to evaluate the effectiveness of this measure, it is necessary to know the rate of employee commuting by mode - solo drivers, carpoolers, public transit riders, alternative mode commuters - both before and after incentives are put in place. These data can be used to calculate the reduction in employee trips, which when combined with the average trip length, produces the total VMT reduction. More precise estimates of VMT reduction can be made if the actual lengths of the trips that are eliminated through use of public transit and alternative modes are known.

SAMPLE CALCULATIONS

Daily emissions reductions are calculated as the sum of emissions reductions due to increased use of public transit vehicles (if any). Emissions from employee vehicles are reduced by the product of the number of employee vehicles replaced by the use of public transit incentives (Nei), the average employee trip length (Le), and the employee fleet emission factor (EFe). Emissions from transit vehicles are increased by the product of the number of new transit vehicles trips (Nti) the average transit vehicle trip length (Lt), and the transit fleet emission factor (EFt).

TCM	CALCULATION
Public Transit Incentives	Nei • Le • EFe + Nti • Lt • EFt

REFERENCES

The results of the Urban Mass Transit Administration's evaluations of transit pass programs can be found in *Transit Fare Prepayment Demonstration*, Charles River Associates for the UMTA, September 1982. An evaluation of employer transit pass promotional programs in Seattle is found in *The 1987 Evaluation of Transportation Management Programs, Final Report*, Seattle Commuter Services, and Bay Area programs are evaluated in *Commute Alternatives: A Manual for Transportation Coordinators*, MTC, 1983. Ventura County's experiences with alternative mode incentives is found in *Congestion Management Measurements*, Comsis Corp. for FhWA, October 1992, and ARCO's experience in Los Angeles is documented in *Evaluation of Travel Demand Management Measures to Relieve Congestion*, Comsis Corp. for FhWA, February 1990. Finally, the lone evaluation of alternative mode incentive programs that deals with airports is found in *California Off Airport Terminals (Draft Report)*, Robert Frazier et. al., Institute of Transportation Studies, July 1992.

5.3.1.2

Passenger VMT Reduction TCMs

Passengers generate the greatest volume of trips and VMT at airports. As discussed in the section on employee trips, employee proportion of airport VMT might range from a low of 5 to 10 percent up to a high of 20 percent, depending on the balance of cargo trips. Quantitative estimates of VMT can be made by applying this percentage range to airports where total VMT is estimated, as per Table 5-3.

Parking Pricing

There is considerable uncertainty and complexity in parking pricing aimed at air passengers for purposes of cutting solo driving and increasing use of high occupancy modes. On the one hand, data from California airports suggests higher prices are associated with greater HOV mode use. Table 5-5 shows quite a strong correlation between the price of long term parking (P) and the percent of non-drive modes (ND), including taxi, limousine, private transit, public transit, hotel shuttle and other. The results suggest every one dollar increase in long term parking is associated with an additional two percent use of non-auto modes. On the other hand, such correlation does not necessarily indicate increased long term parking prices *cause* increased use of transit, taxi, or shuttles. Airports with higher parking prices also tend to have better non-drive services, which also could explain higher use. There also is the possibility that higher long term parking rates increase drop off and pick up. Drop off drives up VMT as the passenger generates four trips (to/from drop and to/from pick up) instead of two (to/from airport). If so, the net effect of increased long term rates might be negative, even if pricing encourages some use of non-drive and HOV modes.

Unfortunately, the relationship between parking policy and drop off rates is not well understood. One dated survey of airport drop off suggests high proportions of autos carrying passengers drop off, but that drop off is unrelated to one key parking variable, parking supply. Data from a 1972 survey of six airports shows between 49 and 68 percent do not park or park only briefly, presumably for drop off and pick up purposes [*Airport User Traffic Characteristics for Ground Transportation Planning,* Table 18 Op. Cit.]. While parking prices are not reported for the six airports, parking space provided per 1,000 annual air passengers are reported. Presuming less parking supply per passenger might be associated with higher prices; or, like pricing, less parking might encourage passengers to drop off rather

TABLE 5-5
Parking Rate Versus Percent Non-Drive[1]

Airport	Parking $/Day	Percent No-Drive %
Bakersfield	3.50	6 3
Burbank	10.00	20 2
LAX	16.00	29 27
Oakland	5.00	14 7
Ontario	8.00	18 73
San Diego	12.00	29 5
Santa Barbara	3.00	3 0
San Francisco	9.00	33 4
San Jose	6.00	5 5
Sacramento	4.00	10 7
John Wayne	7.00	12 4

1. California Aviation System Plan, Tables II and III, Op. Cit.

than seek parking, one would expect the *highest* drop off rates at airports with the least supply of parking per passenger. Table 5-6, which displays results from a 1972 survey, explores the issue. Drop offs include autos that dropped off passengers and immediately left the airport, and autos that dropped off passengers and then parked in short-term lots before leaving the airport.

The table suggests less parking is ***not*** associated with higher drop off rates. In fact, if any relationship is apparent, it seems the three *lowest* drop off rates are associated with the *least* parking supply, and the *higher* rates with the *most* supply. In short, drop off appears unrelated or even negatively related to parking supply, just the opposite of what would be expected if parking policy influenced drop off.

Data collected between 1987 and 1982 from a few California airports confirms that drop off and parking policy - in this case pricing policy - are not clearly related. Table 5-7 shows drop off rates for private autos only and long term parking rates at several airports. Long term rates are explored since short term rates all tend to be about the same, between $0.50 and $1.00 per hour. Thus, if drop off does vary with any parking price variation, it is with long term rates. The table shows *no clear cut relationship* between long term price and drop off/pick up rate. The highest rate is at the San Francisco airport, but this is not the airport with the highest long term parking charge. Los Angeles has the highest parking rate, yet its drop off rate is in the middle of the pack. Finally, San Jose and Oakland have low parking rates, but drop off still tends to be high. Only Sacramento supports the case that lower parking prices are associated with lower drop off. It has both the lowest drop off rate and lowest parking price.

If drop off/pick up is not strongly related to

TABLE 5-6
Passenger Drop Off Versus Parking Supply At Six Airports
— 1972 —

Airport	Parking Spaces Per 1000 Annual Passengers	Percent Of Passenger Carrying Autos Dropping And Picking Up*
High Drop Off Rate		
Boston-Logan	0.67	68
New York - JFK	0.64	66
San Francisco	0.56	63
Low Drop Off Rate		
Atlanta	0.23	49
New York-LaGuardia	0.46	55
New York-Newark	0.79	49

** Percentages refer to private autos only, and not to passengers who arrive at the airport by other modes.*

TABLE 5-7
Passenger Drop Off Versus Long Term Parking Price At Five California Airports
— 1987 TO 1992 —

Airport	Long Term Parking Price $/Day	Percent Of Passenger Carrying Autos Dropping And Picking Up*
Los Angeles[1]	16	77
Oakland[2]	5	76
Sacramento[3]	4	65
San Francisco[2]	9	81
San Jose[2]	6	79

1. Air Passenger Survey, for LAX, Wilbur Smith Associates, 1987, Tab 57.
2. Bay Area Air Passenger Survey, 1990, MTC, Table 4.2.
3. Sacramento Metropolitan Transit Access Study, J.D. Franz Research, 03.

** Percentages refer to private autos only, and not to passengers who arrive at the airport by other modes.*

parking policy, what is it related to? Evidence from Logan Airport in Boston suggests traveler perceptions unrelated to parking may be the key. Researchers there have found drop off is highest for non-business travelers, especially *residents* versus *non-residents* of the area served by the airport [*Logan International Airport Ground Access Non-Pricing Study*, Massachusetts Port Authority, to the Conservation Law Foundation, July 1, 1991]. Seventy one percent of drop off is made up of passengers traveling for *non-business* purposes, and 50 percent by *resident* non-business travelers. Sixty percent of the resident non-business travelers are female and 70 percent check baggage. As for *non-resident*, non-business, here again 59 percent are female; 70 percent check baggage, and most originate from Boston or Cambridge hotels. It appears drop off, at least at this airport, may be related more to perceptions of convenience and travel logistics than to parking supply or price.

The same Logan Airport study supports the finding from California airports that increased long term parking prices are not associated with increased drop off. When long term rates at Logan increased from $8.00 in 1984 to $10 in 1986, pick up and drop off actually declined from 34 percent to 26 percent. Probably a key reason the price change didn't increase drop off has to do with the type of passenger facing the parking charges. The primary users of long term parking (67 percent) are resident business travelers who have the lowest drop off rates, 12 percent. In contrast to the profile of the high drop off population, 75 percent are male and 60 percent do not check luggage. Thus, it is unlikely price increases for this group would increase the drop off rate. As to why drop off declined, there are a couple of possible reasons. One, new and convenient transit service (Logan Express) was initiated during the same period, 1986. Two, short term parking rates also climbed during the same period, from $1.00 to $2.00, possibly discouraging at least some drop off using short term facilities. But the most important finding is increased long term parking rates ***do not necessarily boost drop off***, especially if accompanied by good transit options and, possibly, increased short term rates.

Logan experience also suggests parking pricing combined with transportation service improvements may be most effective in boosting use of door-to-door, scheduled HOV and transit, but service improvements alone also are quite effective. As mentioned, between 1984 and 1987 the airport increased parking rates from $8.00 to $10.00 per day, and started Logan Express service. A water shuttle also started during the same period.

During this period, the proportion of passengers using all high occupancy modes increased from 15 percent to 22, a 7 percent boost. From 1987 to 1990, when parking rates held steady and service improvements on the Logan Express continued (mostly relocating routes and adding park and ride lots), the proportion of high occupancy mode use still climbed, but less dramatically from 22 percent to 26 percent, a four percent increase. It is worth noting the increase in Logan Express ridership since 1987 was 20 percent in spite of two increases in fares [*Logan International Airport Ground Access Pricing Study*, Massachusetts Port Authority, to the Conservation Law Foundation, February 1, 1991]. In short, all else being equal, parking pricing alone may have boosted use of high occupancy modes a few percent, but service improvements (in spite of fare increases) were perhaps equally effective. Most effective is the combination of pricing and service.

Why might parking pricing alone not be more effective in increasing passenger use of high occupancy modes? Again, the profile of the passenger facing the parking pricing is key. At Logan, where the primary users of long term parking are business travelers, 80 percent are subsidized by their companies for travel. Also, 42 percent travel on the same day or only overnight. Clearly, this is the kind of traveler for whom parking cost may be less important in choosing mode of travel than convenience and service.

Other research suggests hiking long term parking rates alone, at least by usual amounts, may bring only small increases in high occupancy mode use. A study of "travel elasticities" for passengers at the San Francisco airport also concluded changes in parking pricing would have to be quite substantial to effect travel choice. The study concludes, "Parking prices could be used to increase the cost of auto travel, although the surcharges required to bring about a significant diversion are quite large" ["Study of Airport Access Mode Choice," By Greig Harvey, *Journal of Transportation Engineering*, Vol. 112, No. 5, September, 1986].

There are several conclusions regarding parking pricing for passengers:

- Increases in parking pricing most likely will increase use of high occupancy modes, but considerable price increases may be needed to bring results. Business travelers especially may not be very sensitive to increased parking prices, at least not unless price changes are substantial and accompanied by improved high occupancy services.

- The evidence does not suggest the drop off rate or underlying reasons for drop off are related to parking supply or prices; however, the evidence is by no means conclusive. There is sufficient uncertainty that airports ought to monitor drop off and multi-occupancy mode use when making adjustments in parking rates.

- Three, the effects of pricing will be very dependent on the proportion of business and non-business passengers utilizing any particular airport, as well as complementary actions such as short term parking rates and quality of high or multi-occupancy mode services.

Because there still is so little evidence on the effects of parking pricing on drop off, it is not possible to provide definitive guidance on VMT reductions due to pricing. However, one study hints at important quantitative guidance. A mode of passenger travel behavior at the San Francisco airport using profiles of traveler incomes, travel mode and other data concludes, "Taking into account the high average income of the business sample, this shows that cost sensitivity for business access travelers is about the same magnitude as cost sensitivity for *weekday work travelers* at comparable income levels". If so, we may take parking elasticity studies for employees and work trips as a rough guide. These studies show parking price effects on employee *vehicle trips and or VMT* (not parking demand) range widely from an elasticity of -0.01 (especially where transit alternatives are poor) to -0.3 at the high end (i.e., a 100% price increase leads to a 1% decrease at the low end to a 30% decrease at the high end.) [*Improving Air Quality Through Transportation Systems Management: What Can Be Expected,* John Suhrbier, Terry Atherton, Elizabeth Deakin, a paper before the Annual Transportation Research Board Meeting, January 1979; also, "A Review of the Impact of parking Policy Measures on Travel Demand," Bernard Feeney, *Transportation Planning and Technology,* Vol. 13, 1989]. At most, then, we might expect a 10 percent increase in parking price to reduce vehicle use and VMT among those facing the parking charge (i.e. excluding drop off and multi-mode users) by 3 percent. For example, looking at Table 5-4, suppose Oakland Airport increased its long term parking price from $5.00 to $7.00 per day, a 40 percent increase. At best this would bring a 12 percent reduction in VMT and emissions among those effected by the price. At this airport, only about 17 percent of passengers drive and park [69 percent use private cars, but only 24 percent of these park for the duration of the trip according to *MTC Passenger Survey*, Op. Cit.]. Thus, presuming VMT proportions follow mode shares closely, only 17 percent of total airport VMT would be reduced by 12 percent, for a reduction in total VMT and emissions of only 2 percent. This translates into about 400 pounds of pollution per day.

Of course, effectiveness will vary depending on the proportion of passengers driving to the airport and parking for the duration of the trip. For example, at San Francisco, only 46 percent of passengers access the airport by private car, and only 18 percent of these park for the duration of the trip (equivalent to 8 percent of total passengers) according to a 1990 passenger survey. Thus, pricing might be less effective than at Oakland [*MTC Passenger Survey*, Op. Cit.]. According to a 1992 passenger survey at Sacramento, 84 percent arrive by car and 35 percent park [Franz Research, Op. Cit.]. Overall, the range of effectiveness might be from 1 to 4 percent reduction in total airport VMT and associated emissions.

CONSTRAINTS

As explained, the effectiveness of parking pricing at reducing VMT will decrease as the percentage of business travelers (Plb) increases. Therefore, parking price increases will be most effective only at airports where non-business travelers make up the majority of all travelers. Also, alternative transportation options must be in place, they must be convenient, and they must be competitively priced if raising parking prices is not to result in increased drop off rates.

APPLICATIONS

Effectiveness will vary between airports depending on the proportion of passengers driving to the airport and parking for the duration of the trip. For example, at San Francisco, only eight percent of all passengers park for the duration of the trip (as mentioned above), and the maximum three percent reduction per ten percent increase in parking price would be applied only to that very small passenger segment. Thus, a forty percent increase in parking prices would bring about a one percent decrease in passenger related VMT and emissions. At Sacramento, on the other hand, 29 percent of passengers park for the duration of their trips. This implies that almost four times as much VMT reduction could be achieved by raising parking prices at Sacramento than would be expected if prices were raised by the same percentage at San Francisco. A range of effectiveness for raising parking prices might be from one to four percent in total passenger VMT and associated emissions.

KEY INPUTS

The most important input for calculating the emissions reduction effect of this measure is the percentage of passengers driving to the airport and parking for the duration of the trip, since this is the group from which any and all VMT and emissions reductions will come. The business percentage of long term parkers (Plb) will be an indication of the chance for success of this control measure, since business parkers are least likely to be concerned with parking prices.

SAMPLE CALCULATION

Daily emissions reductions, in grams, due to increased long term passenger parking prices are calculated as the product of the number of passenger cars removed (Npp), the average passenger trip length (Lp), and the passenger vehicle fleet emission factor (EFp). These emissions reductions would be offset by any increase in the number of public transit vehicles serving the airport due to increased demand from passengers who previously parked for the duration of their trips.

TCM	CALCULATION
Increased Parking Price.........	Npp * Lp * EFp + Ntp * Lt * EFt

* * * * * * *

5.3.2

Idle and Circulation Management TCMs

An alternative to reducing the number of airport related vehicle trips that passengers and commercial vehicles make is to reduce the emissions from vehicles while they are at the airport. Two ways to accomplish this are to restrict the time vehicles spend at idle, and to control access to the terminal areas. These two control measures are discussed below.

5.3.2.1

Idle Restrictions

A significant percentage of the total time a vehicle spends at an airport is at idle. This is especially true for passengers' light duty cars and trucks, taxis, shuttle buses, and vans, all of which tend to idle while dropping off or picking up passengers. Commercial vehicles also idle while loading and unloading cargo, often for considerable lengths of time. By eliminating or significantly curtailing the time spent at idle, the total emissions from these vehicles will be reduced, as idle emissions are generally greater than emissions that result from starting a warmed up vehicle (i.e., a "hot start").

CONSTRAINTS

This control measure is applicable to all vehicles except employees' vehicles, but is effective only if the emissions from an idling vehicle are greater than the emissions from hot starts. This test can be made only after determining, at the individual airports, the average idle time by vehicle type. This must be done through an observational monitoring program or perhaps a survey of airport users. If the product of the average idle time and the average idle emissions for that segment of the vehicle fleet is greater than the average hot start emissions for the vehicle fleet then idle limitations can be effective. (Emission factors for idle, hot start, and other modes are available from the EMFAC model or a California-specific version of EPA's MOBILE model.)

Hot start NO_x emissions from gasoline engines are typically very low, and this control measure is not expected to affect them significantly. Similarly, HC, CO, and NO_x idle emissions from diesel engines are also small. Therefore, this control measure is not suited to controlling those pollutants. However, particulate emissions from diesel engines can be significant and candidates for control, but there is no known documented study which compares diesel engine particulate emissions at idle and hot start.

This measure will impose costs on the airports in the form of salaries for employees who will monitor the parking areas and enforce the idle time limits. It is expected that the monitors can cover more than one area each, especially where idle stands or holding pens are near passenger drop off areas. It may be difficult to enforce idle time restrictions in remote areas of airports, such as cargo loading areas, or to enforce idle restrictions when drivers run their engines to keep their vehicles air conditioned or heated.

Applications

There are no known documented cases of enforcing idle time limits on airport passenger vehicles or cargo vehicles, although many municipalities have legal limits on the length of time a vehicle can idle. Many airports do regulate parking time limits at passenger drop off areas, and many airports also limit parking time and/or idling time for commercial vehicles such as courtesy shuttle buses, taxis, limousines, public and private buses, and on-call door-to-door vans and shuttle buses.

Hot start emissions from light duty vehicles are dependent on the control technology and model year group. Average hot start emissions for light duty cars and trucks were calculated by EEA for the U.S. EPA in 1991, as were average idle emissions. The measurements were made by model year and control technology groupings, so local planning agencies can use EEA's data to calculate average idle and hot start emission rates that are specific to the local light duty fleet. Average hot start and idle emission rates for heavy duty gasoline vehicles will have to be obtained from the EPA or ARB.

Key Inputs

The most important data item needed to measure the effectiveness of idle restrictions is the average idle time by vehicle type. As mentioned above, this idle time will vary between airports, and will have to be measured at each airport where the measure is considered for use. The average idle emission rate and hot start emissions can be obtained with the help of the local agency which is responsible for determining vehicle emission inventories.

Sample Calculation

The change in emissions due to idle restrictions is the sum of the reduced idle emissions and the increased hot start emissions. Separate calculations are made for passenger vehicles, commercial/cargo vehicles, and taxis. Idle emissions are reduced by the product of the number of vehicles (Np, Nc, Nt), the idle emission rate (EFpi, EFci, EFti), and idle time (Ip, Ic, It). Hot start emissions are calculated as the product of the number of vehicles and the average hot start emission factor (EFph, EFch, EFth).

TCM	CALCULATION
Idle Time Restrictions (passenger vehicles)..........	Np • (EFpi • Ip – EFph)
(commercial/ cargo vehicles)..................	Nc • (EFci • Ic – EFch)
(taxi cabs/vans)	Nt • (EFti • It – EFth)

References

There are few documented cases of the effects of idle restrictions on emissions, especially for airports. The relative weighting of idle emissions versus hot start emissions is documented in *Speed Correction Factors for the Updated Version of MOBILE4*, Energy and Environmental Analysis, Inc., for the U.S. EPA, August 1991.

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5.3.2.2

Circulation Management

Most airports regulate curb access for purposes of reducing curb congestion and promoting safety, targeting vehicles such as personal and rental company autos, courtesy vehicles and shuttle buses, taxis, limousines, buses, and on-call door-to-door vans. Typical regulations limit parking time and/or curb access, and are in general use to control congestion for both private and commercial vehicles. Pricing of curb use has the potential to reduce emissions, particularly from commercial vehicles which are the most likely initial targets, but is not easily accomplished and is much less in evidence than other curb access regulations.

Constraints

The most serious constraint is that few vehicles using curbs enter airport parking where conventional pricing mechanisms are implemented, so new means of collecting fees are likely to be required. One study of the San Francisco Airport found four-fifths of vehicles accessing the curb never entered an airport parking facility, and pricing through meters at curb areas is probably not practical.

Applications

The most effective and efficient pricing approach would be pricing all vehicles as they enter the airport, whether they only go to curbs or parking, or pass through. Only Dallas-Fort Worth imposes such a fee, but the fee is only 50 cents and for revenue raising purposes, not to control emissions or VMT. Airport entry fees would likely have to be similar to parking fees in order to effect any decrease in airport trips.

From the standpoint of reducing VMT of curb access vehicles, one promising focus is on rental car, hotel, and parking lot courtesy vehicles or shuttle buses. Most airports limit the number of waiting cabs and limousines through entry permits, holding areas, exclusive contracts, and trip fees for the privilege of picking up at airports, but the same regulations and fees don't tend to apply to courtesy vehicles. The number of rental car shuttles in circulation can be reduced by centralizing rental car offices and consolidating shuttle service to the center. Sacramento and San Francisco airports are planning this approach under future expansions.

Flat fees and "percent of gross" fees are imposed on parking lot shuttles and rental car shuttles at several California airports, but such fees do not provide any direct incentive to limit circulation or to increase shuttle bus occupancy. One exception to flat or gross fees is provided by LAX, which imposes a percent of gross and "circuit fee" on off-airport rental and parking lot shuttles. Circuits around the airport terminal are monitored by an Automatic Vehicle Identification (AVI) system, and operators are charged for excessive circuits. This fee system provides some incentive to get as many riders as possible per trip and limit circulation around the terminal. Such a fee and monitoring system may be extended to include on-airport rental car and parking lot shuttles and hotel courtesy vans at LAX, and implemented in full at other California airports.

On-call van service is now the third most popular mode of travel at Los Angeles, Sacramento, and San Francisco airports, and even with holding pens and starters for these vehicles, drivers tend to circulate for customers before leaving the airport. One method of controlling excess circuits by on-call vans and shuttles is being tried at LAX: LAX requires vans to enter a holding lot and obtain a trip ticket for passenger pick ups, to control illegal entry to the airport. Each vehicle also must be equipped with an electronic transponder (AVI) to allow vehicle circuits to be monitored. A $1.00 per circuit fee is imposed through the transponder for the first two circuits of the central terminal, and additional "excess" circuits cost $9.00. The combination of regulations and fees appears to have reduced circuits about 37 percent: Monthly circuits went from about 110,000 in summer 1990 (before the circuit fee went into effect), to about 70,000 in summer 1991 (after the circuit regulations had been fully implemented).

Estimating the VMT reductions possible through trip fees, consolidated rental car shuttles, and circuit fees for private shared ride vans is difficult. However, it is likely that the direct VMT reductions will be small as a percentage of the total airport VMT, but the indirect VMT reductions can be significant. As an example of such a situation, the 37 percent reduction in *circulation* VMT achieved at LAX does not account for a very large proportion of *total* airport VMT: A circuit at LAX is about 1.5 miles, so a reduction of 1400 circuits per day translates to 2100 miles per day, which is a very small percentage of total airport daily VMT (5.9 million miles). However, reduced circuit VMT probably translates into a larger reduction in emissions, as much circulation is stop and go. Further, circuit and trip fees provide incentives for companies to reduce the number of vehicles serving airports when vehicle occupancies are low, and to seek ways to boost the number of passengers carried per vehicle. Therefore, the reduction in overall VMT through the reduction of circuits may be significant, possibly on the order of one to two percent.

Key Inputs

To calculate the effectiveness of circuit management techniques, it is necessary to first determine the daily circuit VMT and vehicle population before the circuit management program is implemented. After the circuit management program has reached steady state, the daily circuit VMT and vehicle population can be compared to the baseline. The actual correlation between the reduction in the door-to-door van and shuttle (or other targeted vehicle) circuit VMT and overall VMT will vary by airport, and can be determined by tracking trips through the AVI system.

Sample Calculation

Daily emissions reductions, in grams, due to circulation management are calculated as the product of the circuit VMT eliminated for taxis (Ct), door-to-door vans (Cv), and courtesy shuttle buses (Cb) and the respective emission factors.

TCM	*CALCULATION*
Circulation Management............	Ct * EFt + Cv * EFv + Cb * EFb

5.3.3

Alternative Fuels

Motor vehicles which are designed to use alternative fuels such as methanol, natural gas, and liquid petroleum gas (LPG) tend to have lower grams per mile emissions of HC, CO, NOX, and particulate than conventional gasoline and diesel vehicles. In addition, their hydrocarbon emissions are not as photochemically reactive as the HC emissions from their conventional counterparts, which should result in the reduction of secondary ozone and photochemical smog. Therefore, a potential emissions control measure for airport vehicles is to use as many alternative fuel vehicles as possible.

The reality of the situation is, while some alternative fuel vehicles are available, the alternative fuels needed to operate them are not yet widely available to the general public. Alternative fuels will become more available in the future, but the best current candidates for alternative fuel use are fleet vehicles which are centrally fueled, such as shuttle buses, transit buses, and some commercial trucks. Since the majority of all rental cars are rented at and returned to airports where central fueling with alternative fuels is practical, alternative fuel vehicles also may be appropriate for use in rental fleets.

5.3.3.1

Alternative Fuels for Rental Cars

The proportion of rental cars used by passengers has increased significantly in recent years. In fact, at airports in the Bay Area, for example, rental car use is the second most popular passenger ground access mode, second only to private cars. This suggests that rental cars are responsible for a significant portion of the airport VMT and emissions: seventeen percent of passengers at San Francisco used rental cars, and rental cars accounted for 13 percent of all passenger and employee trips generated by the airport at large. If rental car trip length is about average for passenger vehicle trips, then rental cars account for 13 percent of VMT at SFO. San Francisco has a similar proportion of rental car use as at South Coast airports for which information is available, and it is possible that rental cars are responsible for 10 to 15 percent of total VMT at South Coast airports, too. Thus, if alternative fuel vehicles were introduced into airport rental car fleets, some reductions in emissions may be achieved.

CONSTRAINTS

Near term alternative fuel cars and light trucks will be almost exclusively flexible fuel vehicles (FFV) which can use any mixture of gasoline and methanol, from pure gasoline up to 85 percent methanol (M85). Three major constraints to using alternative fuel vehicles in rental fleets are FFVs' higher prices, reduced choice and availability of FFVs compared to conventional gasoline vehicles, and the relative scarcity of alternative fuel filling stations. These constraints are discussed below.

Current flexible fuel vehicles are priced up to $2000 more than their conventional gasoline counterparts. Flexible fuel vehicle cost issues are likely to be overcome through incentives and falling FFV costs and prices. The California Energy Commission (CEC) offers a $400 credit against the purchase of Chrysler, Ford and GM FFVs ordered in 1993, as an incentive to commercial buyers. Chrysler's FFVs are actually priced the same as its conventional vehicles, while the price of Ford and GM FFVs are $2000 more than their similar conventional vehicles. Both manufacturers expect the price differential to decrease as economies of scale lower per unit costs.

FFVs will not be available in all size classes, and will not be available from all manufacturers. Thus, rental agencies cannot easily go to an all FFV fleet, as they would have considerably fewer models and classes of vehicles to offer to renters. Midsize sedans (e.g., Dodge Spirit, Ford Taurus, Chevy Lumina) and minivans (e.g., Chrysler minivans) are popular rental vehicles and the best candidates for FFV, but there are few if any FFVs planned for the subcompact and large/luxury classes, which are also popular with renters.

The third constraint is the scarcity of M85 filling stations. FFV emissions are minimized when M85 is used exclusively, but public M85 filling stations are scarce at this time (there were 39 methanol filling stations in California as of late 1992), although the number of M85 filling stations is expected to increase significantly through the 1990s. For practical purposes, rental agencies must have M85 fueling on-site, but the current lack of public filling stations means that renters are unlikely to refill with M85 away from the airport, and much of the emissions benefit that could come from FFV rentals will be lost in the near term. Even incentives such as offering free refueling for rental FFVs may not be sufficient to keep M85 in FFVs at all times, as shown by the experience of Avis at the Sacramento airport: The company does not charge returning customers a refueling fee on its 20 flexible fuel Chevrolet Luminas, but a company representative estimates only about 60 percent methanol content as an average across the twenty vehicles at any one time.

APPLICATIONS

As discussed above, Avis already has FFVs in its rental fleet at the Sacramento airport, but as far as could be determined, no emissions data have been collected from those vehicles. Emissions testing of other production FFVs has shown that flexible fuel vehicles enjoy a significant emissions benefit when operated on M85, relative to operation on gasoline.

According to the U.S. EPA's MOBILE5 model, the 50,000 mile emission factors for passenger car LEVs are 0.092 g/mi HC, 3.00 g/mi CO, and 0.196 g/mi NOX. At 50,000 miles, passenger car TLEVs are expected to emit 0.147 g/mi HC, 3.93 g/mi CO, and 0.390 g/mi NOX. The in-use emission factors will actually be between the TLEV and LEV factors, since in-use fuel tank methanol content will vary between zero and 85 percent. Compared to 1994 model year conventional gasoline passenger car 50,000 mile emission factors of 0.617 g/mi HC, 9.387 g/mi CO, and 0.78 g/mi NOX, the potential emissions reductions are substantial, even if the rental FFVs run on conventional gasoline.

KEY INPUTS

The inputs needed for the sample calculation are the size of the rental fleets, the percentage of the fleets that can be replaced by FFVs, the average rental FFV VMT, and the average fuel methanol content (to obtain FFV emission factors).

SAMPLE CALCULATION

Daily emissions reductions (in grams) due to the use of alternative fuel rental cars are calculated as the difference between in-use emissions for alternative fueled cars and emissions for conventional cars. In-use emissions are the product of vehicle specific emission factors and average daily VMT. Here it is assumed that conventional rental cars have the same emission factors as the passenger vehicle fleet, but since rental cars are newer, low mileage vehicles, this may overstate the potential reduction.

TCM	CALCULATION
Alternative Fuel Rental Vehicles..........	$Ct * EFt + Cv * EFv + Cb * EFb$

5.3.3.2

Alternative Fuels for Commercial (Heavy Duty) Vehicles

Commercial fleets operating at airports include light duty and heavy duty vehicles. Light duty and medium duty vehicles up to 14,000 pounds gross vehicle weight are covered by California's LEV program, which means that low emissions versions of these vehicles will enter commercial fleets in the next few years. Heavy duty vehicles are not yet covered by an equivalent to the LEV program, although a Low Emissions Truck/Bus program, which will likely result in HD alternative fuel vehicles, has been proposed by the ARB. Another force that may get alternative fuels into commercial heavy duty fleet vehicles is local regulations requiring the use of alternative or clean fuels in fleet vehicles.

Once alternative fuel vehicles are introduced into heavy-duty fleets, these vehicles are more likely than rental cars to use alternative fuels. This is true for dual fuel or flexible fuel fleet vehicles because the vehicles are fueled only at the terminal or home base where refueling with alternative fuel is more likely. It is also true because the majority of heavy duty alternative fuel vehicles will be dedicated to one (alternative) fuel type.

CONSTRAINTS

The biggest constraints to alternative fuel trucks and buses are that, compared to conventional fuel trucks and buses, they are more expensive to buy than conventional fuel trucks and buses and, for methanol fueled trucks and buses, they are more expensive than gasoline and diesel vehicles to operate.

APPLICATIONS

Many state and local authorities, including some in California, have implemented plans to require alternative fuel vehicles in certain fleets, including some types of fleets that operate extensively at airports. Two local alternative fuel regulations could be models for heavy duty alternative fuel vehicle plans. A Washington, D.C. law requires that all commercial vehicles operating in the "central employment area" must use alternative fuels as of January 1, 1998. Such a law could be applied easily to airports. The only known alternative fuel vehicle regulations that are specific to airports are in Denver, where alternative fuel buses are required at Stapleton Airport and will be required at the New Denver Airport when it opens.

Based on emissions test results from production and near-production alternative fuel heavy duty engines, methanol and natural gas heavy duty engines will meet ARB's proposed Low Emissions Truck and Bus standards. In-use emission factors for alternative fuel heavy duty engines are not available, but those values can be estimated as the product of the heavy duty gasoline vehicle emission factors from MOBILE5 and the ratio of certification standards for heavy duty vehicles and low emissions trucks and buses. This methodology results in LEB 50,000 mile emission factors of 1.27 g/mi HC, 13.33 g/mi CO, and 1.79 g/mi NOX, compared to model year 1994 heavy duty gasoline emission factors of 1.27 g/mi HC, 14.35 g/mi CO, and 4.47 g/mi NOX.

KEY INPUTS

The emissions reductions that can be achieved by the use of alternative fuels in commercial (heavy duty) vehicles can be estimated once the average VMT of commercial vehicles and the commercial vehicle alternative fuel penetration rate are determined.

SAMPLE CALCULATION

Daily emissions reductions due to the use of alternative fuels in commercial (heavy-duty) vehicles are calculated as the difference between in-use emissions for alternative fueled commercial vehicles and emissions for conventional commercial vehicles. In-use emissions are the product of vehicle specific emission factors and average daily commercial vehicle VMT.

TCM	*CALCULATION*
Alternative Fuel Commercial Vehicles......	Nc * (EFc - EFac) * VMTc

✤ ✤ ✤ ✤ ✤ ✤ ✤

5.3.4

Other Control Measures

Other airport specific transportation control measures include extending rail service to terminals or parking lots, offering transit discounts or subsidies to passengers, and creating satellite park-and-ride lots and systems for employees. Estimates of the effectiveness of these control measures cannot be made at this time, as no data are available.

5.4

Conclusions

This section has discussed many control measures that can be used to reduce emissions associated with vehicle trips to and from California's airports. Those TCMs are summarized in Table 5-8, which shows the TCMs for employees can reduce employee related vehicle emissions from less than one percent to ten percent or move, according to data from studies at various U.S. airports.

Quantitative results for passenger TCMs are not so easily obtained, but restricting long term parking through increased prices may decrease passenger VMT and emissions by as much as four percent. Other TCMs for passengers include restricting passenger vehicle idle times, and increasing the use of satellite parking facilities with shuttle bus service. This last TCM has the effect of eliminating all on-airport VMT for passengers' vehicles.

The most promising commercial vehicle TCM is circulation management, which may decrease on-call van and shuttle bus on-airport VMT by as much as 40 percent, and which may also lead to greater overall VMT reductions if marginally used services decide to curtail airport operations. Other commercial vehicle TCMs include the use of alternative fuels such as methanol and natural gas. Electric shuttle buses, of course, emit no pollutants from the vehicle.

TABLE 5-8

Airport Transportation Control Measures

Transportation Control Measure - TCM	Mode/ Component Affected	Effect on Mode or Emissions	Additional Data Requirements
Variable shifts for employees, including work at home	Employee VMT	Decrease 2 to 5%	Employee share of total VMT (internal & external)
Rideshare/Carpool incentives for employees	Employee VMT	Decrease 0 to 5%	Same as above; effect on transit ridership
Transit incentives for employees	Employee VMT	Decrease 0 to 3%	Same as above
Alternative mode incentives for employees	Employee VMT	Decrease 5 to 7%	Same as above; more research on effectiveness
End employee parking subsidy or offer cashout	Employee VMT	Decrease 10% or more	Same as above
Increase long term parking rates	Passenger VMT & idle	Can decrease VMT 1 to 4%, but can increase VMT & idle times by increasing dropoffs	Passenger share of total VMT; business share of parking
Passenger vehicle idle time limits	Idle & hot starts	Decrease idle by unknown %; increase hot starts	Current idle practices
Passenger & employee satellite parking (long term & short term) w/ shuttle bus service	Passenger & employee internal VMT; shuttle bus VMT	Decrease passenger & employee internal VMT 100% - similar for idle; increase shuttle bus internal VMT	Passenger & employee share of internal VMT; effect on bus VMT
Taxi & bus idle time restrictions	Taxi/limo/van & bus idle & hot starts	Decrease idle by unknown %; increase hot starts	Current taxi & bus idle practices
Idle restrictions for delivery, service & commercial vehicles	Delivery/service/comm. vehicle idle & hot starts	Decrease idle by unknown %; increase hot starts	Current idle practices
Circulation management for on-call vans & shuttles	On-call van & shuttle bus internal VMT	Decrease on-call van & shuttle bus internal VMT 30 to 40%	On-call share of internal & total VMT
Restrict airport shuttle bus use; pool buses	Rental car/hotel shuttle bus VMT	Decrease internal VMT by unknown %	Shuttle bus population & VMT
Alternative fuels for airport shuttle buses	Exhaust & evaporative emissions	Emissions benefits depend on fuel type	Same as above
Electric shuttles	All	Eliminate emissions	Same as above
Alternative fuels for delivery/ service/ commercial vehicles	Exhaust & evaporative emissions	Reduce emissions relative to conventional fuel vehicles	Commercial veh. share of internal & total VMT
Alternative fuels for taxis & rental cars	Exhaust & evaporative emissions	Reduce emissions relative to conventional fuel vehicles, maybe not relative to LEVs	Taxi & rental car shares of internal & total VMT
Extend rail service to airport or shuttle bus service from rail to airport	Passenger & employee VMT; congestion	Decrease VMT by unknown amount; increase avg. speed	% reduction of trips; effect on avg. speed
Congestion relief via road construction projects	Avg. speed of all vehicles	Increase by unknown amount; may lead to more trips & higher VMT	Effect on avg. speed

— SECTION 6 —

Mitigation Measures In Use At Existing Airports

Several airports in the U.S. and Europe have innovative projects and plans that reduce air pollution. Even though some of the measures were implemented for other reasons, all of the measures discussed decrease air emissions somewhat. In some cases, measures that were considered but not implemented are described. This is not a comprehensive list of airports and/or measures. Key phrases identifying mitigation measures and variations discussed are listed after the airport name. This discussion does not quantify the effect of the measures on air emissions.

6.1

U.S. Airports

California

Los Angeles International

GSE fuel use, vehicle fuel use, central power systems, transportation access system

An innovative project that would reduce airside emissions is being negotiated at Los Angeles International Airport (LAX). Emissions from mobile and stationary sources must be reduced under the Air Quality Management Plan. The use of alternate fuels for both vehicles and equipment using internal combustion engines are being considered actively. The development and demonstration of CNG-fueled airport service vehicles and equipment at the airport is being negotiated. The demonstration would be conducted at LAX on United Airlines equipment and supported by several private sponsors. The feasibility and emission benefits of CNG-fueled equipment will be demonstrated.

Landside, several measures are being implemented. A remote terminal option has been investigated over the past few years. The proposed site is twenty miles from LAX and could run in conjunction with the green line metro system. There is a computerized ground transportation access system that provides information to arriving passengers. CRT terminals located throughout the airport terminal display a map from which the passenger can identify his intended destination. Then, a list of alternative vehicle transportation options is provided. LAX has a campaign to encourage mass transit, especially through use of its fly-away terminal. The terminal is twenty miles from LAX at Van Nuys airport and provides parking and bus transportation to LAX. This option is open to both employees and passengers. A people-mover system is in the process of being built. The purpose of the system is to interface with commercial vehicles, such as hotel vans, outside of the terminal area. This would eliminate commercial vehicles from the congested terminal area. Airside, most gates at LAX have central power systems.

Sacramento Metropolitan

Congestion reduction, flextime, rideshare, rail, idle reduction, vehicle fuel, transportation scheduling

Sacramento Metropolitan Airport is planning to build a second terminal, which would have central power systems with air. Airside, there are three bridge-mounted power sources available, which do not provide pneumatics (air or aircraft start). High-speed turnouts and parallel runways have resulted in low taxi times. During peak periods, Sacramento tries to limit general aviation activity to the secondary runway. This separation of general aviation aircraft from jet aircraft helps to reduce congestion.

Landside, Sacramento has several measures being implemented. There is a transportation starter system booth located curbside to schedule transportation for arriving passengers. Two vans and two taxis are allowed to wait at the curb, with one taxi at the end of the terminal. The remaining vans and taxis are in a holding area. Taxi and van engines must be turned off whenever possible. The line-up of vehicles is handled by a person near the transportation booth. Airport policy is for vans to wait fifteen minutes after the first passenger boards in order to increase the passenger load.

In order for a taxi to service the airport, it must belong to the independent airport taxi association. The association requires taxis to meet certain restrictions on operations. Sacramento is trying to create a similar association for vans, which could establish operating rules or standards that would require limits on idling, circuits, and similar practices that could reduce air emissions. With the new terminal expansion, airport and car rental shuttle services will be consolidated into one system. The airport is looking into acquiring alternative fueled (e.g. electric, methanol, and CNG) buses for the consolidated system. There is a five minute idling limit for cars, which is enforced by the sheriff's office.

Flextime is available for both airport and airline employees. Airport employees can work nine days in a two-week period (9-80s), as long as they are present for the core hours of 10:00am to 2:00pm. They also have the option of telecommuting (working at home) one day per week. Very few airport employees telecommute. Airline employees have the option of working four ten-hour days per week (4-10s).

There are two carpooling programs at the Sacramento Metropolitan Airport. There is a county project that is limited to airport employees. Only a few airport employees choose this option. The second carpooling program is by CalTrans. This option is open to employees of all companies located at the airport. This program coordinates carpooling for approximately 9-12% of the employees. There also are carpooling incentives such as preferential parking and freebees (e.g. pens and frisbees).

Sacramento is physically setup for light rail, however, the rail line has not been extended to the airport. It also was decided not to provide a shuttle connecting the airport to existing light rail, which is near town. The decision was based on the level of car vandalism at rail parking lots and airline preference not to track baggage that would be remotely checked. The airport is continuing to investigate both options.

San Francisco International

Central power systems, aircraft towing, congestion relief, rideshare

Airside, many gates at San Francisco International Airport (SFO) provide central power systems, some with air. United Airlines operates a high-speed aircraft tow, the Krauss-Maffei PTS. United uses the tow for transporting selected aircraft to and from their maintenance area. The diesel-engine tow has a maximum towing speed of 20 mph; aircraft usually taxi at around 3 or 4 mph. Since it can operate at a higher speed, the tow does not need to stop at intersections for crossing clearance. This results in a direct tow, reduced congestion, and fuel cost savings.

Landside, United Airlines encourages employee carpooling because of the lack of parking stalls. As an incentive, United carpoolers receive better parking spaces. The airport was physically designed for bart (rail) hook-up. Although rail tunnels currently exist, there is not rail service yet.

Sonoma County

Central power systems, mass transit

Airside, Sonoma County Airport is not able to provide central power systems due to airport power limitations on the incoming power cable. Bus service to the airport is provided by Sonoma County Transit, but only a small percentage of travelers use it.

Colorado

Stapleton

GSE fuel

Airside, Denver's Stapleton Airport is pursuing a project with several benefits including the reduction of air emissions. A fleet of approximately 100 natural gas ground support vehicles operate at Stapleton. The major airlines at the airport have Natural Gas Vehicle (NGV) programs, as do many of the hotels and rental car companies that operate airport shuttles. Reasons for the use of NGVs at Stapleton are the cleanliness (which saves money on maintenance costs) and low cost of natural gas, a city mandate that a certain number of vehicles run on alternate fuels, a plentiful projected future for natural gas, and the structure of Stapleton's replacement airport, Denver International.

Denver International

Congestion relief, GSE fuel

Denver International Airport is scheduled to open March 1994. Airside emissions will be reduced through special design features of the airport including automated baggage handling, which eliminates the need for many of the baggage carts presently used, and a central terminal close to the many runways, which reduces taxi time. The new airport will have service tunnels connecting the terminals allowing limited use by GSE. The tunnels are intended to reduce runway traffic, a common problem at airports that increases airside congestion. NGVs can be operated in the tunnels due to their lower emission rates.

Pennsylvania

Greater Pittsburgh International

Passenger handling, congestion reduction, air traffic controls

Greater Pittsburgh International Airport's new mid-field terminal opened October 1, 1992. The new X-shaped terminal lies between two main runways, reducing taxi times. The AEG-Westinghouse underground people-mover rail system can transport 13,200 passengers per hour to the mid-field terminal. The airport was the first to receive a Norden Systems' Airport Surface Detection Radar. The radar aids controllers in directing traffic on taxiways, runways, and aprons during low-visibility weather and when the controller's view is obstructed. Landside, there are two roadways accessing the landside terminal, one for use by private vehicle and the other by public vehicle. The measure is intended to increase safety but decreases congestion and curbside idling as well.

Washington, D.C.

Dulles International

Passenger handling

Dulles International Airport's original design envisioned taking passengers to aircraft with as few steps as possible. Bus-type vehicles, called mobile lounges, were used to transport passengers from the main terminal gates to aircraft parked close to the runway. Originally, all aircraft were served directly by lounges.

Around ten years after the airport was built, two significant changes were made at the airport: new lounges and a mid-field terminal. The original lounges were designed for smaller jets. Due to new jumbo jet aircraft, the lounges had to be updated. The new lounges could rise and lower in order to serve the jumbo jets. However, airlines also had begun using the airport for hubbing operations. There were not enough lounges and space during peak operations to park all the aircraft and lounges. Dulles Airport built a mid-field terminal near the runways to accommodate airline hubbing. Now passengers also could be transported from the main terminal to the mid-field terminal. The passengers then board aircraft parked at mid-field terminal gates.

Today, Dulles still transports passengers directly to select aircraft from the main terminal. Two factors determine which aircraft are served directly by lounges. The first is if an airline elects not to have jet ramps. Jet ramps connect the aircraft to the mid-field terminal's gate, allowing passengers to board and depart. Second, for international flights that need customs clearance, passengers are taken by lounges directly to customs. Approximately twenty to twenty-five percent of flights today are served directly by lounges. The remaining seventy-five to eighty percent of flights are served through the mid-field terminal.

National

Operation limits, rail access

Airside, National Airport is one of four U.S. airports with slot limits. For these airports, the number of landing slots is established by faa to limit airspace congestion. The slot limit is determined by the airport's capacity. Limits on the number of operations per hour are set for three operator types:

air carrier, commuter, and other (general aviation).

Landside, National is accessible by Metrorail, the area's subway system. The rail system connects the airport with Washington, DC and nearby suburbs.

6.2

European Airports

European airports have considered or implemented a variety of measures that reduce air pollution, some of which have not been tried in the United States. Airports and governing agencies were contacted in several European countries to discuss air pollution mitigation measures and their affect on airport operations and air pollution. Although the measures affect air emissions, some of them have been implemented for reasons other than the reduction of air pollution. This is not a comprehensive list of airports and/or measures.

France

Orly and Charles de Gaulle

Rail access, roadway improvements, vehicle fuel

Orly and Charles de Gaulle Airports are operated by the Aeroports de Paris (ADP). The ADP feels that the airports are valuable to the region, but a source of environmental problems. Airside, the ADP considers aircraft a small source of overall airport air emissions. As aircraft engines have become increasingly less polluting over the past ten years, the aircraft emissions have reduced accordingly. Based on their view that aircraft engines are a small air emissions source and becoming increasingly cleaner, the ADP has not found it necessary to implement air emission mitigation measures for aircraft.

At Charles de Gaulle Airport, there is a fixed deicing station. Within three years, there will be a number of fixed stations at both airports for deicing as well as aircraft washing. Fixed stations are preferred to reduce the amount of pollutants released into stormwater run-off.

Landside, the ADP is trying to improve ground access to the airports. Currently, 80% of passengers access the airports by private vehicle. At Orly, a commuter train connects the airport to the Paris rail and bus connections are being investigated. At Charles de Gaulle, the connecting highway is being doubled in size. In addition, a third terminal is planned for the airport along with new public transportation options. Options include a new bus station, a shuttle between terminals, and a rail link.

The ADP is phasing out leaded gasoline for airport vehicles. Currently, 20% of the airports' support vehicles are electric. The ADP's goal is to have 30% of airport vehicles operating on electricity by 1996.

Germany

Germany's Air Traffic Act set up a committee to look at airport noise pollution. As of July 1992, the committee also began investigating airport air pollution. There are two reports by the international law firm of Wilmer, Cutler & Pickering that were commissioned by the German Airspace Users Association. *Germany's Airport Capacity Crisis* (1991) discusses capacity problems and recommended solutions, economic and social impacts, and political and legal issues of Germany's airports. *The Crisis of European Air Traffic Control: Costs and Solutions* (1989) discusses air traffic control (ATC) problems, calculates ATC delay and disruption costs, and recommends interim and long-term solutions and implementation methods.

Dusseldorf

Currently, no air pollution reduction measures have been implemented. Air quality measuring equipment are placed at the airport's boundaries collecting HC, CO, and NOX data. Nothing has been done with respect to the data collected.

Frankfurt

Rail connections, congestion relief, aircraft towing

Frankfurt Airport is the second busiest European airport next to London's Heathrow Airport. The new East terminal is planned to open in 1994. A rail station is located directly beneath the airport terminal and receives 130 trains per day. Frankfurt has in operation Sieman's Departure Coordination System (Depcos), which replaces paper flight strips with CRT display. Controllers enter requests and clearances (e.g. start-up, push-back, and taxi) for departing aircraft into the system. The system reduces the time needed to coordinate aircraft for departures. There has been operational test towing of Lufthansa's international flights with their B747-200.

Munich 2

Fleet modernization, congestion reduction, central power systems, passenger handling

Munich 2 opened on May 17, 1992 with many airside systems and features in place that result in the reduction of air pollution. At Munich 2 Airport, the basic fee is paid for ICAO licensed aircraft in accordance with Annex 16, Chapter 3. The modern Chapter 3 (the same as Stage III in the U.S.) aircraft tend to be the cleaner aircraft. Extra fees must be paid for older, polluting aircraft. Each of the parallel runways are 4000m (13,100 feet) long, eliminating the need for arriving aircraft to use reverse thrust. The runways are situated to give them the greatest possible distance. Sieman's Computer Controlled Runway System improves aircraft flow and safety for movements on the taxiway. The Apron Control System is directed by a special team of controllers in the tower who are responsible for aircraft as they enter the apron area from the taxiways. The controllers illuminate colored lights to direct taxiing aircraft to assigned gates. When a taxiing aircraft approaches a gate, a controller identifies the aircraft type and model for the Aircraft Docking Guidance System. Inductive sensor loops laid into the apron detect the aircraft's nose wheel. Colored lights then direct the aircraft to the stopping block at the gate. The post for the docking system also houses the ground servicing connections for communications, electric power, cooling air, and fuel for the aircraft. Sieman's Departure Coordination System (Depcos) replaces paper flight strips with a CRT display. Controllers enter requests and clearances (e.g. start-up, push-back, and taxi) for departing aircraft into the system. The system reduces the time needed to coordinate aircraft for departures. For remote gates, passengers deplane and ride buses to the terminal. To cope with cold weather, the water table was lowered at Munich to ensure frost-free runways, taxiways, and aprons. The airport also has purchased a deicing system that is about 4 times faster than standard deicers.

Landside, a metropolitan railway line connects the airport to the City of Munich. An additional railway connection is planned. There also is bus service available. Company vehicles are partly equipped with double drive (diesel, electric), others with 3-way catalyst. There are agreements with public authorities to reduce car traffic on the airport site if certain air quality standards are exceeded.

Netherlands

Amsterdam's Schiphol

Rail connections, rideshare, congestion reduction, aircraft towing, load factor improvement

Schiphol Airport is experiencing a 1-2% increase in air pollution each year. The airport currently is involved in a large environmental impact study looking at air pollution measures related to airport activity. The study is divided into three phases: ground vehicles, aircraft handling, and air.

Phase 1: Ground Vehicles

Several measures are being implemented to increase public transportation. There is a rail station already in place for which the capacity is being doubled. Check-in is available at the train station and parking fares have been increased to encourage public transportation. The airport is trying to negotiate a contract with tenants to give employees a 40-50% discount off train fares. In addition, the airport is encouraging carpooling and investigating a high-speed train.

Phase 2: Aircraft Handling

Measures to decrease taxi times and the movements of GSE are being investigated. Taxi times are only 10-12 minutes and taxiways are relatively congestion free. Schiphol decided not to tow aircraft because it would be too expensive for the resulting impact.

Phase 3: Air

The aim of Phase 3 is to increase load factors.

Sweden

In Sweden, airports are not the main source of air pollution, but they are the government's main target for air pollution reduction.

Stockholm's Arlanda

Central power systems, congestion relief, GSE fuel, rail connection, fleet management

Arlanda Airport has several measures in place, especially at its new domestic terminal. GSE have been virtually eliminated at the domestic terminal, which is unique to Arlanda. This measure was implemented to reduce air pollution on the apron and provide a better working environment for ground support employees. The elimination of GSE significantly reduces air pollution on the apron, but does not have a large impact on the airport's total emissions. Each gate at the domestic terminal is equipped with a service tunnel from which elevators rise approximately 3 feet to supply the aircraft with fuel, electric power, compressed air, water, and lavatory service. Catering supplies and cleaning equipment are stored in the passenger bridges. Passenger baggage is checked at the gate during check-in, and transferred by conveyor belt directly to the aircraft hold. An electrically powered system, PullBack, is installed for moving aircraft to and from the gate. The system has a hydraulically powered chain link that moves a trolley along a track in the ramp surface to an arriving aircraft. The trolley then locks onto the nose wheel and pulls the aircraft to its park position. The process is reversed for departing aircraft.

At other terminal gates, measures also have been implemented. A ground power source provides heat and fuel to aircraft. For diesel GSE, a regulation requires the purest diesel fuel to be used.

Arlanda Airport currently is investigating emission reduction measures in response to emission limits placed on the airport by authorities. Total emissions of NOX and CO in 2000 are limited to 1990 emission levels. Landside, a rail link is being considered because the only public transportation currently available is bus service. Increased parking prices also is being investigated as a landside measure. Airside, higher landing fees may be charged for aircraft with higher emitting engines.

Switzerland

Zurich

Rail connections, rideshare, idle restrictions, central power systems, passenger handling, congestion reduction, aircraft towing

Within 5 years, the management of Zurich Airport would like to claim that it is the most environmentally advanced airport in the world. Switzerland has a clean air act similar to the United States'. As required, the Canton of Zurich set up a program to limit emissions of air pollutants. In the program, the airport is asked to contribute its share to reducing emissions. Zurich Airport's emissions are regulated and not allowed to increase. A Master Plan Project is underway that looks at air, water, and land emissions. The project will be used as a guideline for airport expansion to cope with increasing traffic. For air emissions, the primary pollutant of concern is NOX. The airport plans to set up a program to reduce airport air emissions (especially NOX) from air and land traffic.

Landside, the airport is encouraging people to use public transportation in various ways. There is an underground railway system located beneath the airport, which connects to both the Swiss national and international networks. Railway facilities are going to be increased to accommodate rail passengers. Facility plans include a baggage check-in station at the railway exit and better connections that coincide with employee schedules. Swiss Air attempted a carpooling program for employees that failed. The airport would rather encourage public transportation than carpooling. Short term parking fees are high to encourage the use of public transportation. There also is a shopping mall at the airport that is open 7 days a week and includes a grocery store. Airport parking fees also affect mall shoppers' parking. Efforts have resulted in 35% of passengers and 25% of employees using public transportation on weekdays. For those people who come by private car to the airport, federal and state laws prohibit any car idling at the terminal.

Emission certificates and regulatory taxes are being considered. HC emissions at Zurich Airport are low and expected to decrease due to the large percentage of Chapter 3 (same as Stage III in the U.S.) aircraft. The airport has 28 primary gates, 18 gates in Terminal A and 10 gates in Terminal B. A ground power supply system for docked aircraft provides electricity and pre-conditioned air for all primary gates. As of January 1, 1993, all APUs must be turned off as soon as aircraft are docked. The ground power supply results in power savings as well as pollutant reduction. The airport also has a number of "open" gates that are located 200-300 yards from the terminal to handle overflow aircraft. GSE provide service to the open gates, and passengers are bused to the terminal. Slot coordinated engine startup is planned in which the delivery clearance to start an aircraft's engines will not be given before the assigned slot for the aircraft is actually approved. Aircraft are towed by a high-speed towbarless tractor between the terminal and maintenance facility. This alternative will not be implemented for taxiing aircraft due to short taxiways and infrequent ground delays that result in average taxi times of 8.5-10 minutes. To optimize taxi traffic, some double taxiways as well as holding bays may be built that would enable passing maneuvers in case of changed departure sequences. An airside shuttle for employees is planned to avoid and reduce the individual use of cars.

United Kingdom

Gatwick

Idle restrictions, rail connections, central power systems

Gatwick has 50 main terminal gates and a few remote gates. The airport handles 20 million passenger per year, most of which are international. Landside, there is a heavy volume of traffic, but good traffic flow. There are no idling restrictions at the airport terminal. There is a reserve area for taxis and only a small demand for service. There are approximately 12 hotels with shuttles that usually run on demand. There is a rail link directly to London, which services other UK areas. Approximately 20-25% of airport passengers travel by rail to the airport. Employees tend to drive by car to work. Airside, taxi times are fairly quick, and fixed ground power at the main terminal gates provides electricity to aircraft.

Heathrow

Congestion reduction, vehicle fuel, rail connections, aircraft towing, reduced engine taxiing, GSE fuel

Heathrow has 4 terminals, 3 of which are located in the central terminal area between the runways. An underground tunnel connects to the central terminal area. The airport is not implementing many measures because it meets local air quality standards. The airport is going to begin monitoring for air quality concentrations in the airfield.

Landside, there are a couple of measures planned. A campaign is to be implemented on 'how to drive a car'. The campaign will explain that how a car is driven affects the car's emissions. It will be directed towards airport and tenant employees, focusing on diesel fueled vehicles. Heathrow wants to encourage public transportation for employees and passengers. There are plans for a direct rail link between London and the airport to be available in 1997. The trip will be an estimated 18 minutes, a significant reduction from the 1 hour trip by subway.

Airside, numerous measures have been considered and implemented for aircraft and GSE. Aircraft towing was investigated and rejected due to the numerous runways and taxiways to cross. Airlines at Heathrow taxi with reduced engines for fuel economy reasons. Generally, reduced engine taxiing is left up to the pilot's discretion. Heathrow is very interested in encouraging electric GSE. Two restrictions are being considered for

GSE. First, an airside pass from the airport may be required for all GSE. This pass price would be discounted if the vehicle was electric. Second, certain apron areas that are prone to high air pollution may be restricted to electric GSE.

Manchester

Rail connections, idle restrictions, congestion reduction, fleet management, GSE fuel, aircraft towing, reduced engine taxiing

Manchester Airport only has a couple of measures being implemented, but several are being considered. Landside, the airport will probably have control measures on point sources (e.g. power plants) in the future. A new rail link connecting Manchester to the main line will come online in April 1993. There is free parking and no carpooling program for airport employees. Airport employees will probably be charged for parking in the future. Passengers and tenant's employees are charged for parking. Taxis are held in a pool, with a limited number allowed at the stands. Passenger vehicles are not allowed to be left unattended at the curb due to security reasons. If there is a driver waiting for a passenger, he is asked to park the car in a lot.

Airside, Manchester is most concerned with HC emissions. Better gate hold procedures, increased emission taxes and certificates for high emitting aircraft, and electric GSE are possible measures. The airport is not considering towing aircraft or reduced engine taxiing.

Appendix A

Data Required To Evaluate Aircraft Measures

— APPENDIX A —

Data Required To Evaluate Aircraft Measures

The data required to evaluate mitigation measures from aircraft operations are aircraft type, number of LTOs, engine type, engine emission factors, and mode times. The data and sources listed below were used to calculate the reference emissions estimate. The data used was specific to the airports noted in the report. For each measure, the key data and sources (other than the ones below) are detailed in the key inputs and references sections of the measure's discussion. Unless noted in a measure's key inputs section, the data and sources listed below were used to calculate the measure's emission estimate. Contact airlines if more detailed or airport specific data is needed.

The FAA's *Airport Activity Statistics of Certificated Route Air Carriers* is a yearly publication that lists aircraft types and annual LTOs by airport, airline, and aircraft. The type of aircraft, including cargo, and number of LTOs for all service were obtained from the document.

The particular engines that operate on aircraft, engine emissions factors, and default time-in-modes are provided in the U.S. EPA's *Procedures for Emission Inventory Preparation*, Chapter 5 - Aircraft, which is included in this appendix, as well as in *FAA's Aircraft Engine Emissions Database (FAEED)*. FAEED is an automated (computerized) menu-driven procedure for calculating an aircraft emissions inventory. The database was used in conjunction with EPA's report to calculate the commercial aircraft emissions. Default time-in-modes, as provided in FAEED, were chosen for all aircraft except for taxi time. EEA has confidential data from three airlines that provides taxi times for some California airports. Weighted average taxi times based on this data was used in the calculations. When selecting an aircraft's engine, there sometimes is a weighted average option that calculates an average engine's emissions by population market share. This option was chosen when available. When the weighted average option was not available due to lack of sufficient information, the most common engine was chosen.

— NOTE —

Energy and Environmental Analysis, Inc. recently updated EPA's *Procedures for Emission Inventory Preparation*, Chapter 5 – Aircraft.

This document is an excellent reference describing the concepts and procedures for developing airport emission inventories and provides information on engines and engine emission factors for commercial and military aircraft. It is reproduced in its entirety beginning on the following page. The default values described have not been approved by ARB. Calculations should be made using actual data, specific to local conditions, to the extent possible.

— CHAPTER 5 —

Emissions From Aircraft

This chapter describes the procedure for calculating emissions from civilian and military aircraft within an inventory area. The basic methodology determines aircraft fleet make-up and level of activity and then calculates air pollutant emissions on an annual basis. Variations to the methodology, which account for seasonal changes or specific operational considerations, are covered also. Finally, changes expected in the fleet in the future and the effect on emissions are briefly described at the end of the chapter.

The inventory methodology and emission factors have been updated since the last edition of this report. This chapter also updates the emission factor information that appears in *Compilation of Air Pollutant Emission Factors, Fourth Edition and Supplements*, AP-42 (Reference 1). Subsequent to the publication of this document, AP-42 will be formally updated and may include some additional data, primarily on general aviation and military aircraft, which was unavailable when this report was prepared.

5.1 Overview Of The Inventory Methodology

Preparing an emissions inventory for aircraft focuses on the emission characteristics of this source relative to the vertical column of air that ultimately affects ground level pollutant concentrations. This portion of the atmosphere, which begins at the earth's surface and is simulated in air quality models, is often referred to as the mixing zone. The aircraft operations of interest within this layer are defined as the landing and takeoff (LTO) cycle. The cycle begins when the aircraft approaches the airport on its descent from cruising altitude, lands, and taxis to the gate. It continues as the aircraft taxis back out to the runway for subsequent takeoff and climbout as it heads back up to cruising altitude. Thus, the five specific operating modes in an LTO are:

- Approach
- Taxi/idle-in
- Taxi/idle-out
- Takeoff
- Climbout

Most aircraft go through a similar sequence during a complete operating cycle. Helicopters may combine certain modes such as takeoff and climbout.

5.1.1 Factors Affecting Emissions

The LTO cycle provides a basis for calculating aircraft emissions. During each mode of operation, the aircraft engines operate at a fairly standard power setting for a given aircraft category. Emissions for one complete cycle for a given aircraft can be calculated by knowing emission factors for specific aircraft engines at those power settings. Then, if the activity of all aircraft in the modeling zone can be determined for the inventory period, the total emissions can be calculated. Each of the dominant factors that affect the emissions from this source is discussed below.

5.1.1.1 **Aircraft Categorization** - For a single LTO cycle, aircraft emissions vary considerably depending on the category of aircraft and the resulting typical flight profile. Aircraft can be categorized by use. Commercial aircraft include those used for scheduled service transporting passengers, freight, or both. Air taxis also fly scheduled service carrying passengers and/or freight but usually are smaller aircraft and operate on a more limited basis than the commercial carriers. Business aircraft support business travel, usually on an unscheduled basis, and general aviation includes most other non-military aircraft used for recreational flying, personal transportation, and various other activities.

For the purpose of creating an emissions inventory, business aircraft are combined with general aviation aircraft because of their similar size, use frequency, and operating profiles. In this inventory methodology they are referred to simply as general aviation. Similarly, air taxis are treated much like the general aviation category because they are typically the same types of aircraft. Military aircraft cover a wide range of sizes, uses, and operating missions. While they often are similar to civil aircraft, they are handled separately because they typically operate exclusively out of military air bases and frequently have distinctive flight profiles. Helicopters, or rotary wing aircraft, can be found in each of the categories. Their operation is distinct because they do not always operate from an airport but may land and takeoff from a heliport at a hospital, police station, or similarly dispersed location. Military rotorcraft are included in the military category and non-military rotorcraft are included in the general aviation category since information on size and number are usually found in common sources. However, they are combined into a single group for calculating emissions since their flight profiles are similar.

Commercial aircraft typically are the largest source of aircraft emissions. Although they make up less than half of all aircraft in operation around a metropolitan area their emissions usually represent a large fraction of the total because of their size and operating frequency. This may not hold true, of course, for a city with a disproportionate amount of military activity or a city with no major civil airports.

5.1.1.2 **Pollutant Emissions** - Aircraft pollutants of significance are hydrocarbon (HC), carbon monoxide (CO), oxides of nitrogen (NO_X), sulfur dioxide (SO_2), and particulates (PM_{10}). The factors that determine the quantity of pollutant emitted are the emission index for each operating mode (pounds of pollutant per 1000 pounds of fuel consumed), the fuel consumption rate, and the duration of each operating mode. HC and CO emission indexes are very high during the taxi/idle phases when aircraft engines are at low power and operate at less than optimum efficiency. The emission indexes fall as the aircraft moves into the higher power operating modes of the LTO cycle. Thus, operation in the taxi/idle mode, when aircraft are on the ground at low power, is a significant factor in calculating total HC and CO emissions. For areas which are most concerned about the contribution of aircraft to the inventory of HC and CO, special attention should be paid to the time the aircraft operate in the taxi/idle modes.

NO_X emissions, on the other hand, are low when engine power and combustion temperature are low but increase as the power level is increased and combustion temperature rises. Therefore the takeoff and climbout modes have the highest NO_X emission rates. If NO_X is a primary concern for the inventory area, special effort should focus on determining an accurate height of the mixing layer, which affects the operating duration of climbout.

Sulfur emissions typically are not measured when aircraft engines are tested. In evaluating sulfur emissions, it is assumed that all sulfur in the fuel combines with oxygen during combustion to form sulfur dioxide. Thus, sulfur dioxide emission rates are highest during takeoff and climbout when fuel consumption rates are high. Nationally the sulfur content of fuel remains fairly constant from year to year at about 0.05% wt. for commercial jet fuel, 0.025% wt. for military fuel, and 0.006% wt for aviation gasoline. This is the basis for the sulfur dioxide emission indexes in the tables included in this methodology. If the sulfur content of fuel varies significantly on a local basis, the emission index can be adjusted according to a ratio of the local value to the national value.

Particulates form as a result of incomplete combustion. Particulate emission rates are somewhat higher at low power rates than at high power rates since combustion efficiency improves at higher engine power. However, particulate emissions are highest during takeoff and climbout because the fuel flow rate also is high. It is particularly difficult to estimate the emissions of this pollutant. Direct measurement of particulate emissions from aircraft engines typically are not available, although emission of visible smoke is reported as part of the engine certification procedure. Particulate emission factors for only a few aircraft engines are included in this chapter.

5.1.1.3 **Aircraft Engines** - The aircraft powerplant is the source of emissions of the key pollutants that result from fuel combustion. Emission rates vary depending on the fuel consumption rate and engine specific design factors. In 1984, EPA established standards for HC emissions. In developing the emission limits, EPA defined an operating regimen to standardize the engine certification testing procedure and method for determining engine HC emissions. The standard applies to jet engines over 6,000 lbs-thrust and emissions are calculated based on a specific LTO cycle. EPA considered in-use engine deterioration when the standards were developed but concluded that, because of the high levels of maintenance of aircraft engines for reasons of safety and fuel economy, emission performance would not deteriorate significantly. The operating parameters used in the standard for the LTO cycle can be used as default values in calculating emissions when more specific information is not known. These default values are defined in later sections of this methodology.

When the standards went into effect, some engines in production could already meet them due to design changes made previously for improved fuel efficiency. Other engines had to be redesigned to reduce their HC emissions so that they could remain in production. In-service engines were not required to be retrofitted in the normal course of periodic servicing and rebuilding. These older engines, many of which remain in service, have HC emissions that exceed the standard. New engine designs, produced since the standards went into effect, have HC emissions much lower than the standards. As a result of design changes made to the engines that meet the HC standard, emissions of CO also generally went down while NO_X emissions tended to increased. However, the change in these pollutants was much less dramatic than the decrease in hydrocarbons. The smoke number for the newer engines also is lower due to specific design changes intended to reduce smoke production, which is regulated by EPA.

5.1.1.4 **Operating Modes** – During the LTO cycle, aircraft operate for different periods of time in various modes depending on their particular category, the local meteorological conditions, and operational considerations at a given airport. The "Time-In-Mode," or TIM, as used in this methodology, takes these factors into consideration. Table 5–1 shows representative LTO cycle times for several aircraft categories.

Duration in approach and climbout depends largely on the local meteorology. Since the period of interest is during operation of the aircraft within the air modeling zone, the inversion layer thickness determines how long the aircraft is in this zone. The inversion layer thickness is also known as the mixing height or mixing zone since the air in this layer is completely mixed and pollutants emitted anywhere within the layer will be carried down to ground level. When the aircraft is above the mixing layer, whether on descent or when climbing to cruising altitude, the emissions tend to disperse, rather than being trapped by the inversion, and have no ground level effect.

TABLE 5-1

Default Time-In-Mode For Various Aircraft Categories[1]

Aircraft	Time in Mode (Minutes): Taxi/ Idle-out	Takeoff	Climbout	Approach	Taxi/ Idle-in	Total
Civil[2]						
Commercial Carrier						
Jumbo, long and medium range jet	19.0	0.7	2.2	4.0	7.0	32.9
Turboprop	19.0	0.5	2.5	4.5	7.0	33.5
Transport- piston	6.5	0.6	5.0	4.6	6.5	23.2
General Aviation						
Business jet	6.5	0.4	0.5	1.6	6.5	15.5
Turboprop	19.0	0.5	2.5	4.5	7.0	33.5
Piston	12.0	0.3	5.0	6.0	4.0	27.3
Helicopter	3.5	—	6.5	6.5	3.5	20.0
Military[3]						
Combat[4]						
USAF	18.5	0.4	0.8	3.5	11.3	34.5
USN[5]	6.5	0.4	0.5	1.6	6.5	15.5
Trainer - Turbine						
USAF T-38	12.8	0.4	0.9	3.8	6.4	24.3
USAF general	6.8	0.5	1.4	4.0	4.4	17.1
USN[5]	6.5	0.4	0.5	1.6	6.5	15.5
Transport - Turbine[6]						
USAF general	9.2	0.4	1.2	5.1	6.7	22.6
USN	19.0	0.5	2.5	4.5	7.0	33.5
USAF B-52 and KC-135	32.8	0.7	1.6	5.2	14.9	55.2
Military - Piston	6.5	0.6	5.0	4.6	6.5	23.2
Military - Helicopter	8.0	—	6.8	6.8	7.0	28.6

1 Source: AP-42 (Reference 1).

2 Civil aircraft data is for large congested metropolitan airports.

3 USAF - U.S. Air Force, USN - U.S. Navy.

4 Fighters and attack aircraft only.

5 Time-in mode is highly variable. Taxi/idle out and in times as high as 25 and 17 minutes, respectively, have been noted. Use local data base if possible.

6 Includes all turbine aircraft not specified elsewhere (i.e., transport, cargo, observation, patrol, antisubmarine, early warning, and utility).

Taxi/idle time, whether from the runway to the gate (taxi/idle-in) or from the gate to the runway (taxi/idle-out), depends on the size and layout of the airport, the amount of traffic or congestion on the ground, and airport-specific operational procedures. Taxi/idle time is the most variable of the LTO modes. Taxi/idle time can vary significantly for each airport throughout the day, as aircraft activity changes, and seasonally, as general travel activity increases and decreases.

The takeoff period, characterized primarily by full-throttle operation, typically lasts until the aircraft reaches between 500 and 1000 feet above ground level when the engine power is reduced and the climbout mode begins. This transition height is fairly standard and does not vary much from location to location or among aircraft categories.

This methodology describes techniques and data sources for determining the critical variables in the inventory calculations. When an inventory is being created for a particular area, the fleet make-up, aircraft activity, and times-in-mode will be specific to that area. Engine emission indexes, on the other hand, depend on the engine design and are provided in reference tables.

Where specific information may be difficult to obtain, simplifying assumptions are discussed. An automated (computerized) calculation procedure, which can simplify data management, has been developed by the Federal Aviation Administration (FAA) with support from EPA and can be obtained from the FAA Technology Division, Office of Environment and Energy, 800 Independence Avenue, SW, Washington, DC 20591, (202) 267-8933. The FAA Aircraft Engine Emission Database (FAEED) includes information on the engines mounted on specific aircraft with emission factors for each of the engines, in addition to a menu-driven procedure for calculating an aircraft emissions inventory.

5.2 Inventory Methodology

The steps in the methodology are basically the same for each aircraft classification and each location, even though several factors used in creating an inventory are site specific.

(1) Identify all airports to be included in the inventory

(2) Determine the mixing height to be applied to the LTO cycle

(3) Define the fleet make-up for aircraft category using each airport

(4) Determine airport activity as the number of LTOs for each aircraft category

(5) Select emission indexes for each category

(6) Estimate a time-in-mode for each aircraft category at each airport

(7) Calculate an inventory based on the airport activity, TIM, and aircraft emission factors.

For a specific region where an emissions inventory is being created, steps one and two, the airports to be included and the mixing height, will be determined largely by the assumptions used in defining the scope of the modeling area. Steps three through six are repeated for commercial aircraft, general aviation, military aircraft, and helicopters. The primary difference in creating an inventory for each type of aircraft is the references used to determine the fleet make-up and activity. The following sections discuss each of these steps. Steps one and two are discussed in terms of the specific modeling area while steps three through six are addressed together for each aircraft category.

5.2.1 Airport Selection

Maps and regional information directories are good sources for identifying civil airports and military air fields. Sectional aeronautical charts, published by the Aeronautical Charts Distribution Division (C44), National Ocean Survey, NOAA, Riverdale, MD 20840, (301) 436-6990 ($5.25 per map), particularly show the location of large and small airports. Specific airports to be included will be limited by the geographic boundaries of the modeling area. A secondary reference is *AOPA's Aviation USA* (Reference 2) which lists publicly and privately owned civil airports, including heliports and seaplane bases, and locates them with directions relative to specific cities, as well as providing latitude and longitude coordinates. Much like the sectional aeronautical charts, this reference provides general information on all but a few small landing strips. These small air fields are unlikely to be considered for most analyses because they have low activity, typically can accommodate only small general aviation aircraft, and therefore, contribute insignificantly to the emissions inventory. (Many private use landing sites are listed in Reference 2 by city and site name but a telephone number is the only information given). *FAA Air Traffic Activity* (Reference 3) lists all airports with air traffic control towers operated by the FAA. While this is a subset of the airports listed in these other references, all of the airports in urban areas with significant air traffic are included.

5.2.2 Mixing Height Determination

The height of the mixing zone influences only the time-in-mode for approach and climbout. This factor is significant primarily when calculating NO_X emissions rather than HC or CO. If NO_X emissions are an important component of the inventory, specific data must be gathered on mixing heights. If NO_X emissions are unimportant, mixing height will have little effect on the results and the default value of 3000 feet can be used for more generalized results.

Mixing height should be determined in conjunction with those responsible for the air quality modeling of the region to insure that assumptions used for creating different sections of the overall inventory are consistent. If the inventory is being created independently of any air quality modeling, the mixing height can be determined by contacting the National Meteorological Center at (301) 763-8298 or alternatively the National Climatic Data Center (NCDC) at (704) 259-0682. Another source of mixing height data is the EPA Office of Air Quality Planning and Standards' SCRAM (Support Center for Regulatory Air Models) Bulletin Board. This electronic date base contains data used by various air quality models. Mixing height data, which appears under the Meteorological Data Main Menu, comes from the NCDC. See Reference 4 for information about accessing this bulletin board. As a third alternative, typical mixing heights can be found on Figures 5–1, 5–2, and 5–3 which come from *Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States* (Reference 5). These figures, which show mixing height for a mean annual morning, a mean summer morning, and a mean winter morning, illustrate the seasonal variation in the mixing height. The morning data corresponds to the few hours centered near the morning commuter rush hours, which roughly coincide with the diurnal maximum concentration of slow-reacting pollutants in many urban areas. Figure 5–1, showing annual mixing heights, may be used for creating an annual inventory. If a seasonal inventory is being used for evaluating emissions during a peak ozone period, the summer morning data from Figure 5–2 may be preferred. Episodes lasting two to five days occur most frequently during the winter for much of the U.S. If these episode periods are of primary interest, the data from Figure 5–3 should be used. Reference 5 should be consulted for additional information on the use of these figures. As a final alternative for mixing height, a default of 3000 feet may be used. This value, which is used as the default value for the EPA standard LTO, is incorporated into the calculations used for determining time-in-mode.

FIGURE 5–1
Reproduction Of Figure 1
— FROM REFERENCE 5 —

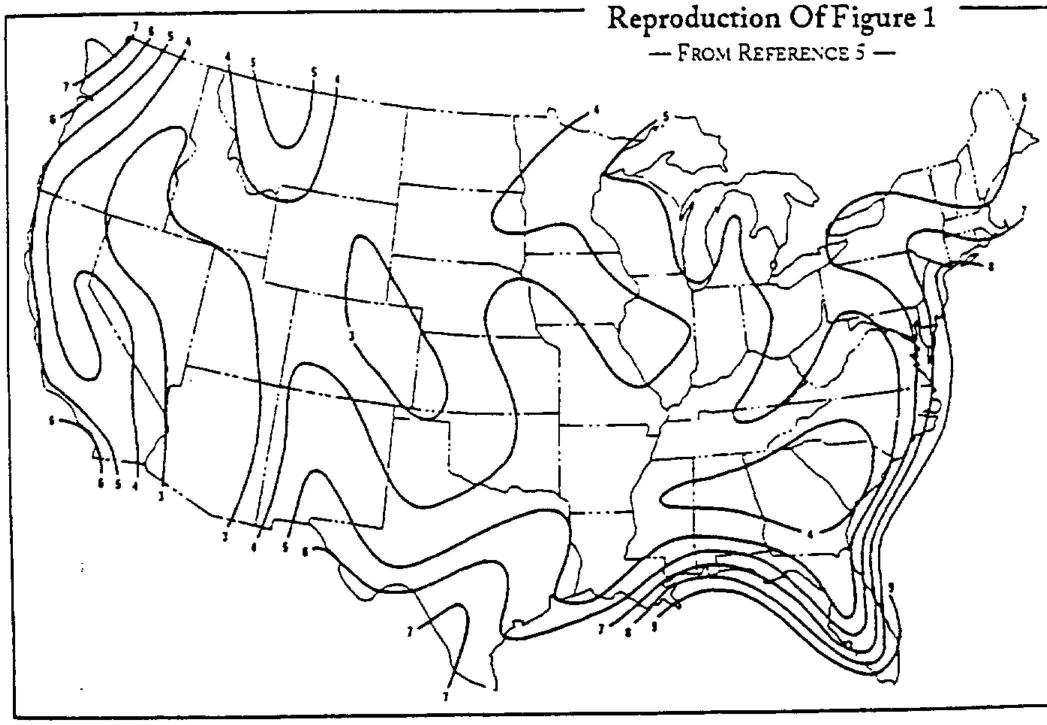

Figure 1. Isopleths (m x 10^2) of mean annual morning mixing heights (see Table B-1 for data).

FIGURE 5-2

Reproduction Of Figure 4

— FROM REFERENCE 5 —

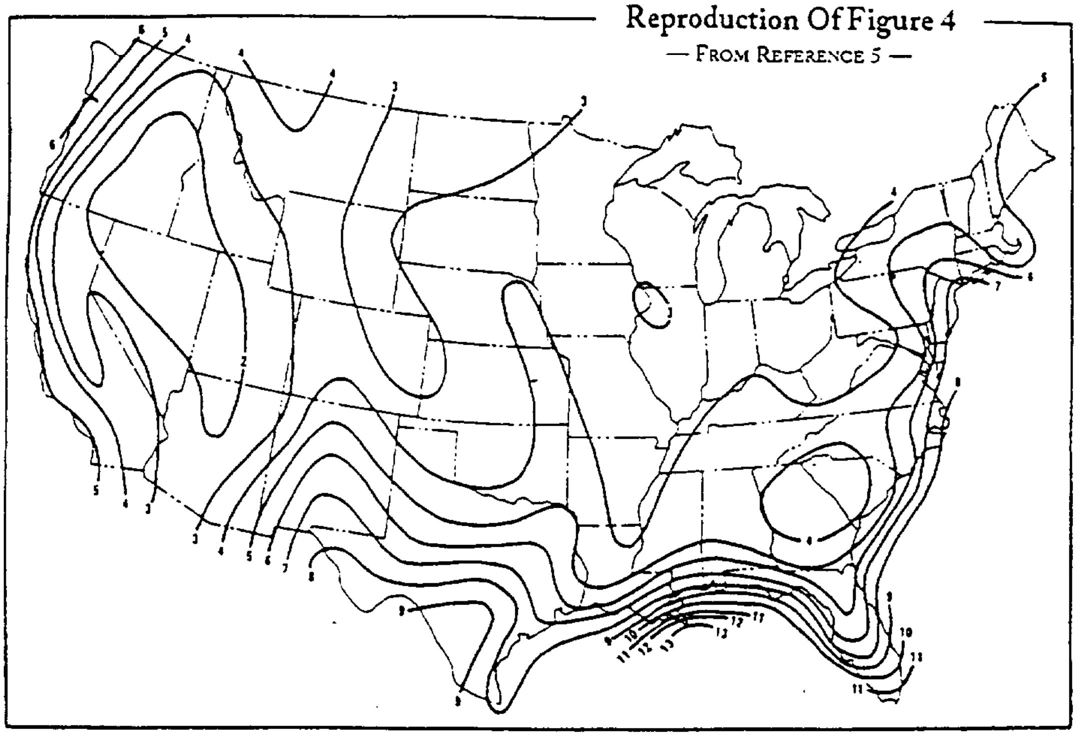

Figure 4. Isopleths (m x 10^2) of mean summer morning mixing heights (see Table B-1 for data).

FIGURE 5-3

Reproduction Of Figure 2

— FROM REFERENCE 5 —

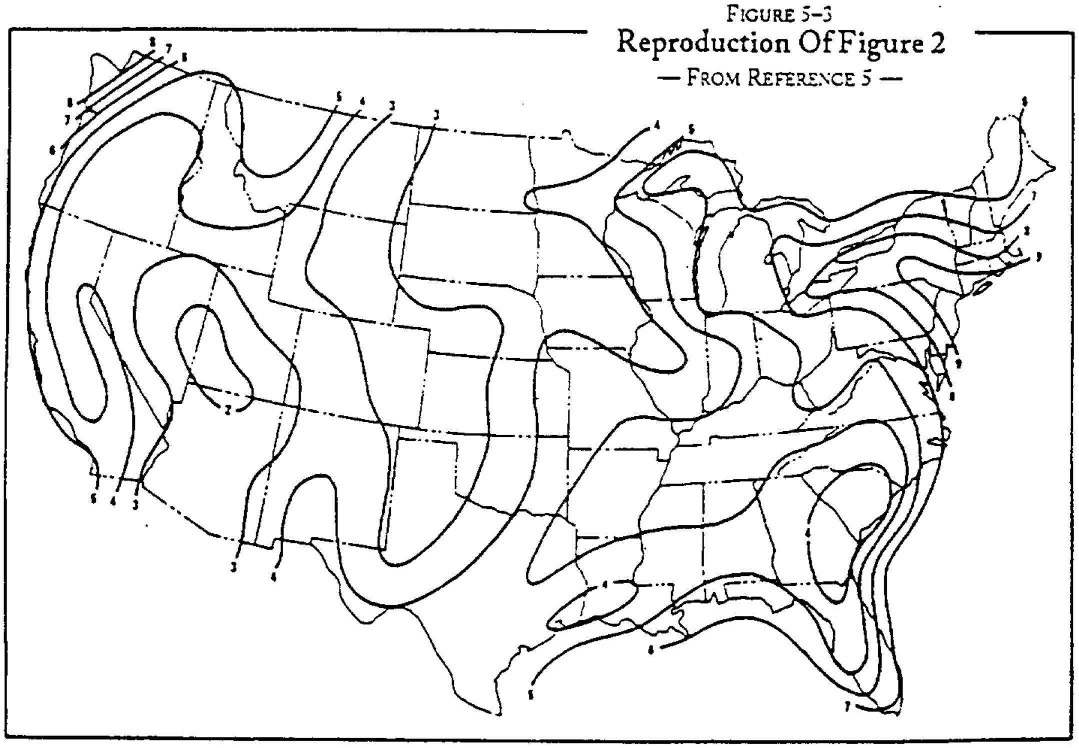

Figure 2. Isopleths (m x 10^2) of mean winter morning mixing heights (see Table B-1 for data).

5.2.3 Activity and Emissions for Commercial Aircraft

The next four steps relate specifically to creating an emissions inventory for commercial aircraft. The procedures for other aircraft categories are discussed subsequently. Definition of the mix of commercial aircraft that uses each airport (step three) can be found in *Airport Activity Statistics of Certified Route Air Carriers* (Reference 6), published annually by FAA. Figure 5-4, a copy of a page from Table 7 of that report, shows the information that is included by airport. All of the commercial aircraft that used the airport for the given year are listed, along with the number of departures during the year. This is the fleet that should be used for the inventory.

In step four the number of LTOs is determined by aircraft type. Since Reference 6 lists departures, which are equivalent to LTOs, it is again the preferred source. From Table 7, the total departures performed for all service (both scheduled and non scheduled) should be used as the number of LTOs for each aircraft type.

The engines used on each aircraft type must be determined to select the emission factors for step five. Table 5-2 lists aircraft and the corresponding engines used to power them. Many aircraft use only a single engine model, while others have been certified to use engines from two or three different manufacturers. When a single engine is listed for an aircraft model, emissions data for that engine should be used. For aircraft with engines from more than one manufacturer, defining the specific engine mix used on the fleet of aircraft operating at a specific airport may be extremely difficult. Individual airlines probably are the only source of detailed fleet data on specific engine models and they likely do not have it readily available. To develop a representative engine mix for aircraft with more than one engine model, the percentage of each model likely to be found on those aircraft in the U.S. fleet is shown adjacent to the engine model number in Table 5-2. The recommended procedure for compensating for the lack of detailed engine data is using the percentages shown in the table as weighing factors. For example, Boeing 757-200 cargos have been sold to U.S. airlines with Pratt & Whitney PW2040 engines as well as Rolls Royce RB.211-535E4 engines. The number of aircraft with each engine model is 15 and 43, respectively, to give the percentages shown in Table 5-2 of 26 and 74. These percentages can be used to divide the total LTOs for B 757-200s into three groups representing the three engine types. This makes the inventory more representative than assigning a single engine for all B 757-200s, since the emission factors are different for each engine.

After identifying the engines included in the fleet, engine emission factors are used to calculate mass of emissions. For some of the engines shown in Table 5-2, emission factors have never been determined. For these engines it is necessary to use emission factors from an alternative engine. Table 5-3 lists alternative engines recommended by the engine manufacturers. For most of these engines, emission factors are available for a very similar engine, usually one of the same model and

FIGURE 5–4

Reproduction Of A Page Of Table 7

— FROM REFERENCE 6 —

TABLE 7—Continued
Aircraft Departures Scheduled and Aircraft Departures Performed, By Community, By Air Carrier, And By Aircraft Type
12 Months Ended December 31, 1990

STATE OR U.S. AREA COMMUNITY (AIRPORT NAME)	CARRIER	OPERATION	TYPE OF AIRCRAFT	TOTAL DEPARTURES PERFORMED: SCHEDULED SERVICE	TOTAL DEPARTURES PERFORMED: NON SCHEDULED SERVICE	TOTAL DEPARTURES PERFORMED: ALL SERVICE	DEPARTURES SCHEDULED
CALIFORNIA—Continued							
LOS ANGELES/BURBNK/LNG.BCH—Continued							
(ORANGE COUNTY)—Continued							
COMMUNITY TOTAL BY CARRIER—Continued			B-757-200	2564		2564	
			B-767-200	2438		2438	
			B-767-300	94		94	
			DC-9-80	10749	1	10750	
			A-300-600	196		196	
			A-310-300	341		341	
			B-727-100	109		109	
			B-727-200	140	1	141	
			DC-10-10	7481	3	7484	
			DC-10-30	319	6	325	
			BAE-146-100	4292		4292	
			ALL TYPES	36930	11	36941	37966
	AP—ASPEN AIRWAYS	TOTAL	BAE-146-100	211	3	214	
			ALL TYPES	211	3	214	212
	AS—ALASKA AIRLINES	TOTAL	DC-9-80	10675	18	10693	
			B-727-100	98		98	
			B-727-200	2545	8	2553	
			ALL TYPES	13318	26	13344	13392
	CO—CONTINENTAL	TOTAL	B-737-300	4093	703	4796	
			B-737-200C	2		2	
			DC-9-30	3		3	
			DC-9-80	3793	6	3799	
			A-300-X4	2260	37	2297	
			B-727-100	199	2	201	
			B-727-200	1621	47	1668	
			DC-10-10	424		424	
			DC-10-30	492		492	
			* DC-10-30	1		1	
			B-747	173		173	
			* B-747	1		1	
			B-747-200	421		421	
			* B-747-200	4		4	
			ALL TYPES	13487	796	14282	13716
	DL—DELTA AIR LINES	TOTAL	B-737-300	5684	2	5686	
			B-737-100/200	6247		6247	
			B-757-200	4786	4	4788	
			B-767-200	1266	1	1267	
			B-767-300	2320		2320	
			DC-9-80	124		124	
			B-727-200	14086	26	14112	
			L-1011/100/20	4066	2	4068	
			ALL TYPES	38558	35	38593	38906
	EA—EASTERN AIR LINES	TOTAL	B-757-200	925		925	
			A-300-X4	861	2	863	
			L-1011/100/20	292		292	
			ALL TYPES	2078	2	2080	2086
	FF—TOWER AIR	TOTAL	B-747		1	1	
			ALL TYPES		1	1	1
	FM—FEDERAL EXPRESS	TOTAL	* BEECH 18	25		25	
			* C-208	384		384	
			* B-727-100	1372		1372	
			* B-727-200	803		803	
			* DC-10-10	460		460	
			* DC-10-30	413	3	416	
			* B-747	168	30	198	
			B-747-200		115	115	
			* B-747-200	404	38	442	

NOTE: * = All Cargo Services

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Table 5-2:
Commercial Aircraft Types And Engine Models

Aircraft[1]	Engine Type[2]	No. Of Engines	Engine Model (% of Aircraft) and Manufacturer[3]					
Aerospatiale ATR-42	TP	2	PW120(53)PWC	PW121(47)PWC				
Airbus A-300-B4	TF	2	CF6-50(100)GE					
Airbus A-300-600	TF	2	CF6-80C2A5(100)GE					
Airbus A-310-200	TF	2	CF6-80A3(0)GE	JT9D-7R4E1(100)PW				
Airbus A-310-300	TF	2	CF6-80C2A2(0)GE	PW4152(100)PW				
Airbus A-320-200	TF	2	CFM56-5A(100)GE					
BEECH 18[4]	TP	2	R-985-AN(100)PW5					
BEECH BH-C99	TP	2	PT6A-36(100)PWC					
BEECH BH-1900	TP	2	PT6A-65B(100)PWC					
Boeing B-707-300B	TF	4	JT3D-3B(100)PW					
Boeing B-707-300C	TF	4	JT3D-3B(100)PW					
Boeing B-727-100[5]	TF	3	JT8D-7(16)PW	JT8D-7A(4)PW	JT8D-7A/7B(<1)	JT8D-7A/9A(1)PW	JT8D-7B(72)PW	JT8D-7B/9A(<1)PW
			JT8D-7C(4)PW	JT8D-9(1)PW	JT8D-9A(1)PW			
Boeing B-727-100[4,6]	TF	3	JT8D-7A(5)PW	JT8D-7A/7B/7C(1)PW	JT8D-7A/7B/9A(2)PW	JT8D-7B(90)PW	JT8D-7B/9A(1)PW	JT8D-9(1)PW
Boeing B-727-200	TF	3	JT8D-7A(<1)PW	JT8D-7B(16)PW	JT8D-9(20)PW	JT8D-9A(9)PW	JT8D-15(26)PW	JT8D-15A(21)PW
			JT8D-15B(<1)PW	JT8D-17(3)PW	JT8D-17A(1)PW	JT8D-17R(3)PW		
Boeing B-737-100/200	TF	2	JT8D-7B(19)PW	JT8D-9A(39)PW	JT8D-15(10)PW	JT8D-15A(24)PW	JT8D-17(7)PW	JT8D-17A(1)PW
Boeing B-737-200C[5]	TF	2	JT8D-7A(10)PW	JT8D-9/9A(5)PW	JT8D-9A(16)PW	JT8D-15(5)PW	JT8D-17(32)PW	JT8D-17A(32)PW
Boeing B-737-300	TF	2	CFM56-3(100)GE[7]					
Boeing B-737-400	TF	2	CFM56-3(100)GE					
Boeing B-747[4]	TF	4	JT9D-7F(100)PW					
Boeing B-747F[4]	TF	4	JT9D-7F(33)PW	JT9D-7Q(17)PW	JT9D-7R4G2(11)PW	JT9D-7QA(39)PW		
Boeing B-747SP	TF	4	JT9D-7A(85)PW	JT9D-7A-SP(15)PW				
Boeing B-747-200[8]	TF	4	CF6-50(3)GE[9]	CF6-80C2B1(0)GE	JT9D-3A(7)PW	JT9D-7(1)PW	JT9D-7A(55)PW	JT9D-7AH(13)PW
			JT9D-7F(5)PW	JT9D-7Q(13)PW	JT9D-7R4G2(3)PW			
Boeing B-747-400	TF	4	PW4056(100)PW					
Boeing B-757-200	TF	2	RB.211-535E4(1)RR	PW2037(92)PW	PW2040(7)PW			
Boeing B-757-200[4]	TF	2	PW2040(26)PW	RB.211-535E4(74)RR				
Boeing B-767-200	TF	2	CF6-80A2(59)GE	CF6-80C2B2(12)GE[10]	JT9D-7R4D(29)PW			
Boeing B-767-300	TF	2	CF6-80C2B6(100)GE[11]	PW4060(0)PW				
Brit. Air Corp. BAC-111-200	TF	2	Spey Mk 511(100)RR[12]					
Brit. Aero. BAe-146-1	TF	4	ALF502R-5(100)Lyc					
Brit. Aero. BAe-146-2	TF	4	ALF502R-5(100)Lyc					
Brit. Aero. Concorde	TF	4	Olympus 593 Mk610(100)RR					
Brit. Aero. JETSTREAM 31	TP	2	TPE 331-10UF(100)Grt[12]					
CESSNA 404[4]	P	2	TSIO-520-VB(100)Con[12]					
Convair CV-580	TP	2	501D13H(100)All.[12]					
Convair CV-640[4]	TP	2	Dart 542-4(100)RR					
de Havilland DASH-7	TP	4	PT6A-50(100)PWC					
de Havilland DHC-6	TP	2	PT6A-20(26)PWC	PT6A-27(74)PWC				
de Havilland DHC-8	TP	2	PW120(17)PWC	PW120A(83)PWC				
EMBRAER13	TP	2	PT6A-34(100)PWC					
EMBRAER EMB-120	TP	2	PW118(85)PWC	PW118A(15)PWC				
Fairchild FH-227	TP	2	Dart 532-7(100)RR					
Fokker 100	TF	2	Tay 620-15(75)RR	Tay 650(25)RR				
Fokker F-27 SERIES	TP	2	Dart 514-7(15)RR	Dart 528-7E(10)RR	Dart 532-7(5)RR	Dart 532-7N(3)RR	Dart 532-7P(24)RR	
			Dart 532-7R(3)RR	Dart 535-7R(9)RR	Dart 536-7E(2)RR	Dart 552-7R(29)RR		
Fokker F-28-1000[14]	TF	2	Spey 555-15(100)RR					
Fokker F-28-4000/6000[14]	TF	2	Spey 555-15H(12)RR	Spey 555-15P(88)RR				

TABLE 5-2:

Commercial Aircraft Types And Engine Models — Continued

Aircraft	Engine Type[2]	No. Of Engines	Engine Model (% of Aircraft) and Manufacturer[3]				
Lockheed L-100-30[4]	TP	4	501D22A(100)All.[12]				
Lockheed L-188A/C	TP	4	501D13(100)All.[12]				
Lockheed L-188A/C[4]	TP	4	501D13(100)All.[12]				
Lockheed L-1011/100/200[6]	TF	3	RB.211-22B(99)RR	RB.211-22B/524B4(1)RR			
Lockheed L-1011-500 TR	TF	3	RB.211-524B4(100)RR				
McDonnell Douglas DC-6[4]	P	4	R2800(100)PW[12]				
McDonnell Douglas DC-6A[4]	P	4	R2800(100)PW[12]				
McDonnell Douglas DC-8-60	TF	4	JT3D-3B(57)PW	JT3D-7(43)PW			
McDonnell Douglas DC-8-61[4]	TF	4	JT3D-3B(100)PW				
McDonnell Douglas DC-8-62[4]	TF	4	JT3D-3B(15)PW	JT3D-3BDL(21)PW	JT3D-7(64)PW		
McDonnell Douglas DC-8-63F[4]	TF	4	JT3D-3B(24)PW	JT3D-7(42)PW	JT3D-735E4(7)PW	JT8D-7(27)PW	
McDonnell Douglas DC-8-70	TF	4	CFM56-2-C1(100)GE				
McDonnell Douglas DC-8-71	TF	4	CFM56-2(100)GE				
McDonnell Douglas DC-9-10	TF	2	JT8D-7(100)PW[12]				
McDonnell Douglas DC-9-15F	TF	2	JT8D-7(15)	JT8D-7A(4)	JT8D-7A/7B(4)	JT8D-7B(77)PW	
McDonnell Douglas DC-9-30[6]	TF	2	JT8D-7A/9A(9)PW	JT8D-7B(68)PW	JT8D-9A(19)PW	JT8D-15(3)PW	JT8D-17(1)PW
McDonnell Douglas DC-9-40	TF	2	JT8D-15(100)PW				
McDonnell Douglas DC-9-50	TF	2	JT8D-17(87)PW	JT8D-17A(13)PW			
McDonnell Douglas DC-9-80[15]	TF	2	JT8D-209(5)PW	JT8D-217(12)PW	JT8D-217A(36)PW	JT8D-217C(25)PW	JT8D-219(22)PW
McDonnell Douglas DC-10-10	TF	3	CF6-6(100)GE				
McDonnell Douglas DC-10-10[4]	TF	3	CF6-6(100)GE				
McDonnell Douglas DC-10-30	TF	3	CF6-50(100)GE				
McDonnell Douglas DC-10-30[4]	TF	3	CF6-50(100)GE				
McDonnell Douglas DC-10-40	TF	3	JT9D-20(100)PW				
McDonnell Douglas MD-11	TF	3	CF6-80C2D1F(100)GE	PW4460(0)PW			
NAMC YS-11	TP	2	Dart 542-10J(25)RR	Dart 542-10K(75)RR			
Saab SF-340A	TP	2	CT7-5A( )GE[16]	CT7-5A2( )GE[16]	CT7-7E( )GE[16]		
SHORTS 360	TP	2	PT6A-65AR(17)PWC	PT6A-65R(55)PWC	PT6A-67R(28)PWC		
Swearingen SWEAR-METRO I	TP	2	TPE 331-11U-611G( )Grt[17]		PT6A-45R( )PW[18]		

1 Source of Aircraft, Type, and No. of Engines is Airport Activity Statistics of Certificated Route Air Carriers (Reference 6).

2 Engine Types: TF - Turbofan, TJ - Turbojet, TP - Turboprop, P - Piston

3 Following the engine model is the percent of aircraft in parentheses which correspond to the particular engine and the engine manufacturer. GE engine data obtained from GE Aircraft Engines: Commercial Program Status (Reference 10) and Office of Combustion Technology, GE Aircraft Engines (Reference 11). Corresponding percents of aircraft refer to U.S. commercial and government aircraft in op P&W, P&WC, and RR engine data obtained from Turbine-Engined Fleets of the World's Airlines 1990 (Reference 12). Corresponding percents of aircraft refer only to U.S. airlines.

Engine Manufacturers:
Con - Teledyne/Continental,
GE - General Electric,
Grt - Garrett AiResearch,
Lyc - Avco/Lycoming, PW - Pratt & Whitney, PWC - Pratt & Whitney Canada, RR - Rolls Royce

4 All Cargo Services.

5 Percent of aircraft assumed 100%.

6 Some aircraft have a mixture of engines. In calculating a weighted average of engine emission factors, assign equivalent weights to all engines in the mixture.

7 Refers to B-737-300 and -500 aircraft.

8 Information from the engine manufacturer suggests using the PW JT9D-7F(modV)/7A(modV) engine emission factors in place of PW JT9D-7 engine emission factors.

9 Refers to B-747-200, -300, and SR aircraft.

10 Refers to B-767-200ER aircraft. GE combined the number of aircraft in operation of B-767-200ER and -300ER aircraft. It is assumed that an equal distribution between the two aircraft models exists.

11 Refers to B-767-300ER aircraft. GE combined the number of aircraft in operation of B-767-200ER and -300ER aircraft. It is assumed that an equal distribution between the two aircraft models exists.

12 Source of engine information is Modern Commercial Aircraft (Reference 20). Percent of aircraft assumed 100%.

13 Assumed EMB-110 aircraft.

14 Information from the engine manufacturer suggests using the RR SPEY Mk555 engine emission factors for all Fokker F-28 aircraft.

15 Assumed MD-80 aircraft.

16 Source of engine information is Modern Commercial Aircraft (Reference 20). Percent of aircraft unknown.

17 Source of engine information is Modern Commercial Aircraft (Reference 20). Engine refers to METRO III aircraft. Percent of aircraft unknown.

18 Source of engine information is Modern Commercial Aircraft (Reference 20). Engine refers to METRO IIIA aircraft. Percent of aircraft unknown.

TABLE 5–3

Alternative Source Of Emission Data For Some Aircraft Engines[1]

Manufacturer	Engine Model	Source for Emissions Data[2]
GE	CF6-6	CF6-6D
	CF6-50	CF6-50E/C1/E1/C2/E2
	CT7-5A	CT7-5
	CT7-5A2	CT7-5
	CT7-7E	CT7-5
GE (SCNECMA)	CFM56-2	CFM56-2B
	CFM56-2-C1	CFM56-2B
	CFM56-5A	CFM56-5A1
P&W	JT3D series	Contact manufacturer[3]
	JT8D-7D	JT8D-7/7A/7B
	JT8D-15B	JT8D-15
	JT9D-3A	Contact manufacturer
	JT9D-7A-SP	JT9D-7F/7A
	JT9D-7AH	JT9D-7F/7A
	JT9D-20	JT9D-7F/7A
	JT9D-70A	JT9D-70/59/7Q
	PW4060	PW4460
RR	RB211-535E5	Contact manufacturer[4]
	RB211-535F5	Contact manufacturer
	TRENT 600 series	Contact manufacturer
	TRENT 700 series	Contact manufacturer
	SPEY MK506	Contact manufacturer
	SPEY MK555-15	SPEY MK555
	SPEY MK555-15P	SPEY MK555
	SPEY MK555-15H	SPEY MK555
	SPEY MK512	Contact manufacturer
	TAY MK651	Contact manufacturer
	Dart 514-7	Dart RDa7
	Dart 528-7E	Dart RDa7
	Dart 532-7	Dart RDa7
	Dart 532-7N	Dart RDa7
	Dart 532-7P	Dart RDa7
	Dart 532-7R	Dart RDa7
	Dart 535-7R	Dart RDa7
	Dart 536-7E	Dart RDa7
	Dart 542-4	Dart RDa10
	Dart 542-10J	Dart RDa10
	Dart 542-10K	Dart RDa10
	Dart 552-7R	Dart RDa7

[1] FAA Aircraft Engine Emission Database does not identify these alternative emission factors. A manual adjustment to the database output may be required.
[2] As recommended by engine manufacturers.
[3] See listing at Reference 21 for contact information.
[4] See listing at Reference 25 for contact information.

a related series. For a small number of engines there is no emissions data available and there are no suggested alternatives. In these instances there are three approaches available. First, the needed data may appear in the latest update of the FAEED data base. The FAA should be contacted for the latest version of the data base as mentioned earlier. Second, for an aircraft with several potential engine types, where no emissions data is available for one engine, the recommended procedure is to reallocate the market share among the engines for which data is available. Third, if emission rate information (fuel consumption and emission index) for an engine model still cannot be located the engine manufacturer should be contacted directly. Information on contacting the primary engine manufacturers is listed in the References section below.

After the engine types have been identified, fuel flow rates and emission indexes can be found in Table 5-4. The data in this table has been updated since the last edition of this reference and of AP–42, to include new engine models and to reflect new data on models already in AP–42. The next version of AP–42 may have some additional new data for engines that have not been updated here. (Updates primarily will be for general aviation aircraft engines.) The fuel flow rates and emission indexes that appear in Table 5-4 for commercial aircraft are based on information engine manufacturers provide to FAA and the International Civil Aviation Organization. These data are representative of production engines. Emission indexes are given for specific fuel flow rates which are representative of the power settings used during the different operating modes. The emission index multiplied by the fuel flow rate gives an emission rate.

Step 6 is to specify a time-in-mode for each aircraft type. Take–off time is fairly standard for commercial aircraft and represents the time for initial climb from ground level to about 500 feet. The default take–off time for calculating emissions is 0.7 minutes (42 seconds) and, unless more specific data is available, should be used in this methodology. The time in the approach and climbout modes depends on mixing height. As mentioned earlier, a default mixing height of 3000 feet was assumed for calculating an approach time of 4 minutes and a climbout time of 2.2 minutes, which can be used if specific information on mixing height is unavailable. The procedure for adjusting these times to correspond to a different mixing height is shown below.

The mode most likely to vary by time for each specific airport is taxi/idle time. Total taxi/idle time for a very congested airport can be as much as three or four times longer than for an uncongested airport. Taxi/idle-in time typically is shorter than taxi/idle-out time because there are usually fewer delays for aircraft coming into a gate than for aircraft lining up to takeoff. For a large congested airport the taxi/idle-out time can be three times longer than taxi/idle-in time. Taxi/idle time also may vary by aircraft type. For example, wide-body jets may all use special gates at the terminal that place them further from the runway than narrow-body jets or small regional commuter aircraft so their taxi/idle-in and taxi/idle-out times are longer. Because of the variation in taxi/idle time, it is important to get data specific to the airports of interest in the

Table 5-4: Modal Emission Rates – Civil Aircraft Engines[1]

Model – Series Manufacturer[2] Rated Dry Output (1000 lbs Thrust)	Mode	Power Setting	Fuel Flow (lb/min)	HC	CO	NOX	SO_2[3]	Particulate
				Emission Rates — lbs per 1000 lbs —				
501D22A[4]	Takeoff	100%	39.6	0.28	2.04	9.38	0.54	--
All.	Climbout	85%	36.63	0.89	2.06	9.22	0.54	--
	Approach	30%	19	1.96	5.1	7.49	0.54	--
	Taxi/Idle	7%	10.17	17.61	43.61	3.52	0.54	--
0-200[4]	Takeoff	100%	0.75	20.81	974.1	4.87	0.11	--
Con	Climbout	85%	0.75	20.81	974.1	4.87	0.11	--
	Approach	40%	0.43	33.22	1187.94	1.14	0.11	--
	Taxi/Idle	7%	0.14	29	644.42	1.58	0.11	--
TSIO-360C[4]	Takeoff	100%	2.22	9.17	1081.95	2.71	0.11	--
Con	Climbout	85%	1.66	9.55	960.8	4.32	0.11	--
	Approach	40%	1.02	11.31	995.08	3.77	0.11	--
	Taxi/Idle	7%	0.19	138.26	592.17	1.91	0.11	--
CF6-6D	Takeoff	100%	229.63	0.3	0.5	40	0.54	--
GE	Climbout	85%	189.29	0.3	0.5	32.6	0.54	--
39.3	Approach	30%	64.01	0.7	6.5	11.4	0.54	--
	Taxi/Idle	7%	22.86	21	54.2	4.5	0.54	--
CF6-45	Takeoff	100%	281.22	0.1	1	30.6	0.54	--
GE	Climbout	85%	234.13	0.1	1.3	26.6	0.54	--
45.6	Approach	30%	80.03	0.7	8.2	10.5	0.54	--
	Taxi/Idle	7%	26.72	32.7	59.2	3.9	0.54	--
CF6-45A/A2	Takeoff	100%	268.12	0.09	0.43	25.45	0.54	--
GE	Climbout	85%	219.97	0.14	0.54	21.61	0.54	--
45.6	Approach	30%	78.31	0.35	5.01	9.36	0.54	--
	Taxi/Idle	4%	21.56	2.72	24.04	3.4	0.54	--
CF6-50E/C1/E1/C2/E2	Takeoff	100%	321.17	0.6	0.5	36.5	0.54	--
GE	Climbout	85%	254.63	0.7	0.5	29.6	0.54	--
51.8	Approach	30%	87.86	1	5.7	9.7	0.54	--
	Taxi/Idle	3%	22.24	49.3	61.3	2.4	0.54	--
CF6-80A	Takeoff	100%	283.73	0.29	1	29.8	0.54	--
GE	Climbout	85%	237.44	0.29	1.1	25.6	0.54	--
46.9	Approach	30%	81.35	0.47	3.1	10.3	0.54	--
	Taxi/Idle	4%	19.84	6.29	28.2	3.4	0.54	--
CF6-80A1	Takeoff	100%	283.73	0.29	1	29.8	0.54	--
GE	Climbout	85%	237.44	0.29	1.1	25.6	0.54	--
46.9	Approach	30%	81.35	0.47	3.1	10.3	0.54	--
	Taxi/Idle	4%	19.84	6.29	28.2	3.4	0.54	--
CF6-80A2	Takeoff	100%	298.15	0.3	1	29.6	0.54	--
GE	Climbout	85%	249.34	0.37	1.1	26.6	0.54	--
48.6	Approach	30%	84.79	0.45	2.8	10.8	0.54	--
	Taxi/Idle	4%	19.84	6.28	28.2	3.4	0.54	--
CF6-80A3	Takeoff	100%	298.15	0.3	1	29.6	0.54	--
GE	Climbout	85%	249.34	0.37	1.1	26.6	0.54	--
48.9	Approach	30%	84.79	0.45	2.8	10.8	0.54	--
	Taxi/Idle	4%	19.84	6.28	28.2	3.4	0.54	--
CF6-80C2A1	Takeoff	100%	317.46	0.08	0.56	32.22	0.54	--
GE	Climbout	85%	258.34	0.09	0.54	24.85	0.54	--
57.9	Approach	30%	84.13	2	2.19	9.76	0.54	--
	Taxi/Idle	7%	26.32	9.19	42.24	3.99	0.54	--

TABLE 5-4:

Modal Emission Rates – Civil Aircraft Engines[1]

— Continued —

Model – Series Manufacturer[2] Rated Dry Output (1000 lbs Thrust)	Mode	Power Setting	Fuel Flow (lb/min)	HC	Emission Rates CO	NOx	SO_2[3]	Particulate
				— lbs per 1000 lbs —				
CF6-80C2A2	Takeoff	100%	290.03	0.14	0.58	27.9	0.54	--
GE	Climbout	85%	230.82	0.11	0.56	20.71	0.54	--
52.5	Approach	30%	76.72	0.25	3.04	9.52	0.54	--
	Taxi/Idle	7%	25	10.74	46.65	3.91	0.54	--
CF6-80C2A3	Takeoff	100%	325	0.08	0.59	34.44	0.54	--
GE	Climbout	85%	264.95	0.1	0.57	25.45	0.54	--
58.9	Approach	30%	85.85	0.21	2.15	10.01	0.54	--
	Taxi/Idle	7%	26.72	9.21	42.18	3.96	0.54	--
CF6-80C2A5	Takeoff	100%	341.4	0.07	0.52	34.38	0.54	--
GE	Climbout	85%	275.4	0.08	0.52	22.86	0.54	--
60.1	Approach	30%	90.87	0.2	1.93	9.11	0.54	--
	Taxi/Idle	7%	27.38	8.99	41.65	3.79	0.54	--
CF6-80C2B1	Takeoff	100%	302.25	0.08	0.58	28.11	0.54	--
GE	Climbout	85%	247.75	0.09	0.55	21.26	0.54	--
56.0	Approach	30%	81.48	0.21	2.37	8.83	0.54	--
	Taxi/Idle	7%	25.93	9.46	43.22	3.73	0.54	--
CF6-80C2B1F	Takeoff	100%	311.25	0.08	0.52	28.06	0.54	--
GE	Climbout	85%	253.04	0.09	0.52	21.34	0.54	--
57.2	Approach	30%	83.6	0.2	2.19	8.97	0.54	--
	Taxi/Idle	7%	27.12	9.68	43.71	3.74	0.54	--
CF6-80C2B2	Takeoff	100%	281.88	0.08	0.57	23.89	0.54	--
GE	Climbout	85%	232.94	0.1	0.55	18.65	0.54	--
52.0	Approach	30%	76.32	0.22	2.65	8.77	0.54	--
	Taxi/Idle	7%	25.4	11.17	48.02	3.7	0.54	--
CF6-80C2B4	Takeoff	100%	321.43	0.08	0.56	29.2	0.54	--
GE	Climbout	85%	262.17	0.09	0.54	21.8	0.54	--
57.2	Approach	30%	85.98	0.21	2.33	8.9	0.54	--
	Taxi/Idle	7%	26.32	9.74	43.91	3.67	0.54	--
CF6-80C2B6	Takeoff	100%	341.14	0.07	0.52	30.81	0.54	--
GE	Climbout	85%	275.27	0.08	0.52	22.94	0.54	--
60.1	Approach	30%	90.74	0.2	1.93	9.11	0.54	--
	Taxi/Idle	7%	27.38	8.99	41.66	3.79	0.54	--
CF6-80C2D1F	Takeoff	100%	337.83	0.08	0.52	32.54	0.54	--
GE	Climbout	85%	268.39	0.1	0.53	23.55	0.54	--
60.2	Approach	30%	85.36	0.21	1.98	9.29	0.54	--
	Taxi/Idle	7%	26.01	9.96	44.41	3.79	0.54	--
CFM56-2A	Takeoff	100%	148.55	0.03	0.9	21.05	0.54	--
GE (SNECMA)	Climbout	85%	122.62	0.04	1	17.18	0.54	--
24.0	Approach	30%	45.64	0.1	3.4	8.62	0.54	--
	Taxi/Idle	7%	17.46	1.17	24.9	4.12	0.54	--
CFM56-2B	Takeoff	100%	132.54	0.05	0.9	19.06	0.54	--
GE (SNECMA)	Climbout	85%	110.72	0.08	0.9	16.3	0.54	--
22.0	Approach	30%	42.59	0.1	3.7	8.14	0.54	--
	Taxi/Idle	7%	16.27	1.67	29.5	3.66	0.54	--
CFM56-3	Takeoff	100%	134.92	0.04	0.9	18.5	0.54	--
GE (SNECMA)	Climbout	85%	111.51	0.05	0.9	16	0.54	--
20.1	Approach	30%	44.71	0.1	3.5	8.4	0.54	--
	Taxi/Idle	7%	16.01	1.83	31	3.9	0.54	--

TABLE 5-4:

Modal Emission Rates – Civil Aircraft Engines[1]

— Continued —

Model – Series Manufacturer[2] Rated Dry Output (1000 lbs Thrust)	Mode	Power Setting	Fuel Flow (lb/min)	HC	Emission Rates CO	NOx	SO_2[3]	Particulate
				— lbs per 1000 lbs —				
CFM56-3B GE (SNECMA) 22.0	Takeoff	100%	150.79	0.04	0.9	20.7	0.54	--
	Climbout	85%	123.02	0.05	0.9	17.3	0.54	--
	Approach	30%	47.62	0.08	3.1	9.7	0.54	--
	Taxi/Idle	7%	17.2	1.25	27	4.1	0.54	--
CFM56-3-B4 GE (SNECMA) 18.5	Takeoff	100%	116.4	0.04	0.9	16.6	0.54	--
	Climbout	85%	96.56	0.05	1.1	14.5	0.54	--
	Approach	30%	35.71	0.11	4.2	8	0.54	--
	Taxi/Idle	7%	14.55	3.33	38.5	3.9	0.54	--
CFM56-3C GE (SNECMA) 23.5	Takeoff	100%	156.09	0.04	0.9	20.17	0.54	--
	Climbout	85%	128.31	0.04	1	17.15	0.54	--
	Approach	30%	44.97	0.09	3.2	3.88	0.54	--
	Taxi/Idle	7%	15.87	2.14	33.4	4	0.54	--
CFM56-5A1 GE (SNECMA) 25.0	Takeoff	100%	142.8	0.23	0.83	28.03	0.54	--
	Climbout	85%	116.4	0.23	0.87	23.1	0.54	--
	Approach	30%	39.68	0.4	2.47	9.48	0.54	--
	Taxi/Idle	7%	14.55	1.53	18	4.36	0.54	--
TFE 731-2 Grt 3.51	Takeoff	100%	27.12	0.11	1.39	15.25	0.54	--
	Climbout	85%	22.88	0.13	2.03	13.08	0.54	--
	Approach	30%	8.86	4.26	22.38	5.9	0.54	--
	Taxi/Idle	7%	3.17	20.04	58.6	2.82	0.54	--
TFE 731-3 Grt 3.7	Takeoff	100%	29.76	0.06	1.13	19.15	0.54	--
	Climbout	85%	24.6	0.07	1.62	16.02	0.54	--
	Approach	30%	9.52	1.41	15.56	6.92	0.54	--
	Taxi/Idle	7%	3.44	9.04	47.7	3.72	0.54	--
TPE 331-3[5] Grt	Takeoff	100%	7.63	0.11	0.76	12.36	0.54	1.75
	Climbout	90%	6.82	0.15	0.98	11.86	0.54	1.47
	Approach	30%	4.17	0.64	6.96	9.92	0.54	2.4
	Taxi/Idle	7%	1.97	79.11	61.52	2.86	0.54	2.95
ALF 502L-2 Lyc 7.50	Takeoff	100%	52.9	0.02	0.4	13.43	0.54	-
	Climbout	85%	42.8	0.02	0.3	12.03	0.54	-
	Approach	30%	15.5	0.18	3.97	6.47	0.54	-
	Taxi/Idle	7%	6.31	6.65	45.63	3.38	0.54	-
ALF 502R-3 Lyc 6.69	Takeoff	100%	45.98	0.06	0.43	11.2	0.54	
	Climbout	85%	38.1	0.05	0.5	9.94	0.54	
	Approach	30%	13.58	0.29	8.43	6.15	0.54	
	Taxi/Idle	7%	5.71	6.51	44.67	3.3	0.54	
ALF 502R-5 Lyc 6.96	Takeoff	100%	47.37	0.06	0.3	13.53	0.54	
	Climbout	85%	39.09	0.05	0.25	10.56	0.54	
	Approach	30%	13.68	0.22	7.1	13.53	0.54	
	Taxi/Idle	7%	5.4	5.39	40.93	3.78	0.54	
O-320[4] Lyc	Takeoff	100%	1.48	11.78	1077.44	2.19	0.11	
	Climbout	85%	1.11	12.38	989.51	3.97	0.11	
	Approach	40%	0.78	19.25	1221.51	0.95	0.11	
	Taxi/Idle	7%	0.16	36.92	1077	0.52	0.11	
D-36 MKB 14.3	Takeoff	100%	83.86	0	0.5	26	0.54	
	Climbout	85%	70.5	0	0.4	22	0.54	
	Approach	30%	27.91	0	2.7	9	0.54	
	Taxi/Idle	7%	0	5.4	20.7	5.5	0.54	

Table 5-4:
Modal Emission Rates – Civil Aircraft Engines[1]

— Continued —

Model - Series Manufacturer[2] Rated Dry Output (1000 lbs Thrust)	Mode	Power Setting	Fuel Flow (lb/min)	Emission Rates HC	 CO	 NO_x	 SO_2[3]	Partic- ulate
				— lbs per 1000 lbs —				
NK-86	Takeoff	100%	267.07	0	1.3	13.6	0.54	--
NPO	Climbout	85%	218.26	0	1.7	10	0.54	--
29.5	Approach	30%	75.66	0	5	3.8	0.54	--
	Taxi/Idle	7%	32.14	4.4	27.6	2.5	0.54	--
IAE V2500	Takeoff	100%	147.22	0.1	0.55	37.13	0.54	--
P&W	Climbout	85%	122.22	0.11	0.55	30.82	0.54	--
25	Approach	30%	44.18	0.15	0.77	13.45	0.54	--
	Taxi/Idle	7%	16.4	0.22	7.76	5.91	0.54	--
JT8D-7/7A/7B	Takeoff	100%	130.85	0.4	1.5	17.1	0.54	--
P&W	Climbout	85%	107.32	0.5	2	13.5	0.54	--
13.9	Approach	30%	37.84	1.6	10.5	5.5	0.54	--
	Taxi/Idle	7%	17.08	10.6	35.5	2.7	0.54	--
JT8D-9/9A	Takeoff	100%	137.57	0.47	1.24	17.92	0.54	--
P&W	Climbout	85%	111.91	0.47	1.66	14.21	0.54	--
14.5	Approach	30%	39.42	1.73	9.43	5.64	0.54	--
	Taxi/Idle	7%	17.46	10	34.5	2.9	0.54	--
JT8D-11	Takeoff	100%	148.28	0.4	1.2	18.9	0.54	--
P&W	Climbout	85%	120.85	0.45	1.9	14.6	0.54	--
15.0	Approach	30%	44.17	1.4	9.4	5.8	0.54	--
	Taxi/Idle	7%	19.25	10	35	2.75	0.54	--
JT8D-15[6]	Takeoff	100%	155.82	0.25	0.72	19.12	0.54	--
P&W	Climbout	85%	125	0.25	1.01	15.01	0.54	--
15.5	Approach	30%	45.01	1.57	9.12	5.97	0.54	--
	Taxi/Idle	7%	19.54	10.33	33.88	3.01	0.54	--
JT8D-15A	Takeoff	100%	147.49	0.25	1.08	18.1	0.54	--
P&W	Climbout	85%	118.45	0.33	1.2	13.9	0.54	--
15.5	Approach	30%	41.27	0.65	2.9	6.6	0.54	--
	Taxi/Idle	7%	18.15	2.29	12.43	3.1	0.54	--
JT8D-17[6]	Takeoff	100%	164.68	0.66	0.75	19.3	0.54	--
P&W	Climbout	85%	131.88	0.75	1.01	15.26	0.54	--
16.0	Approach	30%	46.83	1.86	8.13	6.23	0.54	--
	Taxi/Idle	7%	19.44	9.57	29.56	3.29	0.54	--
JT8D-17A	Takeoff	100%	155.16	0.25	1.07	19.1	0.54	--
P&W	Climbout	85%	123.6	0.3	1.16	14.3	0.54	--
16	Approach	30%	43.7	0.64	2.88	6.7	0.54	--
	Taxi/Idle	7%	18.53	2.02	12.46	3.2	0.54	--
JT8D-17AR	Takeoff	100%	180.56	0.21	0.93	24.5	0.54	--
P&W	Climbout	85%	138.49	0.27	1.08	16	0.54	--
17.4	Approach	30%	47.28	0.55	2.68	8	0.54	--
	Taxi/Idle	7%	19.54	1.33	10.7	3.2	0.54	--
JT8D-17R	Takeoff	100%	187.44	0.21	0.95	25.3	0.54	--
P&W	Climbout	85%	145.9	0.27	1.03	17.6	0.54	--
17.4	Approach	30%	49.67	0.53	2.54	8.4	0.54	--
	Taxi/Idle	7%	20.5	0.95	9.43	3.3	0.54	--
JT8D-209	Takeoff	100%	157.54	0.35	1.03	22.8	0.54	--
P&W	Climbout	85%	130	0.5	1.4	19	0.54	--
19.2	Approach	30%	47.51	1.69	4.37	8.8	0.54	--
	Taxi/Idle	7%	17.24	4.03	14.1	3.5	0.54	--

Table 5-4:
Modal Emission Rates – Civil Aircraft Engines[1]

— Continued —

Model – Series Manufacturer[2] Rated Dry Output (1000 lbs Thrust)	Mode	Power Setting	Fuel Flow (lb/min)	Emission Rates HC	CO	NO_x	SO_2[3]	Particulate
				— lbs per 1000 lbs —				
JT8D-217/217A/217C	Takeoff	100%	174.6	0.29	0.8	25.7	0.54	--
P&W	Climbout	85%	142.59	0.43	1.23	20.6	0.54	--
20.8	Approach	30%	50.7	1.6	4.17	9.1	0.54	--
	Taxi/Idle	7%	18.15	3.33	12.27	3.7	0.54	--
JT8D-219	Takeoff	100%	179.1	0.27	0.73	27	0.54	--
P&W	Climbout	85%	143.52	0.42	1.2	20.8	0.54	--
21.7	Approach	30%	50.49	1.59	4.07	9.13	0.54	--
	Taxi/Idle	7%	17.78	3.48	12.63	3.6	0.54	--
JT9D-7F(modV)/7A(modV)	Takeoff	100%	286.67	0.3	0.4	46	0.54	--
P&W	Climbout	85%	233.33	0.3	0.4	34.4	0.54	--
46.7	Approach	30%	82.5	0.5	2.9	7.8	0.54	--
	Taxi/Idle	7%	28.97	26	54	3.1	0.54	--
JT9D-7R4D/7R4D1	Takeoff	100%	271.83	0.15	0.51	38.5	0.54	--
P&W	Climbout	85%	221.96	0.12	0.48	32	0.54	--
46.7	Approach	30%	100.44	0.13	1.36	9.8	0.54	--
	Taxi/Idle	7%	27.17	1.25	10	4.1	0.54	--
JT9D-7R4E/E1(AI500)	Takeoff	100%	280.16	0.16	0.57	41.6	0.54	--
P&W	Climbout	85%	228.04	0.13	0.53	34.2	0.54	--
52.4	Approach	30%	86.36	0.13	1.23	10.4	0.54	--
	Taxi/Idle	7%	29.23	1.11	8.27	4.1	0.54	--
JT9D-7R4E1(H) (A1-600)	Takeoff	100%	293.39	0.15	0.67	36.9	0.54	--
P&W	Climbout	85%	241.93	0.13	0.67	29.7	0.54	--
48.5	Approach	30%	84.66	0.22	1.46	8.5	0.54	--
	Taxi/Idle	7%	29.17	3.35	14	3.5	0.54	--
JT9D-7R4G2	Takeoff	100%	321.3	0.15	0.74	41.3	0.54	--
P&W	Climbout	85%	248.68	0.14	0.63	32.1	0.54	--
53.3	Approach	30%	87.17	0.18	1.4	8.8	0.54	--
	Taxi/Idle	7%	29.62	1.55	11.82	3.8	0.54	--
JT9D-7R4H1/H2	Takeoff	100%	332.28	0.15	0.74	45.2	0.54	--
P&W	Climbout	85%	264.42	0.14	0.63	34.2	0.54	--
53.9	Approach	30%	95.6	0.18	1.39	8.9	0.54	--
	Taxi/Idle	7%	32.46	1.48	11.63	3.8	0.54	--
JT9D-70/59/7Q	Takeoff	100%	323	0.2	0.2	31.6	0.54	--
P&W	Climbout	85%	264.5	0.2	0.2	25.6	0.54	--
51.1	Approach	30%	90	0.3	1.7	7.8	0.54	--
	Taxi/Idle	7%	31.35	12	53	3	0.54	--
PW2037	Takeoff	100%	203.44	0.05	0.4	31.1	0.54	--
P&W	Climbout	85%	167.46	0.06	0.41	24.8	0.54	--
37.6	Approach	30%	52.78	0.21	2.3	10.3	0.54	--
	Taxi/Idle	7%	18.65	2.26	23.1	4.4	0.54	--
PW2040	Takeoff	100%	241.01	0.03	0.2	47.7	0.54	--
P&W	Climbout	85%	191.54	0.04	0.2	27.7	0.54	--
40.8	Approach	30%	65.21	0.18	2.6	11	0.54	--
	Taxi/Idle	7%	20.5	2.36	23.6	4.4	0.54	--
PW2041	Takeoff	100%	253.57	0.03	0.2	37	0.54	--
P&W	Climbout	85%	203.18	0.04	0.2	29	0.54	--
42.8	Approach	30%	68.39	0.16	2.5	11	0.54	--
	Taxi/Idle	7%	21.03	2.23	23.1	4.5	0.54	--

TABLE 5-4:
Modal Emission Rates – Civil Aircraft Engines[1]
— Continued —

Model – Series Manufacturer[2] Rated Dry Output (1000 lbs Thrust)	Mode	Power Setting	Fuel Flow (lb/min)	Emission Rates HC	 CO	 NO_x	 SO_2[3]	Partic- ulate
				— lbs per 1000 lbs —				
PW4056/4156 P&W 55.9	Takeoff	100%	309.79	0.06	0.44	29.1	0.54	--
	Climbout	85%	255.29	0.01	0.57	22.9	0.54	--
	Approach	30%	87.04	0.13	2	11.6	0.54	--
	Taxi/Idle	7%	27.51	1.92	21.86	4.9	0.54	--
PW4152 P&W 51.9	Takeoff	100%	287.96	0.13	0.12	26.9	0.54	--
	Climbout	85%	236.11	0.16	0.17	22.7	0.54	--
	Approach	30%	78.44	0.15	1.09	11.1	0.54	--
	Taxi/Idle	7%	23.41	0.74	12.76	4.9	0.54	--
PW4158 P&W 57.9	Takeoff	100%	328.18	0.09	0.4	30.2	0.54	--
	Climbout	85%	265.08	0.02	0.54	23.7	0.54	--
	Approach	30%	90.21	0.14	1.88	11.8	0.54	--
	Taxi/Idle	7%	27.91	1.78	20.99	4.8	0.54	--
PW4460 P&W 59.9	Takeoff	100%	350.13	0.1	0.37	32.9	0.54	--
	Climbout	85%	275.8	0.03	0.51	24.7	0.54	--
	Approach	30%	92.99	0.14	1.78	12	0.54	--
	Taxi/Idle	7%	28.17	1.66	20.32	4.9	0.54	--
JT15D-1 P&WC 2.39	Takeoff	100%	19.58	0.01	2.65	7.6	0.54	--
	Climbout	85%	16.4	0.01	3.5	6.77	0.54	--
	Approach	30%	6.75	4.43	40.5	3.44	0.54	--
	Taxi/Idle	7%	3.04	50.5	132	1.75	0.54	--
JT15D-4 P&WC 2.72	Takeoff	100%	22.45	0.09	2.1	9.23	0.54	--
	Climbout	85%	18.92	0.19	3.18	8.56	0.54	--
	Approach	30%	7.8	5.15	32	5.29	0.54	--
	Taxi/Idle	7%	3.45	40	97	2.63	0.54	--
PT6A-27S P&WC	Takeoff	100%	7.08	0	1.01	7.81	0.54	--
	Climbout	90%	6.67	0	1.2	7	0.54	--
	Approach	30%	3.58	2.19	23.02	8.37	0.54	--
	Taxi/Idle	7%	1.92	50.17	64	2.43	0.54	--
PT6A-414 P&WC	Takeoff	100%	8.5	1.75	5.1	7.98	0.54	--
	Climbout	90%	7.88	2.03	6.49	7.57	0.54	--
	Approach	30%	4.55	22.71	34.8	4.65	0.54	--
	Taxi/Idle	7%	2.45	101.63	115.31	1.97	0.54	--
M45H-01 RR 7.29	Takeoff	100%	65.87	0.75	6.2	11.5	0.54	--
	Climbout	85%	55.03	0.74	7.9	9.3	0.54	--
	Approach	30%	19.31	7.4	51	3.6	0.54	--
	Taxi/Idle	7%	7.01	59.5	178.4	1.5	0.54	--
OLYMPUS 593 MK610 RR 37	Takeoff	100%	841.94	2.9	29	9.5	0.54	--
	Climbout	65%	308.07	1.7	19.9	9.3	0.54	--
	Descent	15%	90.61	22	73.2	2.5	0.54	--
	Approach	34%	154.9	11.4	52.9	3.5	0.54	--
	Taxi/Idle	7%	55.69	33.4	100.1	1.7	0.54	--
RB.211-22S RR 41	Takeoff	100%	246.83	0.36	2.48	34.32	0.54	--
	Climbout	85%	203.97	0.39	4.14	25.63	0.54	--
	Approach	30%	73.15	7.73	26.38	9.05	0.54	--
	Taxi/Idle	7%	30.03	65.37	93.17	2.7	0.54	--
RB.211-524B/B2/B3/B4 RR 49.1	Takeoff	100%	315.21	0.52	1.83	47	0.54	--
	Climbout	85%	256.48	0.4	2.82	33	0.54	--
	Approach	30%	91.67	4.98	20	9.75	0.54	--
	Taxi/Idle	7%	35.98	50.6	82.2	3.53	0.54	--

TABLE 5-4:

Modal Emission Rates – Civil Aircraft Engines[1]

— Continued —

Model – Series Manufacturer[2] Rated Dry Output (1000 lbs Thrust)	Mode	Power Setting	Fuel Flow (lb/min)	HC	Emission Rates CO — lbs per 1000 lbs —	NO_x	SO_2[3]	Particulate
RB.211-524C2	Takeoff	100%	328.04	0	0.66	41.9	0.54	--
RR	Climbout	85%	267.2	0.22	1.63	32.3	0.54	--
50.5	Approach	30%	97.88	4.42	18.9	10.4	0.54	--
	Taxi/Idle	7%	39.68	54.2	81	3.37	0.54	--
RB.211-524D4[6]	Takeoff	100%	322.12	0.02	0.53	56.97	0.54	--
RR	Climbout	85%	257.96	0.42	1.15	41.06	0.54	--
51.9	Approach	30%	94.97	4.68	16.44	9.66	0.54	--
	Taxi/Idle	7%	38.5	45.11	71.87	4.12	0.54	--
RB.211-524G	Takeoff	100%	346.56	2.28	0.59	58.71	0.54	--
RR	Climbout	85%	275.13	1.46	0.43	40.54	0.54	--
56.8	Approach	30%	92.59	1.14	1.01	9.56	0.54	--
	Taxi/Idle	7%	34.39	3.29	13.74	4.63	0.54	--
RB.211-535C	Takeoff	100%	238.1	0.25	0.7	33.71	0.54	--
RR	Climbout	85%	194.45	0.14	0.27	24.89	0.54	--
36.7	Approach	30%	71.43	0.44	0.84	6.37	0.54	--
	Taxi/Idle	7%	26.46	1.44	18.79	3.44	0.54	--
RB.211-535E4	Takeoff	100%	246.03	0.69	1.01	52.7	0.54	--
RR	Climbout	85%	199.74	0.94	1.23	36.2	0.54	--
39.5	Approach	30%	75.4	1.33	1.71	7.5	0.54	--
	Taxi/Idle	7%	25.13	2.85	15.44	4.3	0.54	--
SPEY MK511	Takeoff	100%	117.59	0.98	1.81	23.27	0.54	--
RR	Climbout	85%	96.03	1.32	2.06	19.18	0.54	--
11.3	Approach	30%	36.91	7.23	20.3	7.94	0.54	--
	Taxi/Idle	7%	15.74	56.73	97.96	1.48	0.54	--
SPEY MK511-8	Takeoff	100%	117.56	0.09	0.12	22.7	0.54	--
RR	Climbout	85%	96.03	0.12	0.63	17.3	0.54	--
11.3	Approach	30%	36.77	0.18	2.65	7.2	0.54	--
	Taxi/Idle	7%	16.9	3.69	31.77	3.6	0.54	--
SPEY MK555[7]	Takeoff	100%	73.5	0.74	0.41	19.61	0.54	--
RR	Climbout	85%	60.13	1.27	0.16	15.07	0.54	--
9.89	Approach	30%	22.66	5.43	17.96	6.12	0.54	--
	Taxi/Idle	7%	11.74	71.84	74.68	2.26	0.54	--
TAY MK620-15/MK611-8	Takeoff	100%	100.53	0.8	0.7	21.1	0.54	--
RR	Climbout	85%	83.33	0.3	0.8	16.8	0.54	--
13.8	Approach	30%	30.42	0.9	3.9	5.7	0.54	--
	Taxi/Idle	7%	14.55	3.4	24.1	2.5	0.54	--

1 Source: ICAO Engine Exhaust Emissions Databank (Reference 13) unless otherwise noted.

2 MANUFACTURERS: All. - Allison, Con - Teledyne/Continental, GE - General Electric, Grt - Garrett AiResearch, Lyc - Avco/Lycoming, P&W - Pratt & Whitney, P&WC - Pratt & Whitney Canada, RR - Rolls-Royce

3 SO_2 emissions based on national average sulfur content of aviation fuels from Aviation Turbine Fuels, 1989 (Reference 23).

4 Source of data is AP-42 (Reference 1). Nitrogen oxides reported as NO_2. HC refers to total hydrocarbons (Volatile organics, including unburned hydrocarbons and organic pyrolysis products)

5 Source of data is AP-42 (Reference 1). Source of Particulate data is AP-42 Reference 4 (M. Platt, et al., The Potential Impact of Aircraft Emissions upon Air Quality, APTD-1085, U.S. Environmental Protection Agency, Research Triangle Park, NC, December 1971). The indicated reference does not specify series number for this model engine.

6 Source of engine data is ICAO (Reference 13). Data are sales weighted averages of two versions of this engine. The basis is 93% high emission combustors and 7% low emission combustors.

7 Source of engine data is ICAO (Reference 13). Data are sales weighted averages of two versions of this engine. The basis is 77% high emission combustors and 23% low emission combustors.

inventory. Commercial airlines must keep track of their taxi/idle time at each airport for different aircraft types so that their flight schedules reflect anticipated daily and seasonal variations. These data are important to the airlines since they report schedule delays to the Department of Transportation as a measure of their operating performance. Therefore, the airlines' Flight Operations departments at their headquarters locations are the best source of data for taxi/idle time by aircraft type at a particular airport. Since all airlines using a particular airport will experience similar taxi/idle times it is only necessary to get information from a single source. If taxi/idle times are not available for a particular airport, Table 5–1 lists default values of taxi/idle periods, as well as other modes, for different aircraft classifications. For commercial aircraft this information is based on data collected prior to 1971 at large airports during periods of congestion. Idle times that reflect more recent experience will be incorporated in the next version of AP-42. For the inventory calculations, taxi/idle–in and taxi/idle–out time are added together to get a total time for the taxi/idle mode.

The final step in the procedure is to calculate total emissions for each aircraft type and to sum them for a total commercial aircraft emission rate. The following series of equations illustrates the calculation:

Adjust Approach and Climbout TIM to Represent Local Conditions

These equations adjust the times–in–mode, which are based on a default mixing height of 3000 feet, to an airport specific value based on the local mixing height. Equation 5–2 assumes the climbout mode begins with the transition from takeoff to climbout at 500 feet and continues until the aircraft exits the mixing layer.

$$TIM_{app\text{-}C} = 4 * (H/3000) \quad (5\text{-}1)$$

$$TIM_{clm\text{-}C} = 2.2 * [(H-500)/2500] \quad (5\text{-}2)$$

$TIM_{app\text{-}C}$ - time in the approach mode for commercial aircraft, in minutes

$TIM_{clm\text{-}C}$ - time in the climbout mode for commercial aircraft, in minutes

H - mixing height used in air quality modeling for time and region of interest

Calculate Emissions for Each Aircraft Type

$$E_{ij} = \Sigma (TIM_{jk}) * (FF_{jk}/1000) * (EI_{ijk}) * (NE_j) \quad (5\text{-}3)$$

E_{ij} = total emissions of pollutant i, in pounds, produced by aircraft type j for one LTO cycle

TIM_{jk} = time in mode for mode k, in minutes, for aircraft type j

FF_{jk} = fuel flow for mode k, in pounds per minute, for each engine used on aircraft type j (from Table 5-4)

EI_{ijk} = emission index for pollutant i, in pounds of pollutant per one thousand pounds of fuel, in mode k for aircraft type j (from Table 5-4)

NE_j = number of engines used on aircraft type j (from Table 5-2)

Calculate Total Emissions for All Commercial Aircraft

$$E_{Ti(C)} = \Sigma (E_{ij}) * (LTO_j) \quad (5\text{-}4)$$

$E_{Ti(C)}$ - total emissions of pollutant i, in pounds, produced by all commercial aircraft operating in the region of interest (where j covers the range of commercial aircraft operating in the area)

LTO_j-total number of LTO cycles for aircraft type j, during the inventory period (annual data available from Reference 6, Table 7)

After completing this series of equations, the inventory of emissions is complete for commercial aircraft. The next series of calculations is a repeat of steps three through six for general aviation aircraft.

5.2.4 Activity and Emissions for General Aviation and Air Taxi Aircraft

Defining the mix and activity level of general aviation and air taxi aircraft is more difficult than for commercial. FAA does not track operations by aircraft model for general aviation aircraft and no other sources of these data cover all states. For some states, this information is available for some airports from the State Airport Authority or from the operations officials at individual airports. Detailed model information for aircraft operating in the inventory area is difficult to locate, except perhaps for air taxis, and may add only relatively small improvement in accuracy to the emissions inventory compared to treating general aviation and air taxis as though they were made up of a representative mix of aircraft. For some smaller airports, air taxi activity may predominate and it may be possible to locate aircraft specific information on the operations there. Where information on specific aircraft is available, the procedure for calculating total engine emissions from general aviation and air taxi aircraft is the same as that followed for commercial aircraft. Table 5-5 shows some examples of the aircraft and engine combinations found in the general aviation and air taxi categories. Information on these categories may be expanded in the next update of AP-42 to include more aircraft and engine combinations as well as emission indices for additional engines.

Where detailed information on specific aircraft mix and activity is unavailable, a single emission index can be used which is made up of a representative fleet mix. This will give a rough estimate of emissions for the category. The following indexes were calculated based on 1988 fleet data[1] for general aviation aircraft.

HC 0.394 pounds per LTO

CO 12.014 pounds per LTO

NO_X 0.065 pounds per LTO

SO_2 0.010 pounds per LTO

1 See memo S. Webb to R. Wilcox dated June 10, 1991.

TABLE 5-5:

General Aviation Aircraft Types And Engine Models[1]

Aircraft	No. Of Seats	No. Of Engines	No. Of Aircraft[2]	Engine	Manu.[3]
Piston					
Sellanca 7GCSC Seaplane	3	1	567	0-320	Lyc
Cessna 150	2	1	13760	O-200	Con
Cessna 337 series	6	2	1151	TSIO-360C	Con
Piper PA-18 series	2	1	3590	0-320[4]	Lyc
Turbojet					
Aerospatiale SN601 Corvette	16	2	1	JT15D-4	PWC
Canadair CL-600 Challenger	13	2	61	ALF502L-2	Lyc
Dassault Bregue Falcon 10	7	2	126	TFE731-2	Grt
Dassault Bregue Falcon 50	10	3	125	TFE731-3	Grt
Gates Learjet 35/36	10	2	67	TFE731-2-2B	Grt
Gates Learjet 35A/36A	10	2	342	TFE731-2-2B	Grt
Israel Aircraft IAI 1124	10	2	151	TFE731-3	Grt
Learjet 31	10	2	6	TFE731-2	Grt
Mitsubishi MU-300 series	11	2	75	JT15D-4	PWC
Turboprop					
de Havilland DHC-6-300	22	2	40	PT6A-27	PWC
Fairchild Pilatus PC6 series	8	1	8	PT6A-27[5]	PWC
Helio Aircraft HST-550A Stallion	10	1	1	PT6A-27	PWC
Piper PA-42 series	11	2	105	PT6A-41[6]	PWC

1 Source of aircraft, corresponding engines, and number of engines is <u>FAA Aircraft Engine Emission Database</u> (Reference 14). Source of number of seats, aircraft type, and number of aircraft is <u>Census of U.S. Civil Aircraft</u> (Reference 7).

2 No. of Aircraft refers to Total U.S. Registered Aircraft as of December 31, 1989.

3 Engine Mnf. Abbreviations:
Con - Teledyne/Continental, GE - General Electric,
Grt - Garrett AiResearch,
Lyc - Avco/Lycoming,
P&W - Pratt & Whitney,
PWC - Pratt & Whitney Canada,
RR - Rolls-Royce

4 Engine refers to a PA-18-150 Super aircraft.

5 Engine refers to a PC6/B2-H2 aircraft.

6 Engine refers to a PA-42 Cheyenne aircraft.

Since air taxis have fewer of the smallest engines in their fleet and more turboprop and turbojet engines, their emission factors are somewhat different.

HC 1.234 pounds per LTO

CO 28.130 pounds per LTO

NO_X 0.158 pounds per LTO

SO_2 0.015 pounds per LTO

Airport activity for general aviation aircraft and air taxis can be found in *FAA Air Traffic Activity* (Reference 3). Figure 5–5 is a copy of a page from Table 4 which reports airport operations at airports with FAA-operated traffic control towers. Table 22 from the same report lists operations at airports with FAA contractor-operated traffic control towers. In this report, an operation could be either a takeoff or landing, so the number of operations should be divided by two to get LTOs. In addition to these airports, general aviation and air taxi activity is common at smaller airports and landing strips not included in FAA's reporting system. These airports must be contacted directly to determine if information is available on general aviation activity. Air taxi operators located at the airports, may be a source for information on air taxi activity. These steps may have little impact on the inventory and should be considered discretionary.

The annual emissions are then calculated as the product of airport activity in LTOs from Reference 3 and the emission index in pounds per LTO listed above. Total emissions are then summed for general aviation and air taxis.

This simplified estimation procedure is based on the default times-in-mode from Table 5-1. If the detailed estimation procedure is being followed based on specific aircraft and engines, airport specific estimates on time-in-mode might be used if available from airport officials. These data likely vary quite widely because of the many different types of services provided by this aircraft category. The rest of the detailed estimation procedure uses the same set of equations used for commercial aircraft.

Adjust Approach and Climbout TIM to Represent Local Conditions

$$TIM_{app\text{-}G} = 6 * (H/3000) \quad (5\text{-}5)$$

$$TIM_{clm\text{-}G} = 5 * [(H-500)/2500] \quad (5\text{-}6)$$

$TIM_{app\text{-}G}$ - time in the approach mode, in minutes

$TIM_{clm\text{-}G}$ - time in the climbout mode, in minutes (assumes transition from takeoff to climbout occurs at 500 feet)

H - mixing height used in air quality modeling for time and region of interest

Figure 5-5

Reproduction Of A Page Of Table 4

— From Reference 3 —

TABLE 4 - FISCAL YEAR 1989

AIRPORT OPERATIONS AT AIRPORTS WITH FAA-OPERATED TRAFFIC CONTROL TOWERS BY REGION AND BY STATE AND AVIATION CATEGORY-CONTINUED

State and Location Name	Location Identifier	Hub	Total	Air Carrier	Air Taxi	General Aviation	Military
CALIFORNIA—Continued							
CHINO	(CNO)	S					
ITINERANT OPERATIONS			112504	0	147	111106	1251
LOCAL OPERATIONS			111099			111026	73
TOTAL OPERATIONS			223603	0	147	222132	1324
CONCORD	(CCR)	L					
ITINERANT OPERATIONS			121566	2599	7169	110902	896
LOCAL OPERATIONS			141406			141323	83
TOTAL OPERATIONS			262972	2599	7169	252225	979
EL MONTE	(EMT)	N					
ITINERANT OPERATIONS			90343	0	4515	85539	289
LOCAL OPERATIONS			99366			99366	0
TOTAL OPERATIONS			189709	0	4515	184904	289
FRESNO AIR TERMINAL	(FAT)	S					
ITINERANT OPERATIONS			198015	13200	67562	106730	9533
LOCAL OPERATIONS			10204			9461	743
TOTAL OPERATIONS			208219	13200	67552	115191	10276
FULLERTON MUNICIPAL	(FUL)	L					
ITINERANT OPERATIONS			91890	0	2652	89189	49
LOCAL OPERATIONS			65349			65336	13
TOTAL OPERATIONS			157239	0	2652	154525	62
HAWTHORNE	(HHR)	L					
ITINERANT OPERATIONS			54789	0	889	53811	89
LOCAL OPERATIONS			41027			41027	0
TOTAL OPERATIONS			95816	0	889	94838	89
HAYWARD	(HWD)	L					
ITINERANT OPERATIONS			126893	0	4161	122111	621
LOCAL OPERATIONS			125441			125433	8
TOTAL OPERATIONS			252334	0	4161	247544	629
LA VERNE BRACKETT	(POC)	N					
ITINERANT OPERATIONS			95669	0	1612	93857	200
LOCAL OPERATIONS			116005			115997	8
TOTAL OPERATIONS			211674	0	1612	209854	208
LANCASTER FOX AIRPORT	(WJF)	N					
ITINERANT OPERATIONS			63304	0	1227	60910	1167
LOCAL OPERATIONS			74505			73723	782
TOTAL OPERATIONS			137809	0	1227	134633	1949
LIVERMORE MUNICIPAL	(LVK)	L					
ITINERANT OPERATIONS			91976	0	357	91250	369
LOCAL OPERATIONS			116108			116072	36
TOTAL OPERATIONS			208084	0	357	207322	405
LONG BEACH	(LGB)	L					
ITINERANT OPERATIONS			267296	20048	7656	236847	2745
LOCAL OPERATIONS			194881			194836	45
TOTAL OPERATIONS			462177	20048	7656	431683	2790
LOS ANGELES INTERNATIONAL	(LAX)	L					
ITINERANT OPERATIONS			626874	427419	151785	42670	5000
LOCAL OPERATIONS			5363			5311	52
TOTAL OPERATIONS			632237	427419	151785	47981	5052
MODESTO CITY COUNTY	(MOD)	N					
ITINERANT OPERATIONS			81571	0	23519	57450	602
LOCAL OPERATIONS			36305			36010	295
TOTAL OPERATIONS			117876	0	23519	93460	897
MONTEREY	(MRY)	S					
ITINERANT OPERATIONS			88025	8106	19338	57773	2808
LOCAL OPERATIONS			19223			17284	1939
TOTAL OPERATIONS			107248	8106	19338	75057	4747
NAPA COUNTY	(APC)	N					
ITINERANT OPERATIONS			70145	0	476	68733	936
LOCAL OPERATIONS			99958			99414	544
TOTAL OPERATIONS			170103	0	476	168147	1480
OAKLAND INTERNATIONAL	(OAK)	L					
ITINERANT OPERATIONS			277745	74882	57281	144980	802
LOCAL OPERATIONS			125468			125304	164
TOTAL OPERATIONS			403213	74882	57281	270284	966
ONTARIO	(ONT)	S					
ITINERANT OPERATIONS			139598	86191	25018	28864	525
LOCAL OPERATIONS			3082			3080	2
TOTAL OPERATIONS			142680	86191	25018	31944	527
OXNARD VENTURA COUNTY	(OXR)	N					
ITINERANT OPERATIONS			87306	0	21326	65345	635
LOCAL OPERATIONS			48622			47351	1271
TOTAL OPERATIONS			135928	0	21326	112696	1906

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Calculate Emissions for Each Aircraft Type

The emission factors that appear in Table 5-4 for general aviation aircraft have not been updated since the last version of AP–42. The next edition of AP–42 should include updates to much of the date that appears in the table.

$$E_{ij} = \Sigma (TIM_{jk}) * (FF_{jk}/1000) * (EI_{ijk}) * (NE_j) \qquad (5\text{-}7)$$

E_{ij} - total emissions of pollutant i, in pounds, produced by aircraft type j for one LTO cycle.

TIM_{jk} - time in mode for mode k, in minutes, for aircraft type j

FF_{jk} - fuel flow for mode k, in pounds per minute, for each engine used on aircraft type j (from Table 5-4)

EI_{ijk} - emission index for pollutant i, in pounds of pollutant per one thousand pounds of fuel, in mode k for aircraft type j (from Table 5-4)

NE_j - number of engines used on aircraft type j (from Table 5-5)

Calculate Total Emissions for All General Aviation Aircraft

$$E_{Ti(G)} = \Sigma (E_{ij}) \cdot (LTO_j) \qquad (5\text{-}8)$$

$E_{Ti(G)}$ - total emissions of pollutant i, in pounds, produced by all general aviation aircraft operating in the region of interest (where j covers the range of general aviation aircraft operating in the area)

LTO_j - total number of LTO cycles for aircraft type j, during the inventory period

5.2.5 Activity and Emissions for Military Aircraft

FAA Air Traffic Activity (Reference 3) contains information on the number of military operations at airports with FAA–operated traffic control towers. This information can be used in much the same way as for general aviation aircraft, however, military air bases are not included in this reference. The information only addresses military operations at civil airports. Military air bases included in the modeling area should be apparent from maps of the area. For these bases, it likely will be difficult to get good information on fleet make up and activity. In some cases, information may be available from the Office of the Base Commander on fleet make-up and possibly some measure or estimate of activity such as LTOs for one day or one month. Where specific information is available for aircraft type and LTOs, Table 5–6 lists military aircraft and their engines and Table 5–7 lists the modal emission rates for these engines. Much of the data in Table 5–7 has been updated since the last version of AP–42.

TABLE 5-6:

Military Aircraft Types And Engine Models[1]

Aircraft	Type[2]	Operator[3]	No. Of Engines	Engine Model	Manu.[4]
Combat					
Boeing B52-H Stratofortress	TF	USAF	8	TF33-P-3	PW
Boeing EC-135C	TF	USAF	4	TF33-P-5	PW
Douglas A-4 Skyhawk[5]	TJ	USN	1	J52-P-8B	PW
Douglas A-4M Skyhawk[5]	TJ	USMC	2	J52-P-408	PW
General Dynamics F-16 Fighting Falcon[5]	TF	USAF	1	F101DFE	PW
	TF	USAF/USN	1	F100-PW-200[1]	PW
Grumman A-6 Intruder[5]	TJ	USN	2	J52-P-8B	PW
Grumman E-2 Hawkeye[5]	TP	USN	2	T56-A-16	All.
Grumman EA-6B Prowler[5]	TJ	USMC/USN	2	J52-P-408	PW
Grumman F-14 Tomcat[5]	TF	USN	2	TF30-P-412A	PW
Learjet Corp C-21-A	TF	USAF	2	TFE 731-2-2B	Gr.
Lockheed S-3 Viking[5]	TF	USN	2	TF34-GE-400	GE
LTV Aircraft A-7E Corsair II	TF	USN	1	TF41-A-2	All.
McDonnell Douglas AV-8[5]	TF	USMC	1	F402	RR
McDonnell Douglas F-4 Phantom II[5]	TJ	USAF/USN	2	J79-GE-10B	GE
McDonnell Douglas F-4B Phantom II[6]	TJ	USMC/USN	2	J79-GE-8D	GE
McDonnell Douglas F-4N Phantom II[6]	TJ	USN	2	J79-GE-8D	GE
McDonnell Douglas F-4S Phantom II	TJ	USN	2	J79-GE-10	GE
McDonnell Douglas F-15C/D Eagle	TF	USAF	2	F100-PW-100	PW
McDonnell Douglas F/A-18 Hornet[5]	TF	USN	2	F404-GE-400	GE
McDonnell Douglas RF-4B Phantom II[6]	TJ	USMC	2	J79-GE-8D	GE
Northrop F-5E Tiger II	TJ	USAF/USN	2	J85-GE-21	GE
Northrop F-5F Tiger II	TJ	USAF/USN	2	J85-GE-21	GE
Northrop RF-5E Tigereye	TJ	USAF	2	J85-GE-21	GE
Rockwell OV-10 Bronco[5]	TP	USAF/USMC	2	T76-G-12A	Gn
Vought A-7 Corsair II[5]	TF	USAF/USN	1	TF41-A-2	All.
Trainer					
Boeing T-43A	TF	USAF	2	JT8D-9	PW
CASA C-101 Aviojet	TF		1	TFE 731-2	Gn
FMA Cordoba PAMPA IA.63	TF		1	TFE 731-2	Gn
Grumman Gulfstream	TF	USN	2	Dart RDa7	RR
McDonnell Douglas D F-15	TF	USAF	1	F100-PW-100	PW
McDonnell Douglas F-15 C/D Eagle	TF	USAF	2	F100-PW-100 /200[7]	PW
McDonnell Douglas F/A-18 Hornet[5]	TF	USN	2	F404-GE-400	GE
Mitsubishi T-2S	TJ	USN	2	J85-GE-2	GE
Transport					
Australia Govt Nomad 22B	TP		2	250B17B	All.
Australia Govt Nomad 24	TP		2	250B17B	All.
BEECH C-12A/B/C	TP	Army/USAF	2	PT6A-41	PWC
Boeing B-747-200	TF		4	JT9D-7R4G2	PW
Boeing C-135B Stratolifter	TF	USAF	4	TF33-P-5	PW
Boeing E-4A/B NEACP	TF	USAF	4	CF6-50E	GE
Boeing VC-25A	TF	USAF	4	CF6-80C2B1	GE
de Havilland UV-18A	TP	Army	2	PT6A-27	PWC
Fairchild C-26A	TP	NG	2	TPE 331	Gn
Grumman C-1A Trader[5]	P	USN	2	R-1820	W
Grumman Gulfstream	TF	USAF	2	Dart RDa7	RR
LASC Georgia C-141B Starlifter	TF	USAF	4	TF33-P-7	PW
Lockheed C-130E Hercules	TP		4	T56-A-7	All.
Lockheed C-130 Hercules[5]	TP		4	T56-A-16	All.
Lockheed C-141 Starlifter	TF	USAF	4	TF33-P-7	PW
Lockheed L-100 Hercules	TP		4	501D22A	All.

Table 5-6: Military Aircraft Types And Engine Models[1] — Continued

Aircraft	Type[2]	Operator[3]	No. Of Engines	Engine Model	Manu.[4]
McDonnell Douglas C-9A Nightingale	TF	USAF	2	JT8D-9	PW
McDonnell Douglas C-9B	TF	USN	2	JT8D-9	PW
McDonnell Douglas KC-10A Extender	TF	USAF	3	CF6-50C2	GE
McDonnell Douglas VC-9C	TF	USAF	2	JT8D-9	PW
Utility					
BEECH RU-231J	TP	Army	2	PT6A-41	PWC
BEECH UC-12F/M	TP	USMC/USN	2	PT6A-41	PWC
Helicopter					
Bell UH-1, AH-1[5]	TS	Army	1	T53-L-11D	Lyc
Boeing Vertol H-46 Sea Knight[5]	TS	USMC/USN	2	T58-GE-8F	GE
Boeing Vertol H-46E Sea Knight[5]	TS	USMC/USN	2	T58-GE-16	GE
Costruzioni HH-3F	TS	USCG	2	T58-GE-5	GE
Kaman H-2 Seasprite[5]	TS	USN	2	T58-GE-8F	GE
Sikorsky H-3 Sea King series[5]	TS		2	T58-GE-8F	GE
Sikorsky H-53 Sea Stallion/ Super Stallion[5]	TS		3	T64-GE-415	GE
Sikorsky HH-3E Jolly Green Giant	TS	USAF	2	T58-GE-5	GE
Sikorsky SH-3E	TS		2	T58-GE-5	GE
Sikorsky SH-3F	TS		2	T58-GE-5	GE
Sikorsky SH-61AA	TS		2	T58-GE-5	GE

1 Source: FAA Aircraft Engine Emission Database (Reference 14) unless otherwise noted.

2 Source of Type information is "Aviation Week & Space Technology "(Reference 16). TYPES: P - Piston, TF - Turbofan, TJ - Turbojet, TP - Turboprop, TS - Turboshaft

3 Source of Operator information is Encyclopedia of Modern Military Aircraft (Reference 17). OPERATORS: Army, NG - National Guard, USAF - U.S. Air Force, USCG - U.S. Coast Guard, USMC - U.S. Marine Corps, USN - U.S. Navy, US - USAF, USCG, USMC, & USN.

4 ENGINE MANUFACTURERS: All. - Allison, GE - General Electric, Grt - Garrett AiResearch, Lyc - Avco/ Lycoming, PW - Pratt & Whitney, W - Curtis Wright

5 Source of aircraft and corresponding engine information is Example of an Air Base Emissions Inventory for the County of San Diego (1987) (Reference 15).

6 Sources: Engines - Summary Table of Gaseous and Particulate Emissions from Aircraft Engines (Reference 18). Aircraft, Type, and No. of Engines - "Aviation Week & Space Technology" (Reference 16). Classification and Operator - Encyclopedia of Modern Military Aircraft (Reference 17).

7 Source: Aviation Week & Space Technology (Reference 16).

Where data on military aircraft operations and fleet make-up cannot be obtained from the base commander, a centralized support office may be able to provide the required information. The Navy (Reference 8)and Air Force (Reference 9) both have environmental support offices responsible for information on emissions from military aircraft including complete inventories for many bases. If inventory information is unavailable after contacting the Navy or Air Force environmental support office, a letter requesting an inventory should be sent to the base commander through the EPA regional office with copies to the appropriate environmental support office.

If data on fleet make up and activity are obtained from the base commander or the environmental support offices, the procedure for calculating an inventory for military aircraft is the

TABLE 5-7:

Modal Emission Rates — Military Aircraft Engines[1] —

Model – Series Manufacturer[2] Rated Dry Output (1000 lbs Thrust)	Mode	Power Setting	Fuel Flow (lb/min)	HC	Emission Rates CO	NOx	SO_2[3]	Particulate
				— lbs per 1000 lbs —				
250B17B[4] All.	Takeoff	Military	4.42	0.26	7.81	6.60	0.54	--
	Climbout	95%	4.08	0.37	9.02	5.96	0.54	--
	Approach	30%	1.42	5.18	48.59	2.24	0.54	--
	Idle	Idle	1.05	20.16	97.30	1.43	0.54	--
501D22A[4] All.	Takeoff	Military	39.6	0.28	2.04	8.88	0.54	--
	Climbout	95%	36.63	0.89	2.06	9.22	0.54	--
	Approach	30%	19	1.96	5.10	7.49	0.54	--
	Idle	Idle	10.17	17.61	43.61	3.52	0.54	--
T56-A-7[4] All.	Takeoff	Military	34.65	0.38	2.12	9.28	0.54	1.78[5]
	Climbout	95%	31.8	0.47	2.41	9.22	0.54	1.57[5]
	Approach	30%	17.55	0.47	3.51	7.41	0.54	2.85[5]
	Idle	Idle	9.13	20.99	31.93	3.83	0.54	2.92[5]
T56-A-15[6] All.	Takeoff	100%	39.87	0.18	1.60	11.71	0.54	--
	Climbout	90%	36.45	0.18	1.60	10.18	0.54	--
	Approach	30%	19.10	0.28	3.00	6.38	0.54	--
	Idle	7%	8.23	14.96	17.69	2.50	0.54	--
T56-A-16 All.	Takeoff	Military	36.98	0.16	0.65	10.45	0.54	--
	Climbout	Military	36.98	0.16	0.65	10.45	0.54	--
	Approach	75%	33.27	0.17	0.42	9.93	0.54	--
	Idle	L/S Gr. idle	9.98	27.32	30.11	3.53	0.54	--
T63-A-5A[7] All.	Takeoff	Military	3.58	0.08	7.54	5.07	0.54	--
	Climbout	75%	2.92	0.24	14.31	4.61	0.54	--
	Approach	30%	1.75	3.27	38.59	2.90	0.54	--
	Idle	Gr. idle	1.02	20.30	79.15	1.42	0.54	--
TF41-A-2[7] All.	Takeoff	Intermediate	149.00	0.64	1.64	22.46	0.54	--
	Climbout	Intermediate	149.00	0.64	1.64	22.46	0.54	--
	Approach	75% M/C	100.00	0.73	2.17	16.85	0.54	--
	Idle	Idle	18.17	51.26	94.80	1.71	0.54	--
TF41-A-2 All.	Takeoff	IRP	149.00	0.74	1.62	22.46	0.54	--
	Climbout	IRP	149.00	0.74	1.62	22.46	0.54	--
	Approach	75% M/C	100.00	0.85	2.17	16.85	0.54	--
	Idle	Idle	18.17	59.48	94.73	1.71	0.54	--
0-200[4] Con	Takeoff	100%	0.75	20.81	974.10	4.87	0.11	--
	Climbout	75%	0.75	20.81	974.10	4.87	0.11	--
	Approach	30%	0.43	33.22	1187.84	1.14	0.11	--
	Idle	7%	0.14	29.00	644.42	1.58	0.11	--
T400-CP-400[7] CP	Takeoff	Military	6.87	0.11	0.75	6.66	0.54	--
	Climbout	Cruise	4.72	0.15	2.64	4.90	0.54	--
	Approach	Fl. idle	2.38	7.46	30.71	3.08	0.54	--
	Idle	Gr. idle	2.30	8.98	29.78	3.05	0.54	--
CF6-50E/C1/E1/C2/E2[8] GE 51.79	Takeoff	100%	321.17	0.60	0.50	36.50	0.54	--
	Climbout	85%	254.63	0.70	0.50	29.60	0.54	--
	Approach	30%	87.86	1.00	5.70	9.70	0.54	--
	Idle	3%	22.24	49.30	81.3	2.40	0.54	--
F404-GE-400[7] GE	Takeoff	A/B max	473.28	0.13	23.12	9.22	0.54	--
	Climbout	IRP	134.71	0.31	1.05	25.16	0.54	2.81
	Approach	76%	109.02	0.35	1.09	14.80	0.54	6.1
	Idle	Gr. idle	10.40	58.18	137.34	1.16	0.54	12.38

TABLE 5-7:

Modal Emission Rates
— Military Aircraft Engines[1] —
Continued

Model – Series Manufacturer[2] Rated Dry Output (1000 lbs Thrust)	Mode	Power Setting	Fuel Flow (lb/min)	HC	Emission Rates CO	NO_x	SO_2[3]	Particulate
				— lbs per 1000 lbs —				
F404-GE-400 GE	Takeoff	A/B max	473.28	0.13	23.12	9.22	0.54	--
	Climbout	IRP	143.12	0.31	1.05	25.16	0.54	--
	Approach	76%	109.02	0.33	1.09	14.80	0.54	--
	Idle	Gr.idle	10.40	58.18	137.34	1.16	0.54	--
J79-GE-8D[7] GE	Takeoff	Afterburner	571.92	0.91	13.25	4.72	0.54	10.67
	Climbout	Military	157.55	0.14	2.07	10.44	0.54	--
	Approach	75% rpm	25.33	4.40	30.61	2.98	0.54	15.34
	Idle	Idle	20.08	16.93	55.70	2.37	0.54	19.12
J79-GE-10[4] GE	Takeoff	Afterburner	589.83	0.49	17.29	6.82	0.54	8.475
	Climbout	Military	163.83	1.63	5.29	15.44	0.54	7.905
	Approach	85%	103.17	0.66	7.37	11.29	0.54	10.825
	Idle	Idle	18.33	8.91	43.64	2.91	0.54	52.559
J79-GE-10B GE	Takeoff	Afterburner	571.92	1.05	13.25	4.72	0.54	--
	Climbout	Military	166.67	1.42	1.63	10.35	0.54	--
	Approach	85% rpm	60.67	2.69	13.63	4.60	0.54	--
	Idle	Idle	20.83	45.47	111.41	1.33	0.54	--
J79-GE-10B[7] GE	Takeoff	Afterburner	583.33	0.52	14.56	4.51	0.54	4.43
	Climbout	75% Thrust	126.30	1.60	2.74	8.26	0.54	--
	Approach	30% Thrust	57.03	2.94	20.04	4.23	0.54	9.50
	Idle	Idle	20.83	39.19	111.41	1.33	0.54	15.73
J85-GE-2 GE	Takeoff	Military	48.17	0.45	21.56	6.40	0.54	--
	Climbout	Military	48.17	0.45	21.56	6.40	0.54	--
	Approach	75% Thrust	35.92	0.64	28.38	5.67	0.54	--
	Idle	Idle	9.33	11.86	111.86	3.68	0.54	--
J85-GE-2[7] GE	Takeoff	Military	48.17	0.45	21.56	6.40	0.54	--
	Climbout	75%	35.92	0.64	28.36	5.67	0.54	--
	Approach	30%	17.42	2.40	65.53	4.02	0.54	--
	Idle	Gr idle	9.33	11.86	111.86	3.68	0.54	--
J85-GE-21[4] GE	Takeoff	Afterburner	177.50	0.10	36.40	5.60	0.54	--
	Climbout	Military	53.33	0.25	21.56	5.00	0.54	--
	Approach	85%	20.00	2.58	46.25	2.92	0.54	--
	Idle	Idle	6.67	24.25	159.00	1.25	0.54	--
T58-GE-5[4] GE	Climbout	70%	14.77	0.79	5.64	7.22	0.54	0.90[5]
	Approach	50%	14.77	0.79	5.64	7.22	0.54	0.90[5]
	Idle	Idle	2.22	96.99	169.17	1.50	0.54	0.75[5]
T58-GE-8F GE	Climbout	Max.cont.	11.42	0.85	12.96	4.90	0.54	-
	Approach	Approach	9.68	1.30	17.23	4.47	0.54	-
	Idle	Idle	2.20	151.34	178.44	1.43	0.54	-
T58-GE-8F[7] GE	Takeoff	Takeoff	13.10	0.40	9.03	5.47	0.54	--
	Climbout	Approach	9.68	1.12	17.23	4.47	0.54	-
	Approach	Cruise	10.45	0.80	14.13	4.68	0.54	-
	Idle	Idle	2.20	130.42	178.44	1.43	0.54	-
T58-GE-16[7] GE	Takeoff	Military	17.00	1.32	7.73	11.60	0.54	--
	Climbout	5% Normal	12.98	0.63	10.89	9.47	0.54	--
	Approach	60% Normal	10.93	0.38	14.56	7.88	0.54	-
	Idle	Gr idle	2.50	40.91	139.73	3.03	0.54	-

TABLE 5-7:
Modal Emission Rates — Military Aircraft Engines[1] — Continued

Model - Series Manufacturer[2] Rated Dry Output (1000 lbs Thrust)	Mode	Power Setting	Fuel Flow (lb/min)	HC	Emission Rates — lbs per 1000 lbs — CO	NOx	SO_2[3]	Partic-ulate
T64-GE-6B[7] GE	Takeoff	Max.cont.	23.80	0.55	1.50	10.11	0.54	--
	Climbout	Military	22.83	0.51	1.87	9.80	0.54	--
	Approach	75% hp	17.72	0.41	4.27	7.80	0.54	--
	Idle	Idle	5.35	13.24	57.27	2.75	0.54	--
T64-GE-413[7] GE	Takeoff	Maximum	28.68	0.27	0.49	11.42	0.54	--
	Climbout	Intermediate	27.68	0.34	0.67	10.92	0.54	--
	Approach	75% hp	21.45	0.35	1.94	8.54	0.54	--
	Idle	Idle	4.33	17.28	51.83	2.62	0.54	--
T64-GE-415[7] GE	Takeoff	Max.rated	33.42	0.19	1.47	10.83	0.54	--
	Climbout	Military	31.93	0.28	1.29	9.99	0.54	--
	Approach	75%	24.88	0.13	2.10	8.09	0.54	--
	Idle	Idle	4.48	24.35	74.33	2.12	0.54	--
T64-GE-415 GE	Climbout	Military	31.93	0.33	1.29	9.99	0.54	--
	Approach	75% hp	24.88	0.16	2.10	8.09	0.54	--
	Idle	Idle	4.48	28.25	74.33	2.12	0.54	--
TF34-GE-400[7] GE	Takeoff	Military	63.33	0.39	5.95	7.51	0.54	2.11[10]
	Climbout	75% rpm	7.67	2.63	33.57	3.42	0.54	6.85[10]
	Idle	Idle	8.08	14.99	90.98	1.69	0.54	3.26[10]
TF34-GE-400 GE	Takeoff	Military	63.33	0.39	5.95	7.51	0.54	--
	Climbout	Military	63.33	0.39	5.95	7.51	0.54	--
	Approach	Military	63.33	0.39	5.95	7.51	0.54	--
	Idle	Idle	8.08	17.40	90.98	1.69	0.54	--
T76-G-12A[7] Grt	Climbout	Military	6.37	0.05	1.69	7.18	0.54	--
	Approach	High idle	3.53	6.13	24.59	4.50	0.54	--
	Idle	Gr.start	3.00	10.21	28.29	4.30	0.54	--
T76-G-12A Grt	Takeoff	Military	6.37	0.06	1.69	7.18	0.54	--
	Climbout	Military	6.37	0.06	1.69	7.18	0.54	--
	Approach	High idle	3.53	7.12	24.59	4.50	0.54	--
	Idle	High idle	3.53	7.12	24.29	4.50	0.54	--
	Idle	Gr.start	3.00	11.85	28.59	4.30	0.54	--
TFE 731-2[8] Grt 3.51	Takeoff	100%	27.12	0.11	1.39	15.25	0.54	--
	Climbout	85%	22.88	0.13	2.03	13.08	0.54	--
	Approach	30%	8.86	4.26	22.38	5.90	0.54	--
	Idle	7%	3.17	20.04	58.60	2.92	0.54	--
T53-L-11D[7] Lyc	Takeoff	Takeoff	11.50	0.27	3.85	7.75	0.54	--
	Climbout	Military	11.42	0.26	3.34	6.34	0.54	--
	Approach	Nor.rated	10.75	0.57	6.83	6.43	0.54	--
	Idle	Fl.Idle	3.70	13.57	37.79	2.53	0.54	--
	Idle	Gr.Idle	2.42	58.09	31.51	1.58	0.54	--
T53-L-11D Lyc	Takeoff	Takeoff	11.50	0.32	3.85	7.75	0.54	--
	Climbout	Military	11.42	0.30	3.34	6.34	0.54	--
	Approach	Nor.rated	10.75	0.66	6.83	6.43	0.54	--
	Idle	Fl.Idle	3.70	15.75	37.79	2.53	0.54	--
	Idle	Gr.Idle	2.42	67.41	31.51	1.58	0.54	--

Table 5-7:
Modal Emission Rates
— Military Aircraft Engines[1] —
Continued

Model - Series Manufacturer[2] Rated Dry Output (1000 lbs Thrust)	Mode	Power Setting	Fuel Flow (lb/min)	HC	Emission Rates CO	NO_x	SO_2[3]	Particulate
				— lbs per 1000 lbs —				
F100-PW-100[4]	Takeoff	Military	736.67	0.10	55.10	16.50	0.54	0.00[11]
P&W	Climbout	95%	173.33	0.05	1.80	44.00	0.54	0.83[11]
	Approach	30%	50.00	0.60	3.00	11.00	0.54	0.33[11]
	Idle	Idle	17.67	2.26	19.34	3.96	0.54	0.09[11]
F101DFE	Takeoff	Military	167.88	0.10	0.90	19.69	0.54	--
P&W	Climbout	Military	167.88	0.10	0.90	19.69	0.54	--
	Approach	75% Thrust	109.77	0.20	0.90	12.04	0.54	--
	Idle	Idle	14.45	4.10	44.2	2.58	0.54	--
J52-P-6B[7]	Takeoff	Military	105.47	0.33	3.01	9.00	0.54	7.75
P&W	Climbout	75% Thrust	66.28	0.65	6.00	5.84	0.54	13.13
	Approach	3000lbsThrust	38.35	0.82	16.57	3.91	0.54	--
	Idle	Idle	11.90	23.88	86.37	2.07	0.54	19.94
J52-P-8B[7]	Takeoff	Military	122.83	0.93	0.71	13.05	0.54	--
P&W	Climbout	75% Thrust	72.00	0.58	3.00	10.10	0.54	--
	Approach	3000lbsThrust	38.33	1.72	10.54	6.34	0.54	--
	Idle	Idle	11.33	42.20	63.78	1.79	0.54	--
J52-P-8B	Takeoff	Military	122.83	1.08	0.71	13.05	0.54	--
P&W	Climbout	Nor.rated	102.17	0.69	0.87	12.13	0.54	--
	Approach	75% Thrust	72.00	0.67	3.00	10.10	0.54	--
	Idle	Idle	11.33	48.96	63.78	1.79	0.54	--
J52-P-408[7]	Takeoff	Military	157.98	0.57	1.47	12.32	0.54	--
P&W	Climbout	Intermed 2	95.87	0.67	3.18	8.38	0.54	--
	Approach	Intermed 1	42.45	1.40	11.12	6.17	0.54	--
	Idle	Idle	12.98	28.33	55.96	2.38	0.54	--
J57-P-10	Takeoff	Military	139.50	1.00	1.16	10.37	0.54	--
P&W	Climbout	Military	139.50	1.00	1.16	10.37	0.54	--
	Approach	75% Thrust	94.50	0.88	3.21	7.40	0.54	--
	Idle	Idle	18.33	112.10	80.52	1.87	0.54	--
J57-P-10[7]	Takeoff	Military	139.50	0.86	1.16	10.37	0.54	--
P&W	Climbout	Nor.rated	120.83	1.00	1.79	9.00	0.54	--
	Approach	75% Thrust	94.50	0.76	3.21	7.40	0.54	--
	Idle	Idle	18.33	96.60	80.52	1.87	0.54	--
J57-P-420[7]	Takeoff	Afterburner	662.02	2.54	14.20	5.16	0.54	--
P&W	Climbout	75% Thrust	96.12	1.09	4.32	6.99	0.54	--
	Approach	30% Thrust	56.88	4.54	14.83	4.45	0.54	--
	Idle	Idle	22.03	76.46	80.74	1.53	0.54	--
JT8D-9/9A[8]	Takeoff	100%	137.57	0.47	1.24	17.92	0.54	--
P&W	Climbout	85%	111.91	0.47	1.66	14.21	0.54	--
14.5	Approach	30%	39.42	1.73	9.43	5.64	0.54	--
	Idle	7%	17.46	10.00	34.50	2.90	0.54	--
JT9D-7R4G2[8]	Takeoff	100%	321.30	0.15	0.74	41.30	0.54	--
P&W	Climbout	85%	248.68	0.14	0.63	32.10	0.54	--
53.84	Approach	30%	87.17	0.18	1.40	8.80	0.54	--
	Idle	7%	29.62	1.55	11.82	3.80	0.54	--

TABLE 5-7:
Modal Emission Rates – Military Aircraft Engines[1] — Continued —

Model - Series Manufacturer[2] Rated Dry Output (1000 lbs Thrust)	Mode	Power Setting	Fuel Flow (lb/min)	HC	Emission Rates CO	NOx	SO2[3]	Particulate
				— lbs per 1000 lbs —				
TF30-P-6C[7] P&W	Takeoff	Military	111.67	0.91	1.56	13.29	0.54	--
	Climbout	75% Thrust	59.33	0.54	4.75	7.38	0.54	--
	Approach	30% Thrust	33.83	1.84	14.87	4.77	0.54	--
	Idle	Idle	11.17	12.92	70.58	2.03	0.54	--
TF30-P-412A P&W	Takeoff	Afterburner	796.67	0.20	10.79	4.79	0.54	--
	Climbout	Military	117.50	0.77	1.38	19.60	0.54	2.98[12]
	Approach	75% Thrust	71.67	1.48	3.43	10.74	0.54	7.99[12]
	Idle	Idle	15.33	36.45	55.60	3.22	0.54	8.96[12]
TF33-P-3/5/7[4] P&W	Takeoff	Afterburner	166.32	0.30	1.30	11.00	0.54	8.00[5]
	Climbout	Military	122.05	0.40	1.80	9.00	0.54	14.00[5]
	Approach	85%	63.28	3.79	9.01	7.30	0.54	13.98[5]
	Idle	Idle	14.10	91.96	98.53	1.77	0.54	5.20[5]
Dart RDa7[4] RR	Takeoff	Military	23.48	6.21	3.40	6.04	0.54	--
	Climbout	95%	0.80	1.72	3.41	4.45	0.54	--
	Approach	30%	10.75	0.00	33.30	0.88	0.54	--
	Idle	Idle	6.85	62.09	91.51	0.71	0.54	--
F402 RR	Takeoff	100%	178.53	0.41	2.70	14.80	0.54	--
	Climbout	100%	178.53	0.41	2.70	14.80	0.54	--
	Approach	85%	103.10	0.73	8.20	8.00	0.54	--
	Idle	Idle	18.95	18.80	106.30	1.70	0.54	--
F402[7] RR	Takeoff	100%	178.53	0.40	2.70	14.80	0.54	--
	Climbout	85%	103.10	0.70	8.20	8.00	0.54	--
	Idle	Idle	18.95	18.80	106.30	1.70	0.54	--
J65-W-5F[7] W	Takeoff	Military	115.77	0.61	5.31	5.23	0.54	--
	Climbout	8000 rpm	99.50	0.72	7.39	5.71	0.54	--
	Approach	7450 rpm	72.83	0.95	12.61	7.30	0.54	--
	Idle	Idle	22.00	9.78	47.16	2.46	0.54	--
R-1820 W	Takeoff	IRP	19.43	94.68	531.73	1.72	0.54	--
	Climbout	IRP	14.37	48.49	435.03	2.09	0.54	--
	Approach	75% M/C	5.38	5.57	384.83	6.50	0.54	--
	Idle	Idle	1.48	150.56	474.16	0.00	0.54	--

1 Source: Example of an Air Base Emissions Inventory for the County of San Diego (1987) (Reference 15) unless otherwise noted.

2 MANUFACTURERS. All. - Allison, Con - Teledyne/Continental, CP - United Aircraft of Canada, GE - General Electric, Grt - Garrett AiResearch, Lyc - Avco/Lycoming, P&W - Pratt & Whitney, RR - Rolls-Royce, W - Curtis Wright

3 SO_2 emissions based on national average sulfur content of aviation fuels from Aviation Turbine Fuels, 1989 (Reference 23).

4 Source of data is AP-42 (Reference 1). Nitrogen oxides reported as NO_2. HC refers to total hydrocarbons (Volatile organics, including unburned hydrocarbons and organic pyrolysis products).

5 Includes all "condensable particulates", and thus may be much higher than solid particulates alone (Reference 1).

6 Source of data is FAA Aircraft Engine Emission Database (Reference 14).

7 Source of data is Summary Tables of Gaseous and Particulate Emissions from Aircraft Engines (Reference 18).

8 Source of data is ICAO Engine Exhaust Emissions Databank (Reference 13).

9 Includes all "condensable particulates," and thus may be much higher than solid particulates alone. Data are interpolated values assumed for calculational purposes, in the absence of experimental data (Reference 1).

10 Particulate data refers to TF34-GE-400A engine.

11 Particulates refer to dry particulates only (Reference 1).

12 Source of Particulate data is Table 4. Particulate Mass Emissions From the TF-30-P-414 Engine. Summary Tables of Gaseous and Particulate Emissions from Aircraft Engines. (Reference 18).

same as that used for both commercial and general aviation. The calculations for each subsequent step follow.

Adjust Approach and Climbout TIM to Represent Local Conditions

$$TIM_{app\text{-}M} = 4 * (H/3000) \qquad (5\text{-}9)$$

$$TIM_{clm\text{-}M} = 1.4 * [(H-500)/2500] \qquad (5\text{-}10)$$

$TIM_{app\text{-}M}$ - time in the approach mode for military aircraft, in minutes

$TIM_{clm\text{-}M}$ - time in the climbout mode for military aircraft, in minutes (assumes transition from takeoff to climbout occurs at 500 feet)

H - mixing height used in air quality modeling for time and region of interest

Calculate Emissions for Each Aircraft Type

$$E_{ij} = \Sigma\,(TIM_{jk}) * (FF_{jk}/1000) * (EI_{ijk}) * (NE_j) \qquad (5\text{-}11)$$

E_{ij} - total emissions of pollutant i, in pounds, produced by aircraft type j for one LTO cycle

TIM_{jk} - time in mode for mode k, in minutes, for aircraft type j

FF_{jk} - fuel flow for mode k, in pounds per minute, for each engine used on aircraft type j (from Table 5-7)

EI_{ijk} - emission index for pollutant i, in pounds of pollutant per one thousand pounds of fuel, in mode k for aircraft type j (from Table 5-7)

NE_j - number of engines used on aircraft type j (from Table 5-6)

Calculate Total Emissions for All Military Aircraft

$$E_{Ti(M)} = \Sigma\,(E_{ij}) * (LTO_j) \qquad (5\text{-}12)$$

$E_{Ti(M)}$ - total emissions of pollutant i, in pounds, produced by all military aircraft operating in the region of interest (where j covers the range of military aircraft operating in the area)

LTO_j - total number of LTO cycles for aircraft type j, during the inventory period

After completing the emissions inventory for military aircraft, the overall inventory is complete, made up of emissions from commercial, general aviation, and military aircraft. The final three sections of the report address changes to the inventory due to alternative operating practices, addition of minor emission sources, and changes to the aircraft fleet in the future.

5.3 Variations To The Inventory Calculation Procedure

There are several variations to the basic inventory procedure that can adjust the period covered by the inventory or address some operational procedures followed by some pilots or airlines that affect aircraft emissions. These adjustments to the inventory are discussed in this section.

5.3.1 Variability of Activity - Daily and Seasonal

The calculation procedure described in the methodology does not address daily or seasonal variations. If the air quality modeling period requires emissions data that accounts for these variations, certain adjustments must be made to the equations. The daily or seasonal variations will be exhibited in LTOs, mixing height, and idle time, primarily idle-out.

The references for determining LTOs in Section 5.2 give data on an annual basis and adjustment may be necessary to capture changes over time. The frequency of LTOs at most civil airports are reasonably uniform during daylight hours with lower activity during the night and uniform during week days with lower activity on the weekends, although some airports that cater to recreational flying may show higher activity on weekend days. For most large urban airports, LTOs are uniform on a monthly basis with a slight increase in activity during the summer, which typically is a time of high travel, although some regions may attract more travelers during the winter as a result of their climate. The seasonal variation in activity at smaller urban airports or airports that serve smaller cities may be more pronounced because of factors that affect travel on a local basis such as tourism or seasonal business activity. Obtaining specific information on daily and seasonal variation is difficult. The best source likely will be the airport operators, many of who keep some type of records of activity such as total number of LTOs, number of visitors/passengers, number of cars using the parking lots, or some similar measure that may be representative of the daily or seasonal variation in use of the airport. Another source of information on the daily and weekly variation of LTOs is published flight schedules. These schedules can be reviewed to evaluate the number of scheduled flights during daylight hours versus night-time hours or week day versus weekend. It would be difficult to use this source to evaluate seasonal variations.

Mixing height changes throughout the day and from season to season depending on meteorological conditions such as wind, cloud cover, temperature, and humidity. The adjustments to the time in approach and climbout mode should be based on a weighted average of the mixing heights for the time periods of interest, using variations in LTOs as the weighing factors. See Section 5.2.2 for more information about determining the mixing height.

Taxi/idle time may vary in proportion to variations in LTOs because they are partially a function of airport congestion such that the greater number of LTOs the more likely that airport congestion will increase the time for aircraft to taxi to the runway. The airlines' scheduling departments are the best sources of taxi/idle-time data and their projections typically show daily variations estimated for a particular season. Airport operators also may have information on taxi/idle time variation during a day or from one season to another. Availability of this data will be highly variable.

5.3.2 Operational Activity that Affects Aircraft Emissions

There are variations to standard operating procedures which pilots follow that will affect the aircraft's emissions. Two examples, which may be found in commercial operations, are single-engine taxiing and derated takeoff. Both of these procedures have the potential to save fuel as well as reduce emissions. Where detailed air quality modeling is being performed, these refinements may merit consideration. However, in most cases these procedures are performed at the discretion of the pilots and their use may not be consistent or predictable.

5.3.2.1 **Reduced Engine Taxiing** - Single-engine taxiing or reduced-engine taxiing is, as the name implies, taxiing with one or more engines shutdown. This is usually practiced during taxi-out. An aircraft can taxi using a single engine at idle without significantly increasing the emissions of that engine since adequate power for taxi generally is available at idle power setting. The emissions reductions are equal to the calculated emissions of the engines that are shutdown. The change to the calculation procedure to account for single-engine taxiing is shown in Equation 5-13.

$$E_{ij} = \Sigma\,(TIM_{jk}) * (FF_{jk}/1000) * (EI_{ijk}) * (NE_{jk}) \qquad (5\text{-}13)$$

E_{ij} - total emissions of pollutant i, in pounds, produced by aircraft type j

TIM_{jk} - time in mode for mode k, in minutes, for aircraft type j

FF_{jk} - fuel flow for mode k, in pounds per minute, for each engine used on aircraft type j (from Table 5-4)

EI_{ijk} - emission index for pollutant i, in pounds of pollutant per one thousand pounds of fuel, in mode k for aircraft type j (from Table 5-4)

NE_{jk} - number of engines used on aircraft type j, for mode k (from Table 5-2)

NE for the taxi/idle-out mode would be the number of engines actually used rather than the number on engines shown in Table 5–2.

5.3.2.2 **Derated Take–off** - A derated take–off is a procedure where the pilot sets the throttle for takeoff at less than 100%. The derated throttle setting is determined based on worst-case operating conditions, i.e., performance of the aircraft as though it were at maximum weight on a hot day. In some cases this may allow a takeoff throttle setting of 90% or less. To adjust the emissions calculations to account for this change, engine manufacturers recommend a linear interpolation between the takeoff and climbout fuel flow rates and emission factors. Information on the degree and frequency of derating for takeoff should be collected directly from the airlines.

Other operational factors may affect engine exhaust emissions, such as the use of full throttle, reverse thrust to decelerate the aircraft during landing. These effects may also be significant and are being evaluated by EPA. Any additional information on operational factors will be included in the next update to AP-42.

5.3.3 Particulate Emissions

As mentioned in Section 5.1.1.2, very few measurements have been made of particulate emissions from aircraft engines. However, for most turbine engines, EPA does limit the amount of smoke that may be emitted. This limit is specified as a smoke number. Attempts have been made to derive a correlation between smoke and particulates which could be used to create a particulate emission index based on smoke number. Thus far, these efforts do not match experimental results very closely. If particulates are of concern for the inventory area it may be of help to discuss the issue further with the engine manufacturers or the FAA Office of Environment and Energy.

5.4 Other Emission Sources

When large aircraft are on the ground with their engines shutdown they need power and preconditioned air to maintain the aircraft's operability. If a ground-based power and air source is unavailable, an auxiliary power unit (APU), which is part of the aircraft, is operated. These units are essentially small jet engines which generate electricity and compressed air. They burn jet fuel and generate exhaust emissions like larger engines. In use, APUs essentially run at full throttle. Emission factors for some APUs used by the military are included in Table 5–8 and are representative of, or the same as, those used by commercial airlines. It will be necessary to contact

TABLE 5-8:

Modal Emission Rates – Auxiliary Power Units[1]

Model-Series	Mode	Fuel Flow (lb/min)	Emission Rates (lb/1000 lb) HC	CO	NO_X	SO_2
GTC85-72	No Load	1.75	5.36	37.43	3.28	0.54
	Load	3.50	0.13	14.83	3.88	0.54
GTCP100-54	No Load	3.75	1.61	12.48	6.32	0.54
	Load	6.88	0.16	5.89	5.95	0.54
GTPC95-2	No Load	2.18	2.16	18.75	4.39	0.54
	Load	4.88	0.36	3.20	5.65	0.54
T-62T-27	No Load	0.83	2.96	29.53	5.31	0.54
	Load	1.70	7.79	42.77	3.94	0.54
WR27-1	No Load	2.33	0.60	3.48	2.13	0.54
	Load	2.33	0.21	5.66	4.63	0.54

1 Source: Summary Table of Gaseous and Particulate Emissions from Aircraft Engines (Reference 18).

the airlines directly to find out whether APUs are used regularly at a specific airport and, if so, how long an aircraft is expected to stay at a gate with the APU running.

For general aviation aircraft, there are evaporative emissions that result from refueling and fuel spillage. Emissions also occur from preflight checks of the aircraft and diurnal temperature cycles that cause the fuel tanks to vent. Refueling emissions are addressed in Volume I, Section 5.4.1. EPA is continuing to evaluate the other emission sources and may provide information in the next update to AP-42.

5.5 Effect Of Future Changes To The Fleet

Airlines continually acquire newer aircraft, gradually phasing out older models. While commercial aircraft often remain in service for more than 25 years, over time, this process phases out the aircraft using engines that do not meet EPA's hydrocarbon emission standard. The current world aircraft fleet averages 12.4 years old according to the 1990 World Jet Inventory published by the Boeing Corporation (Reference 24). Significant among the older aircraft are engines that do not meet the EPA standard such as the Spey MK511 and older JT8Ds and CF6-50s. The JT8Ds and CF6-50s are prevalent on B-727s, DC-9s, and DC-10s, many nearly 20 years old. As new aircraft are added to the fleet the older aircraft are the most likely to be retired. The effect is one of replacing older, dirty engines with newer engines on the new aircraft that are much cleaner from an emissions standpoint. Airport noise regulations also are forcing changes to the commercial aircraft fleet. National noise regulations which were recently passed by Congress are forcing airlines to phase out use of loud aircraft by 2000. This can be accomplished by retiring the loud, older aircraft, replacing their engines with newer, quieter ones, or modifying the engines to muffle the noise. The first two alternatives result in aircraft with reduced emissions. Because this legislation is so new, the airlines are yet to formulate specific plans meeting the requirements. However, as the equipment is updated, the changes to the fleet will be reflected in FAA's reports on aircraft activity. Since there is a significant engineering and development leadtime for producing new aircraft engines, most of the commercial aircraft to be added to the fleet in the next five to seven years will be powered by engines that are included in Tables 5-2, 5-3 and 5-4.

Since specific plans to upgrade their fleets have not been announced recently by the airlines, it is difficult to project what future changes will be and how they will effect the inventory of emissions for all locations. Some carriers will update their fleets more quickly than others so there may be changes that can be captured on an area specific basis. If it is desirable to project changes to the inventory for this source category, the predominant airlines for the airports included in the inventory area should be contacted for their specific plans. EPA is continuing to look at better data sources and methods for projecting changes to aircraft fleet emissions.

Another change that will affect future emissions from aircraft is the growth in travel. Air travel has experienced strong growth over the past several years and this growth is expected to continue for the foreseeable future. Many existing airports are near capacity and others will reach their capacity limits in the near future. This will have two effects: air traffic at small feeder airports and regional hubs will grow and the current major hubs will experience additional congestion. The net effect these changes will have on air quality is unclear. Increased congestion at some airports will increase taxi/idle times but the expanded use of smaller airports may relieve congestion at others.

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Appendix B

FAA Advisory Circular 91-41:

Ground Operational Procedures For Aircraft Engine Emission Reduction And Fuel Conservation

AC NO: 91-41

DATE: MARCH 12, 1974

ADVISORY CIRCULAR

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

SUBJECT: GROUND OPERATIONAL PROCEDURES FOR AIRCRAFT ENGINE EMISSION REDUCTION AND FUEL CONSERVATION

1. PURPOSE. This Advisory Circular recommends ground operational procedures that will minimize air pollution from aircraft ground operations and conserve fuel.

2. BACKGROUND. The Clean Air Amendments of 1970 directed the Administrator of the Environmental Protection Agency, after consultation with the Secretary of Transportation, to set aircraft emission standards. The Amendments also require EPA to study aircraft emissions with regard to their effect on health and welfare. As one result of this study, EPA issued an Advance Notice of Proposed Rule Making proposing to limit the number of engines used for taxi to and from the runway. Concurrently, the existing and projected shortfall of aviation fuel required the analysis of fuel conservation measures by FAA. This study also included the possibility of reducing the number of engines required for taxi. Study estimates indicated substantial reductions in carbon monoxide and hydrocarbon emissions are possible as well as a significant fuel savings.

The FAA, EPA, ATA and ALPA investigated the possibility of reducing the number of operating engines on turbojet aircraft for the taxi and ground idle modes. As a consequence of this investigation, an operational evaluation was conducted at Atlanta International Airport. Test results led to the conclusion that operating fewer engines on three- and four-engine turbojet aircraft is in many cases feasible when taxiing from the runway to the terminal after landings or during protracted holds, but should not be a mandatory requirement at any time.

3. RECOMMENDED PROCEDURES. Operators of three- and four-engine turbojet aircraft should develop procedures for reducing emissions and fuel usage and submit them to FAA. The following taxi and ground idle procedures under the conditions and limitations judged appropriate by the aircraft operator and the pilot-in-command are recommended.

FAA Form 1320-7 (12-71) SUPERSEDES PREVIOUS EDITION

Initiated by: AEQ-10

PART 87—CONTROL OF AIR POLLUTION FROM AIRCRAFT AND AIRCRAFT ENGINES

AUTHORITY: Secs. 231, 301(a), Clean Air Act, as amended (42 U.S.C. 7571, 7601(a)).

SOURCE: 47 FR 58470, Dec. 30, 1982, unless otherwise noted.

Subpart A—General Provisions

§ 87.1 Definitions.

(a) As used in this part, all terms not defined herein shall have the meaning given them in the Act:

"Act" means the Clean Air Act, as amended (42 U.S.C. 7401 et seq.).

"Administrator" means the Administrator of the Environmental Protection Agency and any other officer or employee of the Environmental Protection Agency to whom authority involved may be delegated.

"Aircraft" means any airplane for which a U.S. standard airworthiness certificate or equivalent foreign airworthiness certificate is issued.

"Aircraft engine" means a propulsion engine which is installed in or which is manufactured for installation in an aircraft.

"Aircraft gas turbine engine" means a turboprop, turbofan, or turbojet aircraft engine.

"Class TP" means all aircraft turboprop engines.

"Class TF" means all turbofan or turbojet aircraft engines except engines of Class T3, T8, and TSS.

"Class T3" means all aircraft gas turbine engines of the JT3D model family.

"Class T8" means all aircraft gas turbine engines of the JT8D model family.

"Class TSS" means all aircraft gas turbine engines employed for propulsion of aircraft designed to operate at supersonic flight speeds.

"Commercial aircraft engine" means any aircraft engine used or intended for use by an "air carrier," (including those engaged in "intrastate air transportation") or a "commercial operator" (including those engaged in "intrastate air transportation") as these terms are defined in the Federal Aviation Act and the Federal Aviation Regulations.

"Commercial aircraft gas turbine engine" means a turboprop, turbofan, or turbojet commercial aircraft engine.

"Emission measurement system" means all of the equipment necessary to transport and measure the level of emissions. This includes the sample system and the instrumentation system.

"Engine Model" means all commercial aircraft turbine engines which are of the same general series, displacement, and design characteristics and are usually approved under the same type certificate.

"Exhaust emissions" means substances emitted to the atmosphere from the exhaust discharge nozzle of an aircraft or aircraft engine.

"Fuel venting emissions" means raw fuel, exclusive of hydrocarbons in the exhaust emissions, discharged from aircraft gas turbine engines during all normal ground and flight operations.

"In-use aircraft gas turbine engine" means an aircraft gas turbine engine which is in service.

"New aircraft turbine engine" means an aircraft gas turbine engine which has never been in service.

"Power setting" means the power or thrust output of an engine in terms of kilonewtons thrust for turbojet and turbofan engines and shaft power in terms of kilowatts for turboprop engines.

"Rated output (rO)" means the maximum power/thrust available for takeoff at standard day conditions as approved for the engine by the Federal Aviation Administration, including reheat contribution where applicable, but excluding any contribution due to water injection.

"Rated pressure ratio (rPR)" means the ratio between the combustor inlet pressure and the engine inlet pressure achieved by an engine operating at rated output.

"Sample system" means the system which provides for the transportation of the gaseous emission sample from the sample probe to the inlet of the instrumentation system.

"Secretary" means the Secretary of Transportation and any other officer or employee of the Department of Transportation to whom the authority involved may be delegated.

"Shaft power" means only the measured shaft power output of a turboprop engine.

"Smoke" means the matter in exhaust emissions which obscures the transmission of light.

"Smoke number (SN)" means the dimensionless term quantifying smoke emissions.

"Standard day conditions" means standard ambient conditions as described in the United States Standard Atmosphere, 1976, (i.e., Temperature =15°C, specific humidity =0.00 kg/H_2O/kg dry air, and pressure =101325 Pa.)

"Taxi/idle (in)" means those aircraft operations involving taxi and idle between the time of landing roll-out and final shutdown of all propulsion engines.

"Taxi/idle (out)" means those aircraft operations involving taxi and idle between the time of initial starting of the propulsion engine(s) used for the taxi and turn on to duty runway.

[47 FR 58470, Dec. 30, 1982, as amended at 49 FR 31875, Aug. 9, 1984]

§ 87.2 Abbreviations.

The abbreviations used in this part have the following meanings in both upper and lower case:

FAA Federal Aviation Administration, Department of Transportation.
HC Hydrocarbon(s).
hr. Hour(s).
LTO Landing takeoff
min. Minute(s).
rO Rated output.
rPR Rated pressure ratio.
sec. Seconds.
SP Shaft power.
SN Smoke number.
T Temperature, degrees Kelvin.
TIM Time in mode.
W Watt(s).
° Degree.
% Percent.

[47 FR 58470, Dec. 30, 1982, as amended at 49 FR 31875, Aug. 9, 1984]

§ 87.3 General requirements.

(a) This part provides for the approval or acceptance by the Administrator or the Secretary of testing and sampling methods, analytical, techniques, and related equipment not identical to those specified in this part. Before either approves or accepts any such alternate, equivalent, or otherwise nonidentical procedures or equipment, the Administrator or the Secretary shall consult with the other in determining whether or not the action requires rulemaking under sections 231 and 232 of the Clean Air Act, as amended, consistent with the Administrator's and the Secretary's responsibilities under sections 231 and 232 of the Act. (42 U.S.C. 7571, 7572).

(b) Under section 232 of the Act, the Secretary issues regulations to insure compliance with this part.

(c) With respect to aircraft of foreign registry, these regulations shall apply in a manner consistent with any obligation assumed by the United States in any treaty, convention or agreement between the United States and any foreign country or foreign countries.

§ 87.4 [Reserved]

§ 87.5 Special test procedures.

The Administrator or the Secretary may, upon written application by a manufacturer or operator of aircraft or aircraft engines, approve test procedures for any aircraft or aircraft engine that is not susceptible to satisfactory testing by the procedures set forth herein. Prior to taking action on any such application, the Administrator or the Secretary shall consult with the other.

§ 87.6 Aircraft safety.

The provisions of this part will be revised if at any time the Secretary determines that an emission standard cannot be met within the specified time without creating a safety hazard.

§ 87.7 Exemptions.

(a) *Exemptions based on flights for short durations at infrequent intervals.* The emission standards of this part do not apply to engines which power aircraft operated in the United States for short durations at infrequent intervals. Such operations are limited to:

(1) Flights of an aircraft for the purpose of export to a foreign country, including any flights essential to demonstrate the integrity of an aircraft prior to its flight to a point outside the United States.

(2) Flights to a base where repairs, alterations or maintenance are to be performed, or to a point of storage, and flights for the purpose of returning an aircraft to service.

(3) Official visits by representatives of foreign governments.

(4) Other flights the Secretary determines, after consultation with the Administrator, to be for short durations at infrequent intervals. A request for such a determination shall be made before the flight takes place.

(b) *Exemptions for very low production models.* The emissions standards of this part do not apply to engines of very low total production after the date of applicability. For the purpose of this part, "very low production" is limited to a maximum total production for United States civil aviation applications of no more than 200 units covered by the same type certificate after January 1, 1984.

(1) A maximum annual production rate after January 1, 1984 of 20 units covered by the same type certificate; and

(2) A maximum total production after January 1, 1984 of 200 units covered by the same type certificate.

(c) *Exemptions for New Engines in Other Categories.* The emissions standards of this part do not apply to engines for which the Secretary determines, with the concurrence of the Administrator, that application of any standard under § 87.21 is not justified, based upon consideration of:

(1) Adverse economic impact on the manufacturer.

(2) Adverse economic impact on the aircraft and airline industries at large.

(3) Equity in administering the standards among all economically competing parties.

(4) Public health and welfare effects.

(5) Other factors which the Secretary, after consultation with the Administrator, may deem relevant to the case in question.

(d) *Time Limited Exemptions for In Use Engines.* The emissions standards of this part do not apply to aircraft or aircraft engines for time periods which the Secretary determines, with the concurrence of the Administrator, that any applicable standard under § 87.11(a), § 87.31(a), or § 87.31(c), should not be applied based upon consideration of the following:

(1) Documentation demonstrating that all good faith efforts to achieve compliance with such standard have been made.

(2) Documentation demonstrating that the inability to comply with such standard is due to circumstances beyond the control of the owner or operator of the aircraft.

(3) A plan in which the owner or operator of the aircraft shows that he will achieve compliance in the shortest time which is feasible.

(4) Applications for a determination that any requirements of § 87.11(a), § 87.31(a) or § 87.31(c) do not apply shall be submitted in duplicate to the Secretary in accordance with procedures established by the Secretary.

(e) The Secretary shall publish in the FEDERAL REGISTER the name of the organization to whom exemptions are granted and the period of such exemptions.

(f) No state or political subdivision thereof may attempt to enforce a standard respecting emissions from an aircraft or engine if such aircraft or engine has been exempted from such standard under this part.

[47 FR 58470, Dec. 30, 1982, as amended at 49 FR 31875, Aug. 9, 1984; 49 FR 41002, Oct. 18, 1984]

Subpart B—Engine Fuel Venting Emissions (New and In-Use Aircraft Gas Turbine Engines)

§ 87.10 Applicability.

(a) The provisions of this subpart are applicable to all new aircraft gas turbines of classes T3, T8, TSS and TF equal to or greater than 36 kilonewton rated output, manufactured on or after January 1, 1974, and to all in-use aircraft gas turbine engines of classes T3, T8, TSS and TF equal to or greater than 36 kilonewton rated output manufactured after February 1, 1974.

(b) The provisions of this subpart are also applicable to all new aircraft gas turbines of class TF less than 36 kilonewton rated output and class TP manufactured on or after January 1, 1975 and to all in-use aircraft gas turbines of class TF less than 36 kilonewton rated output and class TP manufactured after January 1, 1975.

[49 FR 41002, Oct. 18, 1984]

§ 87.11 Standard for fuel venting emissions.

(a) No fuel venting emissions shall be discharged into the atmosphere from any new or in-use aircraft gas turbine engine subject to the subpart. This paragraph is directed at the elimination of intentional discharge to the atmosphere of fuel drained from fuel nozzle manifolds after engines are shut down and does not apply to normal fuel seepage from shaft seals, joints, and fittings.

(b) Conformity with the standard set forth in paragraph (a) of this section shall be determined by inspection of the method designed to eliminate these emissions.

Subpart C—Exhaust Emissions (New Aircraft Gas Turbine Engines)

§ 87.20 Applicability.

The provisions of this subpart are applicable to all aircraft gas turbine engines of the classes specified beginning on the dates specified.

§ 87.21 Standards for exhaust emissions.

(a) Exhaust emissions of smoke from each new aircraft gas turbine engine of class T8 manufactured on or after February 1, 1974, shall not exceed: Smoke number of 30.

(b) Exhaust emissions of smoke from each new aircraft gas turbine engine of class TF and of rated output of 129 kilonewtons thrust or greater, manufactured on or after January 1, 1976, shall not exceed:

$SN = 83.6(r0)^{-0.274}$ (r0 is in kilonewtons).

(c) Exhaust emission of smoke from each new aircraft gas turbine engine of class T3 manufactured on or after January 1, 1978, shall not exceed: Smoke number of 25.

(d) Gaseous exhaust emissions from each new commercial aircraft gas turbine engine that is manufactured on or after January 1, 1984, shall not exceed:

(1) Classes TF, T3, T8 engines equal to or greater than 26.7 kilonewtons rated output:

Hydrocarbons: 19.8 grams/kilonewton r0.

(2) Class TSS:

Hydrocarbons $= 140(0.92)^{rPR}$ grams/kilonewton r0.

(e) Smoke exhaust emissions from each gas turbine engine of the classes specified below shall not exceed:

(1) Class TF of rated output less than 26.7 kilonewtons manufactured on or after (one year from date of publication):

$SN = 83.6(ro)^{-0.274}$ (ro is in kilonewtons) not to exceed a maximum of SN = 50.

(2) Classes T3, T8, TSS and TF of rated output equal to or greater than 26.7 kilonewtons manufactured on or after January 1, 1984:

$SN = 83.6(ro)^{-0.274}$ (ro is in kilonewtons) not to exceed a maximum of SN = 50.

(3) Class TP of rated output equal to or greater than 1,000 kilowatts manufactured on or after January 1, 1984:

$SN = 187(ro)^{-0.168}$ (ro is in kilowatts)

(f) The standards set forth in paragraphs (a), (b), (c), (d), and (e) of this section refer to a composite gaseous emission sample representing the operating cycles set forth in the applicable sections of Subpart G of this part, and exhaust smoke emissions emitted during operations of the engine as specified in the applicable sections of Subpart H of this part, measured and calculated in accordance with the procedures set forth in those subparts.

[47 FR 58470, Dec. 30, 1982, as amended at 49 FR 31875, Aug. 9, 1984]

Subpart D—Exhaust Emissions (In-use Aircraft Gas Turbine Engines)

§ 87.30 Applicability.

The provisions of this subpart are applicable to all in-use aircraft gas turbine engines certified for operation within the United States of the classes specified beginning on the dates specified.

§ 87.31 Standards for exhaust emissions.

(a) Exhaust emissions of smoke from each in-use aircraft gas turbine engine of Class T8, beginning February 1, 1974, shall not exceed: Smoke number of 30.

(b) Exhaust emissions of smoke from each in-use aircraft gas turbine engine of class TF and of rated output of 129 kilonewtons thrust or greater, beginning January 1, 1976, shall not exceed:

$SN = 83.6(r0)^{-0.274}$ (r0 is in kilonewtons).

(c) The standards set forth in paragraphs (a) and (b) of this section refer to exhaust smoke emissions emitted during operations of the engine as specified in the applicable section of Subpart H of this part, and measured and calculated in accordance with the procedures set forth in this subpart.

[47 FR 58470, Dec. 30, 1982, as amended at 48 FR 2718, Jan. 20, 1983]

Subparts E-F—[Reserved]

Subpart G—Test Procedures for Engine Exhaust Gaseous Emissions (Aircraft and Aircraft Gas Turbine Engines)

§ 87.60 Introduction.

(a) Except as provided under § 87.5, the procedures described in this subpart shall be the test program to determine the conformity of new aircraft gas turbine engines with the applicable standards set forth in this part.

(b) The test consists of operating the engine at prescribed power settings on an engine dynamometer (for engines producing primarily shaft power) or thrust measuring test stand (for engines producing primarily thrust). The exhaust gases generated during engine operation are sampled continuously for specific component analysis through the analytical train.

(c) The exhaust emission test is designed to measure hydrocarbons, carbon monoxide and carbon dioxide concentrations, and to determine mass emissions through calculations during a simulated aircraft landing-takeoff cycle (LTO). The LTO cycle is based on time in mode data during high activity periods at major airports. The test for propulsion engines consists of a least the following four modes of engine operation: Taxi/idle, takeoff, climbout, and approach. The mass emission for the modes are combined to yield the reported values.

(d) When an engine is tested for exhaust emissions on an engine dynamometer or test stand, the complete engine shall be used with all accessories which might reasonably be expected to influence emissions to the atmosphere installed and functioning, if not otherwise prohibited by § 87.62(a)(2). Use of service air bleed and shaft power extraction to power auxiliary gearbox-mounted components required to drive aircraft systems is not permitted.

(e) Other gaseous emissions measurement systems may be used if shown to yield equivalent results and if approved in advance by the Administrator or the Secretary.

[47 FR 58470, Dec. 30, 1982, as amended at 49 FR 31875, Aug. 9, 1984]

§ 87.61 Turbine fuel specifications.

For exhaust emission testing, fuel meeting the specifications listed below shall be used. Additives used for the purpose of smoke suppression (such as organometallic compounds) shall not be present.

Property and Allowable Range of Values

Specific gravity at 15 °C: 0.78–0.82.
Distillation temperature, °C: 10% boiling point, 160–201; final boiling point, 240–285.
Net heat of combustion, kJ/kg: 42,860–43,500.
Aromatics, volume %: 15-20.
Naphthalenes, volume %: 1.0-3.0.
Smoke point, mm: 20–28.
Hydrogen, mass %: 13.4-14.0.
Sulfur, mass %: less than 0.3%.
Kinematic viscosity at −20 °C, mm/s: 4.0–6.5.

[49 FR 41002, Oct. 18, 1984]

§ 87.62 Test procedure (propulsion engines).

(a)(1) The engine shall be tested in each of the following engine operating modes which simulate aircraft operation to determine its mass emission rates. The actual power setting, when corrected to standard day conditions, should correspond to the following percentages of rated output. Analytical correction for variations from reference day conditions and minor variations in actual power setting should be specified and/or approved by the Secretary:

Mode	Class		
	TP	TF, TJ, T8	TSS
Taxi/idle	(1)	(1)	(1)
Takeoff	100	100	100
Climbout	90	85	65
Descent	NA	NA	15
Approach	30	30	34

1 See paragraph (a)(2) of this section.

(2) The taxi/idle operating modes shall be carried out at a power setting of 7% rated thrust unless the Secretary determines that the unique characteristics of an engine model undergoing certification testing at 7% would result in substantially different HC emissions than if the engine model were tested at the manufacturers recommended idle power setting. In such cases the Secretary shall specify an alternative test condition.

(3) The times in mode (TIM) shall be as specified below:

Mode	Class		
	TP	TF, TJ or T8	TSS
Taxi/idle (minutes)	26.0	26.0	26.0
Takeoff	0.5	0.7	1.2
Climbout	2.5	2.2	2.0
Descent	N/A	N/A	1.2
Approach	4.5	4.0	2.3

(b) Emissions testing shall be conducted on warmed-up engines which have achieved a steady operating temperature.

§ 87.63 [Reserved]

§ 87.64 Sampling and analytical procedures for measuring gaseous exhaust emissions.

The system and procedures for sampling and measurement of gaseous emissions shall be as specified by Appendices 3 and 5 to ICAO Annex 16.

Volume II, Aircraft Engine Emissions, First Edition, June 1981, which are incorporated herein by reference. This document can be obtained from the International Civil Aviation Organization, P.O. Box 400, Succursale: Place de L'Aviation Internationale, 1000 Sherbrooke Street West, Montreal, Quebec, Canada H3A 2R2 at $3.00 per copy. It is also available for inspection at the Office of the Federal Register Information Center, Room 8301, 1100 L Street, N.W., Washington, D.C. 20408. This incorporation by reference was approved by the Director of the Federal Register on September 3, 1982. These materials are incorporated as they exist on the date of the approval and a notice of any change in these materials will be published in the FEDERAL REGISTER. Frequent changes are not anticipated.

§§ 87.65—87.70 [Reserved]

§ 87.71 Compliance with gaseous emission standards.

Compliance with each gaseous emission standard by an aircraft engine shall be determined by comparing the pollutant level in grams/kilonewton/thrust/cycle or grams/kilowatt/cycle as calculated in § 87.64 with the applicable emission standard under this part.

Subpart H—Test Procedures for Engine Smoke Emissions (Aircraft Gas Turbine Engines)

§ 87.80 Introduction.

Except as provided under §87.5, the procedures described in this subpart shall be the test program to determine the conformity of new and in-use gas turbine engines with the applicable standards set forth in this part. The test is essentially the same as that described in §§ 87.60 through 87.62, except that the test is designed to determine the smoke emission level at various operating points representative of engine usage in aircraft. Other smoke measurement systems may be used if shown to yield equivalent results and if approved in advance by the Administrator or the Secretary.

§ 87.81 Fuel specifications.

Fuel having specifications as provided in § 87.61 shall be used in smoke emission testing.

§ 87.82 Sampling and analytical procedures for measuring smoke exhaust emissions.

The system and procedures for sampling and measurement of smoke emissions shall be as specified by Appendix 2, Volume II, Aircraft Engine Emissions to ICAO Annex 16, Aircraft Engine Emissions, First Edition, June, 1981. This document can be obtained from the International Civil Aviation Organization, P.O. Box 400, Succursale: Place de L'Aviation Internationale, 1000 Sherbrooke Street West, Montreal, Quebec, Canada H3A 2R2 at $3.00 per copy. It is also available for inspection at the Office of the Federal Register Information Center, Room 8301, 1100 L Street, N.W., Washington, D.C. 20408. This incorporation by reference was approved by the Director of the Federal Register on September 3, 1982. These materials are incorporated as they exist on the date of the approval and a notice of any change in these materials will be published in the FEDERAL REGISTER. Frequent changes are not anticipated.

§§ 87.83—87.88 [Reserved]

§ 87.89 Compliance with smoke emission standards.

Compliance with each smoke emission standard shall be determined by comparing the plot of SN as a function of power setting with the applicable emission standard under this part. The SN at every power setting must be such that there is a high degree of confidence that the standard will not be exceeded by any engine of the model being tested. The level of confidence required, a practical interpretation of the requirement for total compliance, and a testing program to assure compliance will be established by the Secretary prior to January 1, 1984, and shall be approved by the Administrator.

PARTS 88–99—[RESERVED]

Appendix D

High Density Traffic Airports

14CFR 93.121

Subpart K—High Density Traffic Airports

§ 93.121 Applicability.

This subpart designates high density traffic airports and prescribes air traffic rules for operating aircraft, other than helicopters, to or from those airports.

[Amdt. 93-21, 35 FR 16592, Oct. 24, 1970, as amended by Amdt. 93-27, 38 FR 29464, Oct. 25, 1973]

§ 93.123 High density traffic airports.

(a) Each of the following airports is designated as a high density traffic airport and, except as provided in § 93.129 and paragraph (b) of this section, or unless otherwise authorized by ATC, is limited to the hourly number of allocated IFR operations (takeoffs and landings) that may be reserved for the specified classes of users for that airport:

IFR OPERATIONS PER HOUR

AIRPORT

Class of user	LaGuardia [4]	Newark	O'Hare [2 3]	Washington National [1]
Air carriers	48	40	120	37
Commuters	14	10	25	11
Other	6	10	10	12

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	Air carriers	Commuters	Other
1500	69	15	2
1800	74	12	2
1700	80	13	0
1800	75	10	2
1900	63	12	2

[1] Washington National Airport operations are subject to modifications per Section 93.124.

[2] The hour period in effect at O'Hare begins at 6:45 a.m. and continues in 30-minute increments until 9:15 p.m.

[3] Operations at O'Hare International Airport shall not—

(a) Except as provided in paragraph (c) of the note, exceed 62 for air carriers and 13 for commuters and 5 for "other" during any 30-minute period beginning at 6.45 a.m. and continuing every 30 minutes thereafter.

(b) Except as provided in paragraph (c) of the note, exceed more than 120 for air carriers, 25 for commuters, and 10 for "other" in any two consecutive 30-minute periods.

(c) For the hours beginning at 5:45 a.m., 7:45 a.m., 11:45 a.m., 7:45 p.m. and 8:45 p.m., the hourly limitations shall be 105 for air carriers, 40 for commuters and 10 for "other," and the 30-minute limitations shall be 55 for air carriers, 20 for commuters and 5 for "other." For the hour beginning at 3:45 p.m., the hourly limitations shall be 115 for air carriers, 30 for commuters and 10 for "others", and the 30-minute limitations shall be 60 for air carriers, 15 for commuters and 5 for "other."

[4] Operations at LaGuardia Airport shall not—

(a) Exceed 26 for air carriers, 7 for commuters and 3 for "other" during any 30-minute period.

(b) Exceed 48 for air carriers, 14 for commuters, and 6 for "other" in any two consecutive 30-minute periods.

(b) The following exceptions apply to the allocations of reservations prescribed in paragraph (a) Of this section.

(1) The allocations of resevations among the several classes of users do not apply from 12 midnight to 6 a.m. local time, but the totala hourly limitation remains applicable.

(2) [Reserved]

(3) The allocation of 37 IFR reservations per hour for air carriers except commuters at Washington National Airport does not include charter flights, or other nonscheduled flights of scheduled or supplemental air carriers. These flights may be conducted without regard to the limitation of 37 IFR reservations per hour.

(4) The allocation of IFR reservations for air carriers except commuters at LaGuardia, Newark, O'Hare, and Washington National Airports does not include extra sections of scheduled flights. The allocation of IFR reservations for scheduled commuters at Washington National Airport does not include extra sections of scheduled flights. These flights may be conducted without regard to the limitation upon the hourly IFR reservations at those airports.

(5) Any reservation allocated to, but not taken by, air carrier operations (except commuters) is available for a scheduled commuter operation.

(6) Any reservation allocated to, but not taken by, air carrier operations (except commuters) or scheduled commuter operations is available for other operations.

(c) For purposes of this subpart—

(1) The number of operations allocated to "air carriers except commuters," as used in paragraph (a) of this section refers to the number of operations conducted by air carriers with turboprop and reciprocating engine aircraft having a certificated maximum passenger seating capacity of 75 or more or with turbojet powered aircraft having a certificated maximum passenger seating capacity of 56 or more, or, if used for cargo service in air transportation, with any aircraft having a maximum payload capacity of 18,000 pounds or more.

(2) The number of operations allocated to "scheduled commuters," as used in paragraph (a) of this section, refers to the number of operations conducted by air carriers with turboprop and reciprocating engine aircraft having a certificated maximum passenger seating capacity of less than 75 or by turbojet aircraft having a certificated maximum passenger seating capacity of less than 56, or, if used for cargo service in air transportation, with any aircraft having a maximum payload capacity of less than 18,000 pounds.

(3) Notwithstanding the provisions of paragraph (c)(2) of this section, a limited number of operations allocated for "scheduled commuters" under paragraph (a) of this section may be conducted with aircraft described in § 93.221(e) of this part pursuant to the requirements of § 93.221(e).

[Doc. No. 9113, 34 FR 2603, Feb. 26, 1969, as amended by Amdt. 93-37, 45 FR 62408, Sept. 18, 1980; Amdt. 93-44, 46 FR 58048, Nov. 27, 1981; Amdt. 93-46, 49 FR 8244, Mar. 6, 1984; Amdt. 93-57, 54 FR 34906, Aug. 22, 1989; 54 FR 37303, Sept. 8, 1989; Amdt. 93-59, 54 FR 39843, Sept. 28, 1989; Amdt. 93-62, 56 FR 41207, Aug. 19, 1991]

§ 93.125 Arrival or departure reservation.

Except between 12 Midnight and 6 a.m. local time, no person may operate an aircraft to or from an airport designated as a high density traffic airport unless he has received, for that operation, an arrival or departure reservation from ATC.

[Doc. No. 9974, Amdt. 93-25, 37 FR 22794, Oct. 25, 1972]

§ 93.129 Additional operations.

(a) *IFR.* The operator of an aircraft may take off or land the aircraft under IFR at a designated high density traffic airport without regard to the maximum number of operations allocated for that airport if the operation is not a scheduled operation to or from a high density airport and he obtains a departure or arrival reservation, as appropriate, from ATC. The reservation is granted by ATC whenever the aircraft may be accommodated without significant additional delay to the operations allocated for the airport for which the reservations is requested.

(b) *VFR.* The operator of an aircraft may take off and land the aircraft under VFR at a designated high density traffic airport without regard to the maximum number of operations allocated for that airport if the operation is not a scheduled operation to or from a high density airport and he obtains a departure or arrival reservation, as appropriate, from ATC. The reservation is granted by ATC whenever the aircraft may be accommodated without significant additional delay to the operations allocated for the airport for which the reservation is requested and the ceiling reported at the airport is at least 1,000 feet and the ground visibility reported at the airport is at least 3 miles.

(c) For the purpose of this section a "scheduled operation to or from the high density airport" is any operation regularly conducted by an air carrier or commuter between a high density airport and another point regularly served by that operator unless the service is conducted pursuant to irregular charter or hiring of aircraft or is a nonpassenger flight.

(d) An aircraft operator must obtain an IFR reservation in accordance with procedures established by the Administrator. For IFR flights to or from a high density airport, reservations for takeoff and arrival shall be obtained prior to takeoff.

[Doc. No. 9113, 34 FR 2603, Feb. 28, 1969, as amended by Amdt. 93-25, 37 FR 22794, Oct. 25, 1972; Amdt. 93-44, 46 FR 58049, Nov. 27, 1981; Amdt. 93-46, 49 FR 8244, Mar. 6, 1984]

§ 93.130 Suspension of allocations.

The Administrator may suspend the effectiveness of any allocation prescribed in § 93.123 and the reservation requirements prescribed in § 93.125 if he finds such action to be consistent with the efficient use of the airspace. Such suspension may be terminated whenever the Administrator determines that such action is necessary for the efficient use of the airspace.

[Amdt. 93-21, 35 FR 16592, Oct. 24, 1970, as amended by Amdt. 93-21, 35 FR 16636, Oct. 27, 1970; Amdt. 93-27, 38 FR 29464, Oct. 25, 1973]

§ 93.133 Exceptions.

Except as provided in § 93.130, the provisions of §§ 93.123 and 93.125 do not apply to—

(a) The Newark Airport, Newark, NJ;

(b) The Kennedy International Airport, New York, NY, except during the hours from 3:00 p.m. through 7:59 p.m., local time; and

(c) O'Hare International Airport from 9:15 p.m. to 6:44 a.m., local time.

[Doc. No. 24471, Amdt. 93-46, 49 FR 8244, Mar. 6, 1984]

(b) Within the airspace below 3,000 feet MSL within the perimeter defined for the Ketchikan Control Zone, regardless of whether that control zone is in effect.

[Doc. No. 26653, 56 FR 48094, Sept. 23, 1991, as amended by Amdt. 93-63, 56 FR 65662, Dec. 17, 1991]

EFFECTIVE DATE NOTE: By Amdt. 93-63, 56 FR 65662, Dec. 17, 1991, §93.151 was amended by revising the introductory text, effective September 16, 1993. For the convenience of the user, the revised text follows.

§ 93.151 Applicability.

This subpart prescribes special air traffic rules and communications requirements for persons operating aircraft, under VFR, below 2,500 feet MSL within the lateral boundaries of the surface area of the Class E airspace area designated for Ketchikan International Airport, Alaska, excluding that airspace below 600 feet MSL and—

* * * * *

Appendix E

FAA Advisory Circular 150/5240-7

A Fuel/Energy Conservation Guide For Airport Operators

AC NO: 150/5240-7

DATE: February 19, 1974

ADVISORY CIRCULAR

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

SUBJECT: A FUEL/ENERGY CONSERVATION GUIDE FOR AIRPORT OPERATORS

1. PURPOSE. This advisory circular identifies potential areas where fuel and energy usage can be conserved to assist airport operators in their voluntary actions in reducing fuel and energy consumption. Appendices 1 and 2 contain specific suggested areas.

2. GENERAL.

   a. The Nation faces a critical shortage of fuel and other forms of energy. To meet this situation, the Nation must take strong effective countermeasures. The President has set as a national goal, the independence of the United States from reliance on other nations for fuel, the development of new domestic sources, and the expansion of those already in production. Actions have already been taken through legislation to enable greater production and to spur the development of fuel and energy resources to meet these goals. As an interim measure, the President has launched a nationwide energy conservation drive with a goal of seven percent reduction in energy consumption by the Federal Government and a five percent reduction by the general public within the next year.

   b. Recent actions, such as the passage of the Alaskan Pipeline legislation, to increase domestic supplies have been implemented. However, oil from the large North Slope reserve is not anticipated to be delivered by the pipeline until 1977. In the meantime, efforts such as allocation of fuel oil and conversion to coal burning systems are being taken where possible to keep essential facilities and industries in operation.

   c. The Administrator has stated that the FAA will review its air traffic control procedures to see what changes can be made to expedite traffic flow and thus conserve fuel from that direction. In addition, he has encouraged airports to use the FAA airport grant-in-aid programs to increase airport operational capacities.

Initiated by: AAS-560

3. USE OF GUIDELINES. Airport operators, in their review of their operations and procedures to identify areas where fuel and energy can be conserved, should use these guidelines as an aid to stimulate ideas for further savings. In the implementation of these energy conservation measures, only those changes that will not lower the level of safety should be implemented. The services of local FAA Airports District Offices and Regional Offices (see AC 150/5000-3B) personnel are available to assist in this effort.

4. HOW TO OBTAIN ADDITIONAL COPIES OF THIS CIRCULAR AND OTHER REFERENCES. Additional copies of this circular, AC 150/5240- , A Fuel/Energy Conservation Guide for Airport Operators, as well as reference a below, may be obtained free of charge from the Department of Transportation, Distribution Unit, TAD-484.3, Washington, D.C. 20590.

   a. Advisory Circular 150/5000-3B, Address List for Regional Airports Divisions and Airports District Offices.

   b. The Asphalt Handbook (MS-4) may be obtained from the Asphalt Institute, Asphalt Institute Building, College Park Maryland 20740.

CLYDE W. PACE, JR.
Director, Airports Service

APPENDIX 1. GUIDELINES FOR FUEL/ENERGY CONSERVATION ON AIRPORTS

Following are areas where possible fuel/energy savings may be achieved.

1. LIGHTING.

   a. Street lighting.

   b. Auto parking area lighting.

   c. Lighting in public waiting areas, concourses, concession areas, and administrative areas.

   d. Apron and aircraft parking area lighting.

   e. Taxiway and runway lighting.

   NOTE: Airports which have grant agreements, surplus property agreements, or certification agreements with the Federal Government should consult the local FAA Airports District Office or Regional Airports Division personnel if changes will affect those agreements prior to making the changes. It is of utmost importance that users be advised of changes in the airfield lighting arrangements, such as going from runway lights being on all night to lights on by request or by radio control operation. To accomplish this notification, an appropriate Notice to Airmen (NOTAM) should be issued as well as using other effective means, such as state aviation publications.

2. POWER, HEATING, AND AIR CONDITIONING.

   a. Adjust heating and air conditioning controls to reduce demand on fuel and electrical power.

   b. Reduce use of escalators, people movers, and elevators during period of low activity.

   c. Install dock curtains at cargo loading docks to prevent heat loss around rear of trucks and door openings.

   d. Install shades and/or curtains on windows to reduce heat loss/gain in building areas.

   e. Make prudent use of all motor driven equipment, such as baggage handling conveyors and tractors.

   f. Keep heating and cooling equipment in good operating condition.

   g. Determine need for improving building insulation, including installation of storm windows/doors and weather stripping.

h. Reduce washroom and kitchen water heat temperature consistent with local health authority requirements.

3. ADMINISTRATION.

a. Review airport operations manual to determine if requirements or procedures can be changed that will provide a fuel savings.

b. Review fire department training and practice procedures for potential fuel savings.

c. Review airport procedures to determine what actions can be deferred or time intervals extended between actions where energy or fuel savings can be achieved.

d. Pursue an active energy conservation program with concessionaires, tenants, and Fixed Base Operators.

APPENDIX 2. GUIDELINES FOR FUEL/ENERGY CONSERVATION ON AIRPORTS - CONSTRUCTION AND MAINTENANCE

The following are examples of where fuel/energy savings may be achieved. An engineering analysis for each project should be conducted for identifying savings.

1. Construct taxiways, aprons, holding aprons, or other facilities that will expedite the movement of aircraft on the ground.

2. Substitution of asphalt emulsions in lieu of cut-back asphalts and road oils.

3. Reduction of mixing temperatures for hot-mix asphalt concrete mixtures. Normally, hot-mixes are produced at the lowest practical temperature that will permit proper mixing, lay-down, and compaction. Unfortunately, as a practical matter, the temperature of mixing is further controlled by the temperature needed to dry the aggregate. For maximum energy conservation, the contractor must employ all practical methods to produce and supply aggregates to the dryer at the lowest possible moisture content. This will permit dry-aggregates to enter the pugmill at the lowest possible temperature, but not less than 225 degrees Fahrenheit. The mixing temperature can then be further adjusted so that the particular asphalt cement being used will have a kinematic viscosity near 300 centistokes at the mixing temperature. Data on the temperature-viscosity relationship is most important to consideration of lower mixing temperatures and should be obtained from the producer of each asphalt cement used. Manual Series 4 (MS-4) titled "The Asphalt Handbook" contains more information and is published by the Asphalt Institute. When using lower temperature mixes, it may be necessary to require insulation of trucks or other hauling units in order to retain enough heat for spreading and compaction.

4. Avoiding cold weather operations that would require heating of aggregates and mixing water for concrete production.

5. Using asphalt-rejuvenation and light scarification in lieu of heater-planer operation.

Appendix F

References For Mitigation Measure Information

Sources Of Mitigation Measure Information

Source	AIRSIDE					LANDSIDE								
	Aircraft	Airfield	ATC	GSE	Fuel	Facility	Maintenance	Construction	Park	Road	Transit	/Fuel	/Park	/Rideshare
1	X					X								
2	X	X		X							X	X	X	X
3	X			X										
4											X			
5	X													
6	X	X	X	X						X	X			X
7								X						
8	X	X	X	X	X									
9				X	X	X		X	X	X		X		
10									X	X	X		X	X
11									X		X		X	
12						X					X		X	X
13	X		X											
14	X		X			X				X	X			
15	X			X				X	X	X	X		X	X
16									X	X	X			
17	X	X	X	X	X	X			X	X	X	X		
18								X		X	X		X	X
19											X			
20	X	X	X	X	X	X	X		X		X	X	X	X
21	X		X	X	X						X		X	X
22	X	X	X			X								
23											X		X	X
24	X			X										
25	X			X										
26				X										
27	X			X										
28						X			X		X		X	X
29	X			X										
30	X			X										
31	X			X							X			
32									X		X		X	X
33	X	X				X			X	X	X			
34									X				X	
35				X										
36				X										
37											X	X		
38									X		X		X	X
39	X													
40								X						
41						X			X		X		X	
42									X		X			
43											X	-	X	X
44									X	X	X		X	
45	X			X										
46	X	X	X	X	X	X	X		X	X	X	X	X	X
47	X		X	X	X			X		X	X	X	X	X
48			X											
49											X	X		
50	X	X	X			X								
51	X	X	X						X	X	X		X	X
52	X	X	X											
53						X			X		X		X	
54						X			X	X	X		X	X
55											X		X	X
56	X		X											
57	X													

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Appendix G

Mitigation Measure Ranking

— APPENDIX G —

Mitigation Measure Ranking

This appendix provides a relative ranking of the emission mitigation measures described in this report. It was added at the request of the Air Resources Board to illustrate the impact of the mitigation measures at different airports. The measures are ranked for aircraft, GSE, and ground access vehicles by pollutant (HC, CO, NO_X, and PM_{10}) for large, medium, and small airports. The 1990 levels of activity for Los Angeles International Airport (large), Sacramento Metropolitan Airport (medium), and Long Beach Airport (small) were used to simulate emissions generation both uncontrolled and with mitigation measures applied. This is not to imply that all measures necessarily are appropriate for these particular airports. For example, to illustrate the congestion relief measures it was assumed that the uncontrolled emissions represented congested conditions. This is not necessarily accurate for these airports. Site specific conditions must be considered when applying any mitigation measures. Also, the analysis was performed applying the measures as described in the body of the report. Where more than one option was available the option giving the maximum emissions reduction was used. For example, when converting GSE to alternative fuels maximum conversion to electricity and OEM optimized CNG were assumed rather than more limited use of electricity or CNG conversion of existing equipment.

There are several factors the reader should keep in mind in using these tables. First, as mentioned above for the congestion relief measures, many of these measures are very sensitive to site-specific factors. As a result, the order in which they are listed should be considered a general indicator of their potential not a definitive assessment. Second, several measures potentially have aviation system-wide effects, which could be very expensive, and may not be appropriate as control measures applied at a single airport. Examples include fleet modernization and aircraft engine emission standards. They could be very effective, however, if applied regionally, nationally, or internationally. Third, as discussed in the report, the aircraft measures should be considered in the context of their effect on all pollutants. For example, using larger aircraft to reduce the total number of LTOs may show a significant HC benefit and a high ranking in one table but at the same time there may be a significant NO_X penalty, which cannot be isolated or avoided, and would be ranked low on the NO_X table. Finally, the tables do not necessarily represent specific control strategies. For example, one table ranks the measures by their effect on CO emissions at a small airport. It is unlikely that CO emissions at a small airport would be a significant contributor to a CO nonattainment problem. Thus these measures would not be an important part of a CO control strategy.

Each table in this appendix ranks measures from the most cost effective first to the least cost effective, which depends on both the potential reductions and the cost to implement each measure (to get a relative cost per ton measure). To evaluate emission reduction potential generally, however, an order of magnitude estimate of the emissions of the pollutant covered by the table is provided. This estimate corresponds to the emissions of the individual pollutant calculated as part of the reference emissions used throughout the report. The reduction potential times the emissions estimate gives an estimate of the tons of pollutant affected by a given measure. Note that the reduction potentials are not additive and should be analyzed in combination to determine the potential benefit of multiple measures. Also, there is very little data available for calculating the cost of implementing the measures. The authors based the rankings on their judgement of relative cost effectiveness. Some results are simply noted as indeterminate and no ranking is implied. ARB staff did not have the opportunity to review the detailed calculations supporting the information presented in the Appendix G tables.

AIRCRAFT SOURCES — LARGE AIRPORTS

HC ...POLLUTANT **2,500** ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Single/Reduced Engine Taxiing	22%	Very Low	Measure may result in cost savings. Easy to implement.
Congestion Reduction	25%	Low to Moderate	Benefit and cost highly site specific
Derated Takeoff	0 - 1%	Very Low	Easy to implement. HC benefit small but positive.
Tow Aircraft to Runway	Indeterminate	Moderate	Reduction potential probably large.
Take Passengers to Aircraft	64%	Indeterminate	Cost to implement highly site specific.
Reduce Reverse Thrust	0 - 1%	High	Cost to implement highly site specific.
Fleet Modernization	62%	Indeterminate	This measure potentially has aviation system-wide effects. If so it could have very poor cost effectiveness at a single airport. Would be most effective applied regionally or nationally.
Use Larger Aircraft	33%	Indeterminate	This measure potentially has aviation system-wide effects. If so it could have very poor cost effectiveness at a single airport. Would be most effective applied regionally or nationally.
New Engine Standards	Indeterminate	Indeterminate	This measure has aviation system-wide effects and would have very poor cost effectiveness if all costs assigned to a single airport. Would be most effective applied nationally or internationally.
Increase Load Factor	Indeterminate	Indeterminate	
Limit Aircraft Operations	Indeterminate	Indeterminate	
Manage Fleet to Minimize Emissions	Indeterminate	Indeterminate	This measure potentially has aviation system-wide effects. If so it could have very poor cost effectiveness at a single airport. Would be most effective applied regionally or nationally.

CO ...POLLUTANT **6,000** ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Single/Reduced Engine Taxiing	21%	Very Low	Measure may result in cost savings. Easy to implement.
Congestion Reduction	24%	Low to Moderate	Benefit and cost highly site specific
Derated Takeoff	0 - 1%	Very Low	Easy to implement. CO benefit small but positive.
Tow Aircraft to Runway	Indeterminate	Moderate	Reduction potential probably large.
Take Passengers to Aircraft	58%	Indeterminate	Cost to implement highly site specific.
Reduce Reverse Thrust	0 - 1%	High	Cost to implement highly site specific.
Fleet Modernization	38%	Indeterminate	This measure potentially has aviation system-wide effects. If so it could have very poor cost effectiveness at a single airport. Would be most effective applied regionally or nationally

* Emission Reduction Potential
** Per One Ton Reduction

CO ...CONTINUED

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Use Larger Aircraft	11%	Indeterminate	This measure potentially has aviation system-wide effects. If so it could have very poor cost effectiveness at a single airport. Would be most effective applied regionally or nationally.
New Engine Standards	Indeterminate	Indeterminate	This measure has aviation system-wide effects and would have very poor cost effectiveness if all costs assigned to a single airport. Would be most effective applied nationally or internationally.
Increase Load Factor	Indeterminate	Indeterminate	
Limit Aircraft Operations	Indeterminate	Indeterminate	
Manage Fleet to Minimize Emissions	Indeterminate	Indeterminate	This measure potentially has aviation system-wide effects. If so it could have very poor cost effectiveness at a single airport. Would be most effective applied regionally or nationally

NOx ...POLLUTANT 3,500 ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Single/Reduced Engine Taxiing	3%	Very Low	Measure may result in cost savings. Easy to implement.
Derated Takeoff	3%	Very Low	Easy to implement.
Reduce Reverse Thrust	10%	High	Cost to implement highly site specific.
Congestion Reduction	3%	Moderate to High	Benefit and cost highly site specific
Tow Aircraft to Runway	Indeterminate	Moderate	
New Engine Standards	10%	Indeterminate	This measure potentially has aviation system-wide effects. If so it could have very poor cost effectiveness at a single airport. Would be most effective applied regionally or nationally
Increase Load Factor	Indeterminate	Indeterminate	
Limit Aircraft Operations	Indeterminate	Indeterminate	
Manage Fleet to Minimize Emissions	Indeterminate	Indeterminate	This measure potentially has aviation system-wide effects. If so it could have very poor cost effectiveness at a single airport. Would be most effective applied regionally or nationally
Take Passengers to Aircraft	-8%	Indeterminate	Cost to implement highly site specific.
Fleet Modernization	-8%	Indeterminate	This measure potentially has aviation system-wide effects. If so it could have very poor cost effectiveness at a single airport. Would be most effective applied regionally or nationally
Use Larger Aircraft	-84%	Indeterminate	This measure has aviation system-wide effects and would have very poor cost effectiveness if all costs assigned to a single airport.

* Emission Reduction Potential
** Per One Ton Reduction

AIRCRAFT SOURCES — MEDIUM AIRPORTS

HC ...POLLUTANT **50** ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Single/Reduced Engine Taxiing	21%	Very Low	Measure may result in cost savings. Easy to implement.
Congestion Reduction	22%	Low to Moderate	Benefit and cost highly site specific
Derated Takeoff	0 - 1%	Very Low	Easy to implement. HC benefit small but positive.
Tow Aircraft to Runway	Indeterminate	Moderate	Reduction potential probably large.
Take Passengers to Aircraft	47%	Indeterminate	Cost to implement highly site specific.
Reduce Reverse Thrust	0 - 1%	High	Cost to implement highly site specific.
Fleet Modernization	22%	Indeterminate	This measure potentially has aviation system-wide effects. If so it could have very poor cost effectiveness at a single airport. Would be most effective applied regionally or nationally.
Use Larger Aircraft	33%	Indeterminate	This measure potentially has aviation system-wide effects. If so it could have very poor cost effectiveness at a single airport. Would be most effective applied regionally or nationally.
New Engine Standards	Indeterminate	Indeterminate	This measure has aviation system-wide effects and would have very poor cost effectiveness if all costs assigned to a single airport. Would be most effective applied nationally or internationally.
Increase Load Factor	Indeterminate	Indeterminate	
Limit Aircraft Operations	Indeterminate	Indeterminate	
Manage Fleet to Minimize Emissions	Indeterminate	Indeterminate	This measure potentially has aviation system-wide effects. If so it could have very poor cost effectiveness at a single airport. Would be most effective applied regionally or nationally.

CO ...POLLUTANT **200** ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Single/Reduced Engine Taxiing	20%	Very Low	Measure may result in cost savings. Easy to implement.
Congestion Reduction	21%	Low to Moderate	Benefit and cost highly site specific
Derated Takeoff	0 - 1%	Very Low	Easy to implement. CO benefit small but positive
Tow Aircraft to Runway	Indeterminate	Moderate	Reduction potential probably large.
Take Passengers to Aircraft	39%	Indeterminate	Cost to implement highly site specific.
Reduce Reverse Thrust	0 - 1%	High	Cost to implement highly site specific.
Use Larger Aircraft	11%	Indeterminate	This measure potentially has aviation system-wide effects. If so it could have very poor cost effectiveness at a single airport. Would be most effective applied regionally or nationally.

* Emission Reduction Potential
** Per One Ton Reduction

CO ...CONTINUED

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Fleet Modernization	3%	Indeterminate	This measure potentially has aviation system-wide effects. If so it could have very poor cost effectiveness at a single airport. Would be most effective applied regionally or nationally.
New Engine Standards	Indeterminate	Indeterminate	This measure has aviation system-wide effects and would have very poor cost effectiveness if all costs assigned to a single airport. Would be most effective applied nationally or internationally.
Increase Load Factor	Indeterminate	Indeterminate	
Limit Aircraft Operations	Indeterminate	Indeterminate	
Manage Fleet to Minimize Emissions	Indeterminate	Indeterminate	This measure potentially has aviation system-wide effects. If so it could have very poor cost effectiveness at a single airport. Would be most effective applied regionally or nationally..

NO_x ...POLLUTANT   250 ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Single/Reduced Engine Taxiing	3%	Very Low	Measure may result in cost savings. Easy to implement.
Derated Takeoff	2%	Very Low	Easy to implement.
Reduce Reverse Thrust	7%	High	Cost to implement highly site specific.
Congestion Reduction	2%	High	
Tow Aircraft to Runway	Indeterminate	Moderate	
New Engine Standards	10%	Indeterminate	This measure potentially has aviation system-wide effects. If so it could have very poor cost effectiveness at a single airport. Would be most effective applied regionally or nationally.
Increase Load Factor	Indeterminate	Indeterminate	
Limit Aircraft Operations	Indeterminate	Indeterminate	
Manage Fleet to Minimize Emissions	Indeterminate	Indeterminate	This measure potentially has aviation system-wide effects. If so it could have very poor cost effectiveness at a single airport. Would be most effective applied regionally or nationally.
Take Passengers to Aircraft	-18%	Indeterminate	Cost to implement highly site specific.
Fleet Modernization	-26%	Indeterminate	This measure potentially has aviation system-wide effects. If so it could have very poor cost effectiveness at a single airport. Would be most effective applied regionally or nationally.
Use Larger Aircraft	-84%	Indeterminate	This measure has aviation system-wide effects and would have very poor cost effectiveness if all costs assigned to a single airport.

* Emission Reduction Potential
** Per One Ton Reduction

AIRCRAFT SOURCES — SMALL AIRPORTS

HC ...POLLUTANT **15** ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Single/Reduced Engine Taxiing	14%	Very Low	Measure may result in cost savings. Easy to implement.
Congestion Reduction	21%	Low to Moderate	Benefit and cost highly site specific
Derated Takeoff	0 - 1%	Very Low	Easy to implement. HC benefit small but positive.
Reduce Reverse Thrust	1%	High	Cost to implement highly site specific.
Take Passengers to Aircraft	45%	Indeterminate	
Tow Aircraft to Runway	Indeterminate	Moderate	
Use Larger Aircraft	33%	Indeterminate	This measure potentially has aviation system-wide effects. If so it could have very poor cost effectiveness at a single airport. Would be most effective applied regionally or nationally.
Fleet Modernization	6%	Indeterminate	This measure potentially has aviation system-wide effects. If so it could have very poor cost effectiveness at a single airport. Would be most effective applied regionally or nationally
New Engine Standards	Indeterminate	Indeterminate	This measure has aviation system-wide effects and would have very poor cost effectiveness if all costs assigned to a single airport. Would be most effective applied nationally or internationally.
Increase Load Factor	Indeterminate	Indeterminate	
Limit Aircraft Operations	Indeterminate	Indeterminate	
Manage Fleet to Minimize Emissions	Indeterminate	Indeterminate	This measure potentially has aviation system-wide effects. If so it could have very poor cost effectiveness at a single airport. Would be most effective applied regionally or nationally.

CO ...POLLUTANT **90** ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Single/Reduced Engine Taxiing	13%	Very Low	Measure may result in cost savings. Easy to implement.
Congestion Reduction	22%	Low to Moderate	Benefit and cost highly site specific
Derated Takeoff	0 - 1%	Very Low	Easy to implement. CO benefit small but positive.
Take Passengers to Aircraft	37%	Indeterminate	Cost to implement highly site specific.
Tow Aircraft to Runway	Indeterminate	Moderate	
Reduce Reverse Thrust	0 - 1%	High	Cost to implement highly site specific.
Use Larger Aircraft	11%	Indeterminate	This measure potentially has aviation system-wide effects. If so it could have very poor cost effectiveness at a single airport. Would be most effective applied regionally or nationally

* Emission Reduction Potential
** Per One Ton Reduction

CO ...CONTINUED

MEASURE	ERP*	RELATIVE COST**	COMMENTS
New Engine Standards	Indeterminate	Indeterminate	This measure has aviation system-wide effects and would have very poor cost effectiveness if all costs assigned to a single airport. Would be most effective applied nationally or internationally.
Increase Load Factor	Indeterminate	Indeterminate	
Limit Aircraft Operations	Indeterminate	Indeterminate	
Manage Fleet to Minimize Emissions	Indeterminate	Indeterminate	This measure potentially has aviation system-wide effects. If so it could have very poor cost effectiveness at a single airport. Would be most effective applied regionally or nationally.
Fleet Modernization	-7%	Indeterminate	This measure potentially has aviation system-wide effects. If so it could have very poor cost effectiveness at a single airport. Would be most effective applied regionally or nationally.

NOx ...POLLUTANT 125 ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Single/Reduced Engine Taxiing	2%	Very Low	Measure may result in cost savings. Easy to implement.
Derated Takeoff	2%	Very Low	Easy to implement.
Reduce Reverse Thrust	9%	High	Cost to implement highly site specific.
Congestion Reduction	3%	Moderate to High	Benefit and cost highly site specific
Tow Aircraft to Runway	Indeterminate	Moderate	
New Engine Standards	10%	Indeterminate	This measure potentially has aviation system-wide effects. If so it could have very poor cost effectiveness at a single airport. Would be most effective applied regionally or nationally
Increase Load Factor	Indeterminate	Indeterminate	
Limit Aircraft Operations	Indeterminate	Indeterminate	
Manage Fleet to Minimize Emissions	Indeterminate	Indeterminate	This measure potentially has aviation system-wide effects. If so it could have very poor cost effectiveness at a single airport. Would be most effective applied regionally or nationally.
Take Passengers to Aircraft	-19%	Indeterminate	Cost to implement highly site specific.
Fleet Modernization	-1%	Indeterminate	This measure potentially has aviation system-wide effects. If so it could have very poor cost effectiveness at a single airport. Would be most effective applied regionally or nationally.
Use Larger Aircraft	-84%	Indeterminate	This measure has aviation system-wide effects and would have very poor cost effectiveness if all costs assigned to a single airport.

* Emission Reduction Potential
** Per One Ton Reduction

GSE SOURCES — LARGE AIRPORTS

HC ...POLLUTANT **100** ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Fixed Electrical Systems	90%	Low to Moderate	
Fixed Air-conditioning Systems	35%	Low to Moderate	
Alternative Fuels Conversion	80%	High	

CO ...POLLUTANT **5,000** ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Alternative Fuels Conversion	97%	Low	
Fixed Electrical Systems	84%	Low	
Fixed Air-conditioning Systems	35%	Low	

NOx ...POLLUTANT **275** ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Alternative Fuels Conversion	76%	Low	
Fixed Electrical Systems	76%	Low	
Fixed Air-conditioning Systems	33%	Low to Moderate	

PM ...POLLUTANT **10** ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Alternative Fuels Conversion	100%	Very High	High cost reflects low uncontrolled emissions.
Fixed Electrical Systems	100%	Very High	High cost reflects low uncontrolled emissions.
Fixed Air-conditioning Systems	100%	Very High	High cost reflects low uncontrolled emissions.

* Emission Reduction Potential
** Per One Ton Reduction

GSE SOURCES — MEDIUM AIRPORTS

HC ...POLLUTANT **10** ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Fixed Electrical Systems	81%	Low to Moderate	
Fixed Air-conditioning Systems	34%	Low to Moderate	
Alternative Fuels Conversion	79%	High	

CO ...POLLUTANT **375** ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Alternative Fuels Conversion	97%	Low	
Fixed Electrical Systems	69%	Low	
Fixed Air-conditioning Systems	33%	Low	

NOx ...POLLUTANT **25** ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Alternative Fuels Conversion	77%	Low	
Fixed Electrical Systems	72%	Low	
Fixed Air-conditioning Systems	33%	Low to Moderate	

PM ...POLLUTANT **1.0** ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Alternative Fuels Conversion	100%	Very High	High cost reflects low uncontrolled emissions
Fixed Electrical Systems	100%	Very High	High cost reflects low uncontrolled emissions
Fixed Air-conditioning Systems	100%	Very High	High cost reflects low uncontrolled emissions

* Emission Reduction Potential
** Per One Ton Reduction

GSE SOURCES — SMALL AIRPORTS

HC ...POLLUTANT **5** ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Fixed Electrical Systems	84%	Low to Moderate	
Fixed Air-conditioning Systems	33%	Low to Moderate	
Alternative Fuels Conversion	78%	High	

CO ...POLLUTANT **150** ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Alternative Fuels Conversion	96%	Low	
Fixed Electrical Systems	70%	Low	
Fixed Air-conditioning Systems	33%	Low	

NOx ...POLLUTANT **10** ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Alternative Fuels Conversion	77%	Low	
Fixed Electrical Systems	73%	Low	
Fixed Air-conditioning Systems	33%	Low to Moderate	

PM ...POLLUTANT **0.5** ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Alternative Fuels Conversion	100%	Very High	High cost reflects low uncontrolled emissions.
Fixed Electrical Systems	100%	Very High	High cost reflects low uncontrolled emissions.
Fixed Air-conditioning Systems	100%	Very High	High cost reflects low uncontrolled emissions.

* Emission Reduction Potential
** Per One Ton Reduction

VEHICLE SOURCES — LARGE AIRPORTS

HC ...POLLUTANT 2,500 ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Idle/Circulation Management TCMs	20%	Low	
Trip Reduction TCMs	3%	Low to Moderate	
Alternative Fuels	35%	Moderate to High	

CO ...POLLUTANT 24,000 ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Idle/Circulation Management TCMs	20%	Low	
Trip Reduction TCMs	3%	Low to Moderate	
Alternative Fuels	35%	Moderate to High	

NOx ...POLLUTANT 2,500 ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Idle/Circulation Management TCMs	20%	Low	
Trip Reduction TCMs	3%	Low to Moderate	
Alternative Fuels	20%	Moderate to High	

PM ...POLLUTANT 900 ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Idle/Circulation Management TCMs	20%	Low	
Trip Reduction TCMs	3%	Low to Moderate	
Alternative Fuels	100%	Moderate to High	

* Emission Reduction Potential
** Per One Ton Reduction

VEHICLE SOURCES — MEDIUM AIRPORTS

HC ...POLLUTANT **50** ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Idle/Circulation Management TCMs	20%	Low	
Alternative Fuels	35%	Moderate to High	
Trip Reduction TCMs	3%	Moderate to High	

CO ...POLLUTANT **1,300** ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Idle/Circulation Management TCMs	20%	Low	
Alternative Fuels	35%	Moderate to High	
Trip Reduction TCMs	3%	Moderate to High	

NOx ...POLLUTANT **200** .. TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Idle/Circulation Management TCMs	20%	Low	
Alternative Fuels	20%	Moderate to High	
Trip Reduction TCMs	3%	Moderate to High	

PM ...POLLUTANT **40** ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Idle/Circulation Management TCMs	20%	Low to Moderate	
Alternative Fuels	100%	Moderate to High	
Trip Reduction TCMs	3%	Moderate to High	

* Emission Reduction Potential
** Per One Ton Reduction

VEHICLE SOURCES — SMALL AIRPORTS

HC ...POLLUTANT **65** ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Idle/Circulation Management TCMs	20%	Low to Moderate	
Trip Reduction TCMs	3%	Low to Moderate	
Alternative Fuels	35%	High	

CO ...POLLUTANT **700** ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Idle/Circulation Management TCMs	20%	Low to Moderate	
Trip Reduction TCMs	3%	Low to Moderate	
Alternative Fuels	35%	High	

NOx ...POLLUTANT **100** ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Idle/Circulation Management TCMs	20%	Low to Moderate	
Trip Reduction TCMs	3%	Low to Moderate	
Alternative Fuels	20%	Moderate to High	

PM ...POLLUTANT **15** ...TONS OF EMISSIONS — Per Year Order Of Magnitude

MEASURE	ERP*	RELATIVE COST**	COMMENTS
Idle/Circulation Management TCMs	20%	Low to Moderate	
Alternative Fuels	100%	Moderate	
Trip Reduction TCMs	3%	Moderate	

* Emission Reduction Potential
** Per One Ton Reduction